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Grill workers and air pollution health effects from charcoal combustion in Vientiane capital

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ABSTRACT

Introduction: Grilled street foods are popular in urban communities in Lao People's Democratic Republic (Lao PDR). Charcoal is the main fuel used for, posing a risk of elevated exposure to toxic pollutants. This study explored levels of cooking-related pollutants from grilled food business and workers' health effects.

Materials and methods: A quantitative approach using multiple techniques was conducted during March and April 2022 in Vientiane Capital, Lao PDR. Methods included pollutant emission estimation from charcoal-combusting grill shops/street-carts and Particulate Matter ($PM_{2.5}$) measurement, and examined the exposure and health effects among grill workers. Multiple sampling techniques were applied to identify study samples. Respiratory symptoms were the health effect of interest among grill workers.

Results: Estimated emission of pollutants was over 75 tons/year from grill shops. Average $PM_{2.5}$ level was 84.8 μg/m^3 (21.6 - 254.8 μg/m^3); which is above standard limits. A very high level of $PM_{2.5}$ was found in grill markets. Most grill workers were female, worked 6-7 days/week, at least 8 h/day. Factors contributing to the presence of respiratory symptoms among grill workers were female gender, low income, indoor grilling, more years of grill-work, experience of intense smoke-cough, self-reliance on health and cigarette smoking.

Conclusion: Grilling contributes to ambient air pollution, posing potential adverse environmental and public health impacts. Grill workers are likely to be exposed to high levels of all forms of air pollutants from street food grilling. Effective strategies are required to better protect grill workers from the effect of exposure to these harmful toxins and minimize the negative impacts on their health.

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Introduction

In commercial kitchens, airborne workplace hazards include cooking-related pollutants such as Carbon monoxide (CO), Nitric Oxides (NOx), Polycyclic Aromatic Hydrocarbons (PAHs), ultrafine particles, and Particulate Matter (PM). The heat required when cooking generates these pollutants, especially when food is grilled using charcoal and wood combustion [1]. Apart from these pollutants having a significant adverse influence on overall in-and-outdoor air quality, these pollutants are inhaled by grill workers in their daily work, with potential negative health effects, especially on regarding respiratory health. With limited pollution-control devices or PPE, the exposure can be at hazardous levels [2]. Fine particulate matte ($PM_{2.5}$) a form of fine inhalable particles with diameters 2.5 μm and smaller, is a pollutant of particular concern and is mostly generated through combustion processes during domestic and commercial cooking involving grilling, burning and industrial activities. It can be emitted directly as fine PM, or formed in the atmosphere through reactions between gaseous pollutants, such as NOx, SO_2 and VOCs; which are also emitted during these activities. Most PM emitted from these activities however are in the submicrometer range, and can be inhaled by workers and other individuals in the surrounds [3].

Studies have revealed increasing exposure to PM is associated with increasing mortality rates; the mass concentration of PM_{10} by 10 μg/m^3 increases the mortality rate by approximately 0.5% [4], daily increase of fine particles (i.e., $PM_{2.5}$) 10 μg/m^3 increased the mortality rate by 8 to 18% [5]. $PM_{2.5}$ has been particularly associated with cardiovascular disease, respiratory disease and lung cancer. Studies have reported a strong association between exposure to the emissions of cooking activities with a higher risk to developing cancer in the respiratory tract among cooks and food service workers [6]. The adverse health effects are also dependent on the physical properties (e.g., particle size and number, total surface area, and electrostatic properties) and the chemical and biological compositions of the PM [7, 8] and factors such as a job role, type of cooking, length of period cooking and presence of an exhaust hood [9].

In lower-middle income countries, restaurants, stalls, markets and street-carts with grill food are major sources of workplace pollution. Exposure to this air pollution for both workers and customers is exacerbated by limited (if any) ventilation, pollution-control devices or personal protective equipment [10]. In Lao PDR, such food grill sites or grill shops are common, with charcoal the most commonly used fuel. The grilling stove might be placed in front of their restaurants or inside the kitchens. While grilled meats and poultry cooked using charcoal continues to grow in popularity, there are few regulations or controls and no, or inconsistent, use of pollution-control methods, such as ventilation, or PPE among grill workers, thus workers can be exposed to high levels of pollutants. Despite the recognition of the short and long-erm health effects of restaurant workers' exposure to $PM_{2.5}$, information on their occupational risk is scant, especially in lower-middle income countries such as Lao PDR.

This exploratory study starts to address this gap and aims to answer three key questions: 1) How much of pollution do grill shops contribute in Vientiane capital?, 2) How high is the $PM_{2.5}$ level among grill shops? And 3) What are the exposures, health status and risk factors among grill workers? As an exploratory study, we selected dominant grill sites and a relatively easy to reach population who are known to be at risk through their work of high levels and potentially long-term exposure to $PM_{2.5}$. We also aimed to examine how socio-economic, exposure and health related variables may interact to create different levels of risk.

Materials and methods

Design

This cross-sectional study employed three quantitative techniques as 1) Grill restaurant survey to estimate pollutant emission by charcoal combustion assumption (Technique 1), 2) $PM_{2.5}$ emission measurement at selected charcoal-combusting grill shops/street-carts (Technique 2), and 3) Structured interview with potential grill workers (Technique 3).

Study site

Vientiane capital city is in the central belt of the Lao PDR, covering 3,920 square kilometres over nine districts, with a population density of 209 people per km^2 (eight times higher than the national average). According to the 2015 Census, the population is 820,940 with 78% residing in urban areas, 22% in rural areas with a road, and 0.1% in rural areas without a road. Within the city, it is estimated there are 1741 or more outdoor charcoal grill restaurants and grill street-carts where meats and poultry are grilled, most intensively during the lunch and evening [11]. Most air quality monitoring stations in Vientiane capital have been reporting very-unhealthy level of pollutants, especially the $PM_{2.5}$ is in concern [12-14].

Sample and sample size

Samples for technique 1 were all 1,741 restaurants/stalls from 416 villages in nine districts of Vientiane capital. These grill sites were purposively selected with criterions of regular operation and using charcoal; these include grill restaurants, grill markets and grill carts. Samples for 2nd technique were fourteen grill sites that were purposively selected based on the list of grill sites from 1st technique. The reason for selection of fourteen site was the limited availability of air sampler tool and its high cost. The sample selection was therefore done by research team brainstorming on the popularity of the grilling sites, daily-open and longest operation hours per day.

Samples for the 3rd technique were the potential grill workers of each grill shop. Multistage sampling was performed to identify potential participants for the structured survey. Four urban districts (Chanthabury, Sisattanak, Sikhottabong and Saysetha) of Vientiane capital were purposively selected for this study based on being the most urbanized and densely populated within the city. In each selected district a list of grill shops and grill street-carts was extracted from the technique 1 survey. Simple random sampling was then applied to select the grill shops in each district. The sample size was calculated based on a single population formula, corresponding to a 95% confidence level at Z=1.96, and an estimated prevalence of key respiratory symptoms of 50% (p=0.5) to reach the largest size of sample from a total of 362 gilled shops/restaurants. The absolute precision was d = 0.04, with 1.7 allowed for the design effect and 5% for the non-response rate, producing a sample size of 362 grill workers.

Data collection

For the first technique, we conducted a survey that counted all the grill sites with inclusion criteria. Each grill site, the owner was asked about how many kilograms (kg) of charcoal burned per day and how many days per week to serve the grilling. The grill shop owner could estimate the charcoal kilograms by considering the size of the charcoal bag used up per day; generally, three sizes as small size for 5 kg, medium size for 10 kg and large size 20 kg of charcoal. From totally 1,741 restaurants and stalls in nine districts, the total estimated charcoal combustion was 4716.5kg/day; almost five tons of charcoal burned per day for grilling business in Vientiane Capital. Emission was estimated by quantifying of 11 common pollutants for each kg of charcoal burned and possible amount of emission per year. For the second technique, we measured outdoor $PM_{2.5}$ level at fourteen grilling sites to track on the variation of concentrations between different hours and different grill sites during their operation time. Five grill restaurants, eight grill markets and one grill cart site were purposively selected by team discussion based on the most in-town and popularity of those grill sites. The measurement was done by the Met One Instruments, Inc. BAM 1022, Real-Time Portable Beta Attenuation Mass Monitor, which employs an in-line sampling geometry in which the attenuation of beta rays across filter media is measured and PM is sampled simultaneously. This allows ambient sampling to occur for virtually 60 min each hour with improved sensitivity, time resolution and minimized measurement error due to loss of semi-volatile particulate material or due to excessive moisture in the sample stream. The BAM1022 has US EPA designation for PM 2.5 (EQPM-1013-209) for which a dedicated hourly output channel is available [12].

Fig. 1. Example photos of grill market in Vientiane Capital and the air sampler tool settlement

For the third technique, we conducted a face-to-face structured interview with the main griller of each sampled restaurant. Data about sociodemographic, grilling activities, air pollution awareness, health related information and the history of respiratory symptoms were collected with a pretested questionnaire. The key respiratory symptoms included in the survey were cough, phlegm, Shortness of Breath (SOB), and wheezing, that grill workers considered had disturbed their health and ability to work within the past three months.

Results and discussion

The estimation of pollutant emission from charcoal-combustion grill shops in Vientiane capital

Charcoal-combustion grill shops and stalls contribute to particulate matter and greenhouse gases (GHGs) in urban and peri-urban areas of Vientiane Capital. Fig. 2 shows an average emission (micrograms) of each pollutant from grill shops by every kilogram of charcoal combustion. The emissions in urban and peri-urban areas were more from grill shops than from the stalls. Fig. 3 illustrates the distribution by tons-per-year of each pollutant emitted from charcoal-combustion grill shops and stalls. The estimation of emissions per year were more from the grill shops in urban and peri-urban areas than from the grill stalls.

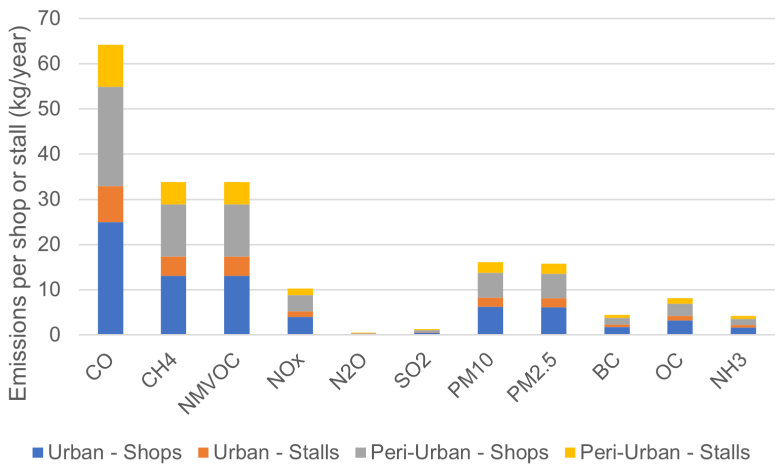

Fig. 2. Emissions of air pollutants per shop in urban and peri-urban areas from charcoal combustion

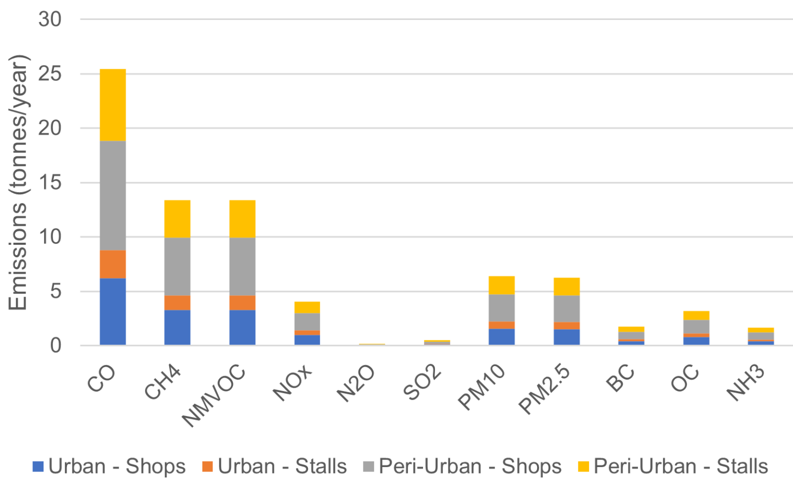

Fig. 3. Total emissions of air pollutants from grill shops and stalls in urban and peri-urban areas

The emission of $PM_{2.5}$ from each type of grill sites From the fourteen sampled grill sites including restaurants, markets and groups of grill carts (Fig. 4), the average emission of $PM_{2.5}$ was 84.8 μg/m³ in each hour. This concentration exceeds the national standard limit (<50 μg/m³). The lowest average per hour was 21.6 μg/m³, while the highest was 254.8 μg/m³. The concentration fluctuates every hour however with higher emission in the morning and evening, but lower in the afternoon (Fig. 5). Both Figs. 4 and 5 demonstrate that grill markets contribute more to the emission levels than grill restaurants and carts.

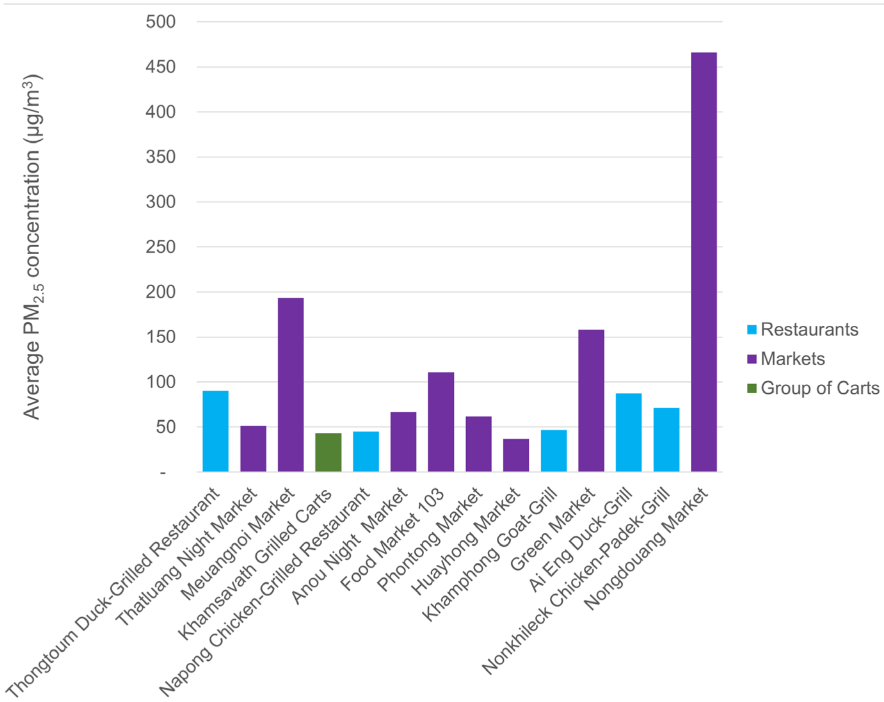

Fig. 4. Average hourly $PM_{2.5}$ concentration recorded during opening hours at each sample site

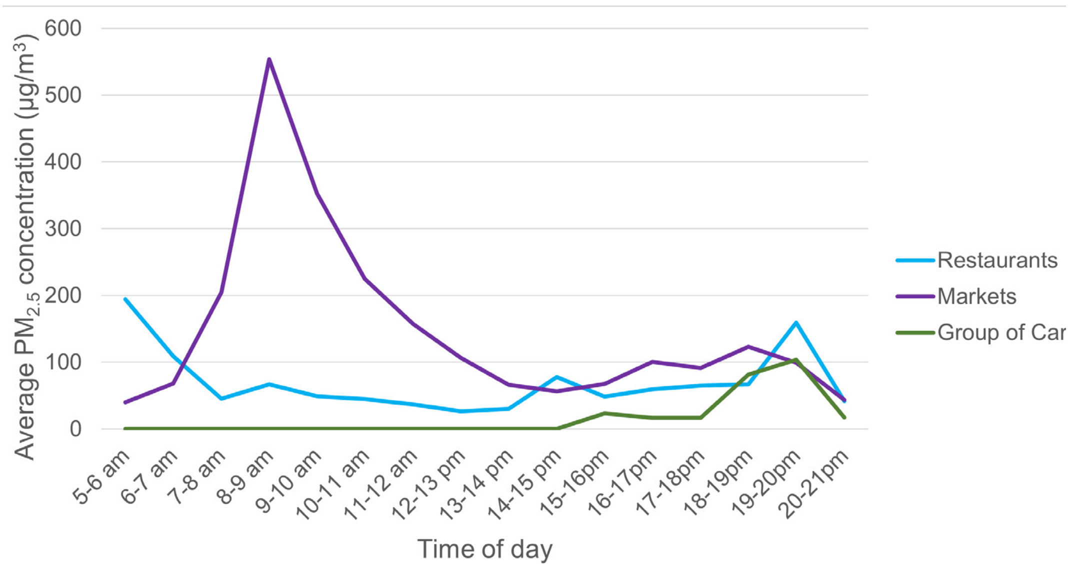

Fig. 5. Average diurnal $PM_{2.5}$ concentrations recorded at restaurants, markets and grill carts

average per hour was 21.6 μg/m^3, while the highest was 254.8 μg/m^3. The concentration fluctuates every hour however with higher emission in the morning and evening, but lower in the afternoon (Fig. 5). Both Figs. 4 and 5 demonstrate that grill markets contribute more to the emission levels than grill restaurants and carts.

Table 1. General characteristics of grill workers and their grill working

General characteristics		Male=93 Freq (%)	Female=269 Freq (%)	Total=362 Freq (%)
Sociodemographic				
Age	<= 35 yrs	42 (45.2)	77 (28.6)	119 (32.9)
	36-50 yrs	41 (44.1)	146 (54.3)	187 (51.6)
	>50 yrs	10 (10.7)	46 (17.1)	56 (15.5)
Education level	Illiterate	4 (4.3)	2 (0.7)	6 (1.7)
	Primary	8 (8.6)	47 (17.5)	55 (15.2)
	Lower secondary	32 (34.4)	81 (30.1)	113 (31.2)
	Upper secondary	32 (34.4)	108 (40.2)	140 (38.7)
	Higher level	12 (12.9)	26 (9.7)	38 (10.5)
	Graduate	5 (5.4)	5 (1.9)	10 (2.8)
Exposure in grilling activity				
Location of grill stove	Indoor			30 (8.3)
	Outdoor			332 (91.7)
Years of working on grilling	<=5 yrs	46 (49.5)	124 (46.1)	170 (47.0)
	6-10 yrs	35 (37.6)	82 (30.5)	117 (32.3)
	> 10 yrs	12 (12.9)	63 (23.4)	75 (20.7)
Days per week for grilling work	4-5 days	17 (18.3)	25 (9.3)	42 (11.6)
	6-7 days	76 (81.7)	244 (90.7)	320 (88.4)
Amount of food grilled per day	<= 5 kg	39 (41.9)	91 (33.8)	130 (35.9)
	6-20 kg	31 (33.3)	127 (47.2)	158 (43.7)
	> 20 kg	23 (24.7)	51 (18.9)	74 (20.4)
Charcoal burning h/day	<= 8 h/day	82 (88.1)	219 (81.4)	301 (83.2)
	>8 h/day	11 (11.8)	50 (18.6)	61 (16.8)
Hours in front of grilling stove	1-3 h/day	55 (59.1)	157 (58.4)	212 (58.6)
	4-6 h/day	34 (36.6)	99 (36.8)	133 (36.7)
	>6 h/day	4 (4.3)	13 (4.8)	17 (4.7)
Having a helper in grilling	Yes	56 (60.2)	140 (52.0)	196 (54.1)
	No	37 (39.8)	129 (47.9)	166 (45.9)
Walk away from grilling stove	Rarely	35 (37.6)	104 (38.7)	139 (38.4)
	Sometimes	58 (62.4)	165 (61.3)	223 (61.6)
Use of PPE and Health related characteristics				
Use of PPE during grilling	No	12 (12.9)	15 (5.6)	27 (7.5)
	Yes*	81 (87.1)	154 (94.4)	335 (92.5)
Self-esteem in health status	Very dissatisfied	1 (1.1)	13 (4.8)	14 (3.9)
	Somewhat dissatisfied	2 (2.2)	4 (1.5)	6 (1.6)
	Neither satisfied or dissatisfied	45 (48.4)	145 (53.9)	190 (52.5)
	Somewhat satisfied	30 (32.3)	87 (32.3)	117 (32.3)
	Very satisfied	15 (16.1)	20 (7.4)	35 (9.7)
Body Mass Index	Under weight (<18.5 kg/m^2)	6 (6.5)	15 (5.6)	21 (5.8)
	Normal weight (18.5-24.9 kg/m^2)	55 (59.1)	168 (62.5)	223 (61.6)
	Over weight (25.0-29.9 kg/m^2)	24 (25.8)	67 (24.9)	91 (25.1)
	Obesity (>= 30 kg/m^2)	8 (8.6)	19 (7.1)	27 (7.4)

Physically exercise at least 30mn/day	Never	71 (76.3)	228 (84.8)	299 (82.6)
	1 - 2 times/week	14 (15.1)	28 (10.4)	42 (11.6)
	3 - 4 times/week	5 (5.4)	5 (1.9)	10 (2.8)
	5 - 7 times/week	3 (3.2)	8 (2.9)	11 (3.0)
Days off per week	Never	46 (49.5)	160 (59.5)	206 (56.9)
	1 day	26 (27.9)	77 (28.6)	103 (28.5)
	≥ 2 days	21 (22.6)	32 (11.9)	53 (14.6)
Hours of sleep per day	< 8 h	32 (34.4)	87 (32.3)	119 (32.9)
	≥ 8 h	61 (65.6)	182 (67.7)	243 (67.1)
Annual health checkup	Never	68 (73.1)	168 (62.5)	236 (65.2)
	Ever	25 (26.9)	101 (37.6)	126 (34.8)
Paying for medication when get sick	Myself	60 (64.5)	174 (64.7)	234 (64.6)
	Family	29 (31.2)	82 (30.5)	111 (30.7)
	Restaurant owner	2 (2.2)	0 (0.0)	2 (0.6)
	Health Insurance	2 (2.2)	13 (4.8)	15 (4.1)
Cigarette smoking	Non-smoker	78 (83.9)	267 (99.3)	345 (95.3)
	Smoker	15 (16.1)	2 (0.7)	17 (4.7)
Health and environmental awareness on pollution from charcoal burning**				
Awareness on health effects	Higher awareness	34 (36.6)	97 (36.1)	131 (36.2)
	Lower awareness	59 (63.4)	172 (63.9)	231 (63.8)
Awareness on environment effects	Higher awareness	27 (29.0)	89 (33.0)	116 (32.0)
	Lower awareness	66 (70.9)	180 (66.9)	246 (68.0)
Respiratory symptom (at least one symptom in last three months that disturbed the daily work***)				
Having respiratory symptom	No disturbed symptoms	77 (82.8)	201 (74.7)	278 (76.8)
	Ever had disturbed symptoms	16 (17.2)	68 (25.3)	84 (23.2)

* The PPE includes face mask, face shield, dustproof glasses, long-sleeved shirt and long pants, ordinary fan blow, exhaust fan, and gloves.
** The awareness was assessed by a set of questions related to the impact of open charcoal burning with right-or-wrong answer; ten questions for health impact and ten questions for environment impact. Questions were about problem from burning, pollution from burning, sources of pollution and protection against smoke. Higher awareness was by having score equal and above 80%.
*** The history of respiratory symptoms was assessed by a set of seven questions that asked about the occurrence of asthma or recurrent bronchitis, recurring blocked or running nose, bouts of coughing, difficulty in breathing, chest tightness, phlegm, and attacks of wheezing.

Potential factors contributing to respiratory health of grill workers

The study revealed statistically significant factors contributing to self-reported respiratory symptoms among grill workers in last three months. Grillers who were female, who worked indoor, who experienced sudden cough due to intense grill-smoke, who had low income, who spent more years in grill-work, and who had self-reliance on health were more likely to develop respiratory symptoms that disturbed daily work in last three months (see Table 2).

Table 2. Factors associated with the presence of respiratory symptoms among Grill workers

Variables		Respiratory symptom(s) in the past three months (n = 362)				
		Frequency (%)*		Binary Analysis	Multiple Regression	
		Presence $n_p = 84$	Absence $n_a = 278$	COR (95%CI)	AOR (95%CI)	p
Socio-demographic characteristics						
Sex	Female	68 (25.3)	201 (74.7)	1.62 (0.88–2.94)	**2.14 (1.10–4.17)**	**0.024**
	Male	16 (17.2)	77 (82.8)	1	**1**	
Age	<= 35 years	21 (17.6)	98 (82.3)	1	1	
	36-50 years	46 (24.6)	141 (75.4)	1.52 (0.85–2.71)	1.31 (0.63–2.72)	0.465
	> 50 years	17 (30.3)	39 (69.6)	2.03 (0.97–4.26)	1.86 (0.72–4.77)	0.193
Marital status	Single/Divorced	15 (19.2)	63 (80.8)	1	-	-
	Married	69 (24.3)	215 (75.7)	1.34 (0.72–2.51)		
Education level	<=Primary	14 (22.9)	47 (77.1)	1	-	-
	L-H secondary	59 (23.3)	194 (76.7)	1.02 (0.52–1.98)		
	Tertiary =>	11 (22.9)	37 (77.1)	0.99 (0.40–2.45)		
Alternative work	Selling	75 (23.4)	246 (76.6)	1	-	-
	Other**	9 (21.9)	32 (78.1)	0.92 (0.42–2.01)		
Owner of grill shop	No	17 (21.3)	63 (78.7)	1	-	-
	Yes	67 (23.8)	215 (76.2)	1.15 (0.63–2.10)		
Total work hours	< = 8 h/day	36 (22.1)	127 (77.9)	1	-	-
	> 8 h/day	48 (24.1)	151 (75.9)	1.12 (0.68–1.83)		
Total income (LAK) / month	<= 1.5 million	10 (18.5)	44 (81.5)	1	-	-
	1.6M-3.0 million	10 (21.7)	36 (78.3)	1.22 (0.45–3.25)		
	> 3.0 million	64 (24.4)	198 (75.6)	1.42 (0.67–2.98)		
Grill Income (LAK)/month	>1.6 million	29 (15.8)	154 (84.2)	1	**1**	
	<= 1.5 million	55 (30.7)	124 (69.3)	2.35 (1.41–3.91)	**2.03 (1.16–3.54)**	**0.012**
Substitution when ill	No	35 (17.5)	165 (82.5)	1	1	0.250
	Yes	49 (30.3)	113 (69.7)	2.04 (1.24–3.35)	1.62 (0.70–3.72)	
Chance to relax	Difficult	32 (18.7)	139 (81.3)	1	1	0.957
	Easy	52 (27.2)	139 (72.8)	1.62 (0.98–2.67)	0.97 (0.40–2.33)	
Exposure to charcoal burning in grill working						
Grill stove setting	Outdoor	70 (21.1)	262 (78.9)	1	**1**	
	Indoor	14 (46.7)	16 (53.3)	3.27 (1.52–7.03)	**3.61 (1.58–8.26)**	**0.002**
Years of grill-job	<= 5 years	30 (17.7)	140 (82.3)	1	**1**	
	> 5 years	54 (28.1)	138 (71.9)	1.82 (1.10–3.02)	**2.07 (1.19–3.60)**	**0.010**
Days charcoal burning/week	<= 5 days/week	14 (33.3)	28 (66.7)	1	1	
	6 – 7 days/week	70 (21.9)	250 (78.1)	0.56 (0.07–1.12)	0.78 (0.16–3.67)	0.764
Charcoal burn per day	<= 5 kg/day	23 (17.7)	107 (82.3)	1	1	
	6 - 20 kg/day	36 (22.8)	122 (77.2)	1.37 (0.76–2.46)	0.77 (0.33–1.80)	0.559
	> 20 kg/day	25 (33.8)	49 (66.2)	2.37 (1.22–4.59)	0.85 (0.28–2.52)	0.774
Charcoal burn h/day	<= 8 h	71 (23.6)	230 (76.4)	1	-	-
	> 8 h	13 (21.3)	48 (78.7)	0.87 (0.44–1.71)		
Hours in front of stove	1 - 3 h/day	39 (18.4)	173 (81.6)	1	1	
	4 - 6 h/day	40 (30.1)	93 (69.9)	1.92 (1.22–3.03)	1.28 (0.66–2.46)	0.453
	> 6 h/day	5 (29.4)	12 (70.6)	2.15 (0.79–5.82)	0.99 (0.27–3.66)	0.997
Sudden smoke cough	Never	43 (17.6)	202 (82.4)	1	**1**	**<**
	Occasion/Often	41 (35.0)	76 (65.0)	2.53 (1.53–4.18)	**2.93 (1.69–5.09)**	**0.001**
Setting fire for grilling	Yes, every time	58 (27.4)	154 (72.6)	1	1	
	Yes, sometimes	26 (17.3)	124 (82.7)	0.55 (0.33–0.93)	0.57 (0.30–1.08)	0.088
Have a helper in grilling	Yes	41 (20.9)	155 (79.1)	1	-	-
	No	43 (25.9)	123 (74.1)	1.32 (0.81–2.15)		

Amount of food grilled per day	<= 5 kg/day	19 (20.2)	75 (79.8)	1	1	
	6 – 20 kg/day	32 (17.7)	149 (82.3)	0.84 (0.45–1.59)	0.62 (0.26–1.47)	0.284
	> 20 kg/day	33 (37.9)	54 (62.1)	2.41 (1.24–4.68)	1.28 (0.42–3.87)	0.651
Walk away from grillstove	Sometimes	31 (22.3)	108 (77.7)	1	-	-
	Often	53 (23.8)	170 (76.2)	1.08 (0.65–1.79)		
Personal protection and health related characteristics						
Use of any PPE	No	5 (18.5)	22 (81.5)	1	-	-
	Yes	79 (23.6)	256 (76.4)	1.35 (0.49–3.70)		
Self-esteem on health	Unsatisfied	34 (16.2)	176 (83.8)	1	**1**	
	Satisfied	50 (32.9)	102 (67.1)	2.53 (1.54–4.18)	**2.43 (1.41–4.21)**	**0.001**
Level of Body Mass Index	Under weight	7 (33.3)	14 (66.7)	1	-	-
	Normal weight	45 (20.2)	178 (79.8)	0.50 (0.19–1.32)		
	Over weight	24 (26.4)	67 (73.6)	0.71 (0.25–1.98)		
	Obesity	8 (29.6)	19 (70.4)	0.84 (0.24–2.87)		
Physical exercise last week	Never	69 (23.1)	230 (76.9)	1	-	-
	Sometimes	15 (23.8)	48 (76.2)	1.04 (0.54–1.97)		
Days off per week	Never	53 (25.7)	153 (74.3)	1	1	
	One day/week	14 (13.6)	89 (86.4)	0.45 (0.23–0.86)	0.81 (0.38–1.72)	0.589
	>= 2 days/week	17 (32.1)	36 (67.9)	1.36 (0.70–2.62)	2.34 (0.56–9.98)	0.243
Sleep h/day	< 8 h	37 (31.1)	82 (68.9)	1	1	
	>= 8 h	47 (19.3)	196 (80.7)	0.53 (0.32–0.87)	1.09 (0.57–2.08)	0.782
Annual health check-up	No	57 (24.2)	179 (75.8)	1	-	-
	Yes	27 (21.4)	99 (78.6)	0.85 (0.50–1.43)		
Payment when get sick	Self-pay	43 (18.4)	191 (81.6)	1	1	
	Others***	41 (32.0)	87 (68.0)	2.09 (1.27–3.44)	1.56 (0.84–2.88)	0.150
Being cigarette smoker	No	78 (22.6)	267 (77.4)	1	**1**	
	Yes	6 (35.3)	11 (64.7)	1.86 (0.66–5.21)	**3.87 (1.03-14.4)**	**0.044**
Level of awareness on health and environmental effects related to charcoal burning						
Awareness on health effects	Higher level	25 (19.1)	106 (80.9)	1	1	
	Lower level	59 (25.5)	172 (74.5)	1.45 (0.85–2.46)	0.95 (0.47–1.91)	0.888
Environmental effects	Higher level	21 (18.1)	95 (81.9)	1	1	
	Lower level	63 (25.6)	183 (74.4)	1.55 (0.89–2.70)	0.99 (0.48–2.05)	0.997

* Percentage by row
** Other works were farming, studying, etc.
*** People to help in payment e.g., family members and shop owners

General situation related to emission and exposure

The study indicates grill workers are exposed to levels of toxic pollutants. Results from the air sampling in 14 areas of grill-shops demonstrated a high level of emission of $PM_{2.5}$ from food-grill activities in restaurants, markets and street carts. The average $PM_{2.5}$ concentration emitted from grill shops was 84.8 µg/m^3. This concentration exceeds the Lao air quality index (50 µg/m^3 as annual mean standard). This level of concentration implicates a risk of negative health impacts, especially where the $PM_{2.5}$ concentration level is higher than 251 µg/m^3 [13, 14]. Given the particles originate from the use of a charcoal fire, they are likely to be particularly hazardous to human health [15]. The findings also highlight the respiratory health effects of exposure, with women reporting more respiratory symptoms than men.

A wide variation in the $PM_{2.5}$ concentration level was observed and is likely to be due to factors such as grill food outlet location, wind speed at time of measurement, and type and amount/ volume of food being grilled. Higher levels of $PM_{2.5}$ (average 143.1 µg/m^3) were found in the grill markets compared to the grill restaurants and carts. This is likely to be due to the number of carts in the market, amount of charcoal used given the larger volume of customers and being surrounded by buildings. The results also suggest $PM_{2.5}$ levels fluctuate based on the time of day and increases or decreases in demand. Other factors that can mediate PM concentrations include the cooking method, type and quality of the energy (heating) source, burner size, use of food, additives, source surface area, cooking temperature, ventilation and position of the cooking pan on the stove [16].

Studies have established the risk of developing respiratory symptoms and abnormal pulmonary function due to smoke from charcoal burning is influenced by the activities performed, amount of charcoal used, frequency of exposure, and preventive measures taken [17-21]. In this study, most grill workers were exposed to smoke from grilling for at least 8 h/ day, six to seven days per week, with 10 Kg-50 Kg of charcoal burned daily. Few studies have examined regarding the amount of the charcoal used to cause respiratory illness [22, 23, 6], but the length and frequency of exposure and the high levels of emissions, suggest grilled workers are at risk of respiratory illness due to workplace pollutants. The extremely high level of $PM_{2.5}$ at the grilled street-carts in location 14 in the Nongdouang Market, are likely to be due to the intensive barbecue cooking, and number of grilled street-carts, and food shops nearby. While our study focused on outdoor concentration of pollutants, the findings align with previous studies of measurement of $PM_{2.5}$ in grill restaurants which demonstrate high particle concentrations in the dining rooms of restaurants with open-kitchen designs [24, 25]. Direct exposure to a large amount of smoke from grilling or inhaling intense smoke can induce sudden cough or more serious health effects [26 ,9]. This study found grill workers who reported sudden coughing due to grill smoke were more likely to develop respiratory symptoms. Overall, nearly one-fourth (23.2%) of grill workers had experienced respiratory symptoms within the past three months, with a higher proportion of females reporting symptoms than males (25.3% vs. 17.2%). Other studies have reported women restaurant workers typically have a higher risk of symptoms from cooking-work than men [9] and it is recommended men and women working in grill restaurants have regular health check-ups [27]. Given women often do most of the cooking at home, they are also likely to be exposed to higher levels of $PM_{2.5}$ and 10, which may explain the difference in increased risk of symptoms. Other reasons for the differences could relate to socio-economic differences, (women tend to earn less than men) biological differences, and perception differences on health consequences and different roles within the grill shops [28]. Women may also have lower levels of education than men [29].

Overall, the prevalence of respiratory symptoms reported in the current study is slightly higher than that reported in studies conducted in Thailand, Brazil, and Nigeria, where 9.9%, 13%, 9.5%, respectively, of study participants had a chronic cough [9, 30, 31]. Using respiratory protection equipment for individuals, or a well-fitted, proper face mask that can filter pollutants - like $PM_{2.5}$, can reduce the risk of respiratory illness from grill smoke [32]. Yet, the use of PPE, including face, was rare in this study. This may mean participants understanding or perception of risk may be low [33], and previous studies have shown low awareness of risk of exposure to grill smoke is associated with respiratory symptoms [31, 34]. Low PPE use may relate to not knowing the benefit of, or be able to consistently access adequate PPE, or due to discomfort when wearing PPE while grilling A higher proportion of reported respiratory symptoms was found in grill workers with lower awareness of the health risks of burning charcoal compared to those with higher awareness (25.6% vs. 18.1%). However, the study did not find the association in both variables of PPE use and awareness on health risk and environment, and did not investigate the knowledge and proper use of PPE; this should be considered in future studies. Nonetheless, previous studies have shown low awareness of risk of exposure to grill smoke is associated with respiratory symptoms [31, 34]. Raising awareness and promoting and providing PPE may help promote more protective health behaviours [35-38].

In this study level of income was associated with experiencing respiratory symptoms. Grill workers with lower income were about two times more likely to develop respiratory symptoms than those with a higher income. This may relate to the well-documented link between level of income and health outcomes [39-41]. Most studies, however, have not specifically looked at income and respiratory health effects. The study also identified a statistically significant association between the location of the grill stove and reporting respiratory symptoms. Confirming other studies [42-45], grill workers using an indoor grill were more likely to suffer from respiratory symptoms than outdoor grill workers, with indoor combustion decreasing air quality [46]. Participants who were satisfied with their health status were more likely to have experienced respiratory symptoms. Self-rated satisfaction might be due to only having experienced mild symptoms [47, 48] or not being aware that symptoms may indicate the need for a health checkup. Previous literature has demonstrated however, that workers often seek treatment only when symptoms become severe [47, 48]. Given the harmful health effects of exposure to $PM_{2.5}$ are well documented [49], grilled health workers should be encouraged to have regular heath check-ups [50]. Grill workers who were cigarette smokers were more likely to develop respiratory symptoms than those who were not. During the analysis, we found two female smokers and one of whom (considerably 50%) developed symptoms; which was higher than the symptom proportion in male smokers (33.3%). Many studies have pointed out the danger of cigarette smoking on our health and wellbeing [51-53]. Further awareness about the effects of tobacco smoke should also be provided to grill workers [54, 55).

Strengths and limitations

This is the first study of air pollution among grill workers in Lao PDR. Strengths of this study are the measurement of $PM_{2.5}$ and the estimation of air pollution from the grill shops. There are however limitations. As a cross-sectional study, a causal effect relationship could not be explored. The study was conducted in only four urban districts of Vientiane capital, and findings may not be representative of the country, especially rural areas. Future studies should extend to more grilling sites, including peri-urban grill markets and/or more indoor grilled restaurants; which may differ in terms of number and type of cooking activities, and number of workers. The small sample size precluded assessment of other contributing factors in exposure to $PM_{2.5}$ (e.g., cigarette smoking and cooking oil type). The small sample size also precluded assessment of gender-specific exposure and gender-specific health risk in this group.

The measurement of $PM_{2.5}$ level in this study was obtained by placing the equipment from the open stove about 3-10 m, based on wind direction, wind speed and proper space; and we did not measure the indoor PM level in the grill restaurants directly. This means observed PM levels in the open grill stove may be different from other spots only a few feet away. Future studies should address this aspect and monitor PM levels in multiple spots of the restaurants as well. Since the grill restaurants/grill-carts were located on the roadside, vehicular emissions may also have resulted in overestimated cooking emissions. Further, the results of this study were obtained only from one single time in a few single open-grill restaurants/carts and grill street-carts of the market sites in Vientiane capital. Although the sampling was only one day for each grill site, it could represent a typical day that the grill activity emits the air pollutants; and cautions should be applied based on the results that the over-standard limits of $PM_{2.5}$ concentration has been found.

Finally, generalization of the results to other open-grill restaurants/carts and grill street-carts of the market sites could be feasible, as grill activities work with many types food material, such as meat, fish, fats, vegebtables, etc. However, the emitted pollutants and intensity of pollution might be varied by different confounders, or due to a variety of factors including type of food, oil, energy source, and so on [16].

Conclusion

There is increasingly recognition of the urgent need to reduce air pollution. This study is one of the few to investigate the extent to which grilled food outlets contribute to air pollution, self-reported respiratory symptoms of grill workers and associated factors. It is to our knowledge, the first such study in the Lao PDR and provides a foundation for future work. Awareness raising and effective strategies are required to increase protection of health among grill workers and reduce pollution. ventilation, cleaner cooking technologies, improving access to PPE and promoting regular health checks are strategies that can improve workplace health and safety measures for grilled food outlet workers. In lower-middle income countries, cost and access are also critical determinants in local restaurants being able to sustain any interventions. Regular monitoring and incentives for restaurants to improve air quality are also urgently required and warrant increased public and environmental health efforts.

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Competing interests

The research has no conflict of interest.

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Ethical considerations

Ethical approval was obtained from the Ethical Committee for Health Research at the University of Health Sciences No. 276, dated 8/12/ 2021. This study was conducted with respect to the rights and interests of the participants, confidentiality and privacy were assured. Informed consent was gained from each participant after the data collector explained about the study objectives, assurance of confidentiality and rights.

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