# ASSESSMENT OF AIR POLLUTANT EMISSIONS FROM RICE STRAW OPEN BURNING IN HOA VANG DISTRICT, DA NANG CITY, VIETNAM

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(Received: September 06, 2024; Revised: September 27, 2024; Accepted: October 04, 2024)

DOI: 10.31130/ud-jst.2024.550E

**Abstract -** This study inventoried the air pollutants from rice straw open burning (RSOB) in Hoa Vang district, Da Nang city, Vietnam. The rice straw in Hoa Vang district tended to decrease due to the shrinking rice cultivation area, of which 73% was reused in mushroom growing, livestock feeding, composting..., the remaining 27% was not reused and burned. The amount of rice straw burned in 2019 and 2023 was 25544 and 23377 tons, respectively. In 2023 the emissions of $CO_2$, CO, $PM_{10}$, $PM_{2.5}$, $SO_2$ and $NO_2$ from RSOB were 27138, 1720, 509, 233, 25.9 and 11.4 tons/year, respectively. Burning conditions affected the air pollutant emissions from RSOB. At 5m from the burning site, the air pollutants were higher than the permissible standards, whereas at 200m from the burning site, the air pollutants decreased to the background concentration. These results are useful for both local and national environment managers in controlling air quality.

**Key words -** Air pollutant; Emission; Emission factor; Emission inventory; Rice straw open burning.

## 1. Introduction

Rice is a very popular food crop in Vietnam. In Vietnam and some countries in the world rice is a main food for daily meals, in addition rice also contributes to the Vietnamese economy through export. For meeting the domestic and export rice demand, the rice plants are often cultivated 2 to 3 crops per year and it only takes a short time to plough for rice cultivation. According to the General Department of Vietnam Customs, Vietnam's rice export turnover in 2023 exceeded 8 million tons, with the revenue of 4.6 billion USD, increased 35% in comparison with the previous year [1].

According to General Statistics Office of Vietnam, in 2022 rice cultivation areas of Viet Nam were about 7,108.9 thousand hectares with the rice productivity of 42,660.8 thousand tons, whereas in 2023 were 7,119.3 thousand hectares and 43,497.7 thousand tons, respectively [2]. Rice is cultivated a lot to provide food as well as income for farmers and the amount of rice straw after harvest as well as rice husks from the rice milling process are quite high. Each year, Viet Nam produced about 43 million tons of rice with about 47 million tons of rice straw, but only about 20% were collected and used for mushroom cultivation, animal feed, fruit transportation cushions,..., the remains were treated by burning on the fields and burying in the soil, resulting in increasing air pollutants, greenhouse gas emissions, and environmental pollution [3]. It is assessed that burning of one ton of rice straw accounts for loss of 5.5 kg Nitrogen (N), 2.3 kg Phosphorus (P), 25 kg Potassium (K), and 1.2 kg Sulphur (S) besides organic Carbon [4]. The inventory results of air pollutant emissions from rice straw open burning (RSOB) on the fields in Hanoi capital using the SAR Sentinel-1 satellite showed that in 2019, an amount of 460 thousand tons of rice straw was burned, thus, created 542 thousand tons of $CO_2$ (90%), 42 thousand tons of CO (7%), and the rest of air pollutants (3%). Air pollutant emissions from RSOB was mainly concentrated in suburban districts such as Ung Hoa, My Duc, and Phu Xuyen where were the large rice cultivation areas [5]. A research of Dung and Thy in 2022 showed that in the Mekong Delta in 2012, the burning of rice straw emitted 1598.8 thousand tons of CO, followed by $CH_4$ was about 164.9 thousand tons, the rests were 39.2 thousand tons of $NO_x$ and 1.2 thousand tons of $N_2O$; By the year 2020, with the change of rice cultivation areas and the reduction of straw burning rate, the estimated emissions were reduced to 1123.6 thousand tons of CO, 115.9 thousand tons of $CH_4$, 27.5 thousand tons of $NO_x$, and 0.8 thousand tons of $N_2O$ [6].

At the global scale, in 2013, Chih-Hua Chang et al. conducted an inventory of air pollutant emissions from RSOB in Taiwan based on the classifying and mapping of burning areas using Formosat-2 satellite images. The research results showed that the annual rice straws of 438,297 tons were burned and emitted 1.73 tons/year of air pollutants, of which PM ($PM_{2.5}$ + $PM_{10}$) were 6,101 tons/year, $CO_2$, CO, $CH_4$, $N_2O$, $NO_x$ and $SO_2$ were 511931, 32609, 421, 25, 799 and 63 tons/year, respectively [7]. The inventory results of air pollutant emissions from RSOB in Thailand in 2018 included: 5.34 ± 2.33 megatons (Mt) of $CO_2$, 44 ± 14 kilotons (Kt) of $CH_4$, 422 ± 179 Kt of CO, 2 ± 2 Kt of $NO_x$, 2 ± 2 Kt of $SO_2$, 38 ± 22 Kt of $PM_{2.5}$, 43 ± 29 Kt of $PM_{10}$ [8].

Rice straw burning emits air pollutants, which not only affects the atmosphere but also affects the human health, these emissions also contribute to increasing the greenhouse effect and climate change.

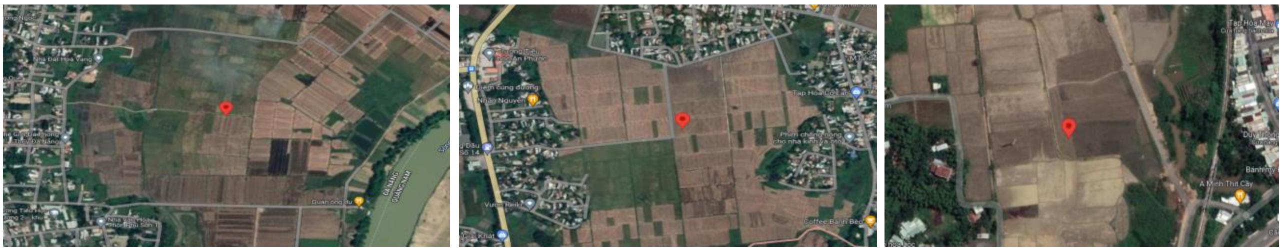
Inventory of air pollutant emissions from rice straw burning in the Central region of Viet Nam has not yet implemented, so this study was conducted to assess the air pollutant emissions from rice straw burning in Da Nang city, Vietnam. Currently, in the suburban Da Nang city, Hoa Vang district, there are a lot of rice cultivation areas. After harvesting, rice straws were still burned directly on the fields, so this study was conducted to inventory the air pollutant emissions and assess the impacts of RSOB to the environment and human health.

There are some methods can be used in emission inventory and impact assessment of RSOB such as continuous monitoring of emission source method, emission source inspection method, emission factor method, material balance method, fuel analysis method, waste estimation model method [9]. This study applied the emission factor method to inventory air pollutant emissions from RSOB and the emission factors were determined through the carbon balance method [10, 11]. The carbon balance method is used to determine the emission factor because this is the most optimal method due to its cost savings, the implementation process and the result are highly reliable [10].

## 2. Materials and methods

### *2.1. Site characteristics and sample collection*

This study was conducted from January 2023 to October 2023 in Hoa Khuong, Hoa Phong and Hoa Chau commune of Hoa Vang district, Da Nang city (Figure 1). Air pollutant emissions from RSOB were sampled and measured at downwind locations. The sampling and measuring sites were selected in the middle of the large fields to determine the maximum distance at which the emissions could affect the surrounding air environment. Characteristics of the sampling and measuring sites are presented in Table 1.



*(a)* *(b)* *(c)*

***Figure 1.*** *Map of sampling sites: (a) Hoa Khuong, (b) Hoa Phong and (c) Hoa Chau*

***Table 1.*** *Information of sampling sites*

| Sampling location | Coordinate | Sampling date | Burning area ($m^2$) | Drying duration of rice straw (day) | Temperature (°C) | Wind speed (m/s) | Wind direction |
|---|---|---|---|---|---|---|---|
| Hoa Khuong commnue | 15°57'06.0"N 108°08'48.2"E | 1 May 2023 | 100 | 3 | 31.0 | 2.22 | Northwest |
| Hoa Phong commnue | 15°58'52.3"N 108°08'37.9"E | 28 April 2023 | 100 | 3 | 29.5 | 2.78 | Northwest |
| Hoa Chau commnue | 15°59'41.0"N 108°11'24.0"E | 25 April 2023 | 100 | 3 | 33.0 | 3.31 | Southeast |

### *2.2. Parameters and analysis methods*

Because RSOB mainly emits the air pollutants including $PM_{10}$, $PM_{2.5}$, CO, $CO_2$, $NO_2$, $SO_2$, this study will select these parameters for assessment.

Due to the unstable wind regime, air samples were collected and measured in the prevailing wind direction during the measuring period. CO, $CO_2$, $NO_2$ and $SO_2$ were measured by Testo 350, Japan, the technical specifications are presented in Table 2.

- $PM_{10}$ and $PM_{2.5}$ were collected using the Sibata LV-250R dust samplers, with a sampling speed of 16.7 L/min.

+ $PM_{10}$ was sampled and analyzed according to the 40 CFR part 50 Method appendix J method specified in Circular 10/2021-BTNMT [12].

+ $PM_{2.5}$ was sampled and analyzed according to the 40 CFR part 50 Method appendix L method specified in Circular 10/2021-BTNMT [12].

+ Mettler Toledo XPR10 analysis balance: Maximum Capacity: 10.1g; Readability: 1 µg; Repeatability: 0.4 µg.

- The technical specifications of Kestrel 5500 microclimate meter are shown in Table 3.

- All devices were tested and calibrated before field measurements.

- Measuring background environment: First, a rapid measurement of background concentrations was conducted to determine the concentration of air pollutants before rice straw burning. The location for rapid measurement of background concentrations was determined basing on the prevailing wind direction at the time of sampling. The sampling head of the devices was placed at a fixed position of 1.5 m above the ground and in the same wind direction. Meteorological conditions (wind speed, temperature, humidity), CO, $CO_2$, $NO_2$ and $SO_2$ were measured continuously during the sampling period.

***Table 2.*** *Specification of Testo 350 meter*

| Parameter | Specification range | Resolution | Accuracy |
|---|---|---|---|
| CO | 0 - 10,000 ppm | 1 ppm | ± 5% |
| $CO_2$ | 0 - 50% | 0.01% | ± 0.3% |
| $NO_2$ | 0 - 500 ppm | 0.1 ppm | ± 5% |
| $SO_2$ | 0 - 5,000 ppm | 1 ppm | ± 5% |

***Table 3.*** *Specification of Kestrel 5500*

| Parameter | Specification range | Resolution | Accuracy |
|---|---|---|---|
| Temperature | -29.0 - 70.0 °C | 0.1 °C | ± 0.5 °C |
| Humidity | 10 - 90% | 0.1% | ± 2% |
| Wind speed | 0.6 - 40.0 m/s | 0.1 m/s | ± 3% |

- Measuring air pollutants during RSOB: The implementation method was similar to that of measuring background concentrations. All devices were placed at the locations where smoke was blowing, and air samples were measured and collected at the downstream of the wind direction at the intervals of 50 m. Air samples were measured continuously to the distance where the emission concentrations reduced to the background concentrations, then the experiment was ended. The burning time and final concentration were recorded.

- The measurement concentrations of air pollutants were converted to the standard conditions at 25ºC and 760 mmHg.

### 2.3. Inventory method

The air pollutant emissions were inventoried by the amount of rice straw burning and the emission factor of the interested air pollutant.

*2.3.1. Determination of rice straw open burning*

The following equation (1) is used to determine the rice straw burning [8]:

$$M = P \times N \times B \times MCE \quad (1)$$

where, M: rice straw burning (ton/year); P: Rice cultivation area (ha/year); N: Rice straw generated by rice cultivation area (kg/m$^2$, ton/ha); B: Ratio of rice straw burning (%); MCE: Modified combustion efficiency (%).

Rice straw generated by rice cultivation area (N): The rice fields were harvested by the combine harvester, so rice straw was spread evenly on the field surface. At the measured fields, standard plots were established with the area of 1m$^2$. Rice straw was collected and weighted in the standard plots, then the rice straw generated in kg per 1m$^2$ was determined.

Modified combustion efficiency (MCE): Under natural conditions, rice straw cannot burn completely, the products of incomplete combustion include CO, $CO_2$, $CH_4$ and some other gases. It is assumed that 90% of carbon in rice straw after burning is converted to CO and $CO_2$. The combustion efficiency is calculated through the emissions of $CO_2$ and CO as follows [11]:

$$MCE = \frac{CO_2}{CO_2+CO} \quad (2)$$

where, MCE: Modified combustion efficiency; CO and $CO_2$: Emission concentrations measured simultaneously in the emission plume (mg/m$^3$).

- MCE > 0.9: flaming combustion, $CO_2$ is used as the reference species;

- MCE < 0.9: smoldering combustion, CO is used as the reference species.

To determine the MCE, 3 RSOB sites were selected randomly for assessment with an area of 100m$^2$ each. Rice straw was left to dry on the field for 3 days before burning.

Ratio of RSOB: The ratio of RSOB was determined by the questionnaires on farmers in the rice cultivation areas in Hoa Chau commune, Hoa Khuong commune and Hoa Phong commune on the current status reuse of rice straw.

Number of questionnaires among the total number of rice cultivation farmers were determined by the Yamane Taro formula [13]:

$$n = \frac{N}{1+N.e^2} \quad (3)$$

where, n: Number of questionnaires; N: Number of rice cultivation farmers; e: Level of significance, e ≈ 10 - 30%, selected e = 20%.

***Table 4.*** *Number of survey questionnaire*

| Commune | Number of households | Percentage of rice cultivation farmers | Number of questionnaires |
|---|---|---|---|
| Hoa Khuong | 3,708 | 35% | 25 |
| Hoa Phong | 4,965 | 65% | 25 |
| Hoa Chau | 6,166 | 37% | 25 |

*2.3.2. Inventory of air pollutant emissions from RSOB*

The emissions from biomass open burning can be estimated by the equation developed by Seiler, W. and Crutzen, P. J. [14], which represents the relationship between the combustion process and its emission, as follows:

$$E_{Ai} = M \times EF_i \times 10^{-6} \quad (4)$$

where $E_{Ai}$: Emission of air pollutant i (ton/year); M: Mass of dry matter burned (ton of dry matter); $EF_i$: Emission factor of air pollutant I (g/kg).

Emission factor (EF) of an air pollutant was determined by the method involving the carbon balance and emission ratio. The carbon balance method is one of the popular methods in determining emission factors from RSOB [10, 15, 16]. Basing on the difference in C measured before and after burning, the carbon emitted with carbon containing species, i.e. $CO_2$, CO, $CH_4$, Non-methane hydrocarbon (NMHC) and particulate C is calculated. The EF of other species are then determined using the concentration ratio of the interested species to a reference species, either $CO_2$ or CO, measured simultaneously in the emission plume [17].

When CO is used as a reference species (smoldering combustion), emission factor of an air pollutant I is determined as follows:

$$EF_i = ER_{i/CO} * ER_{CO/CO2} * EF_{CO2} \quad (5)$$

When $CO_2$ is used as a reference species (flaming combustion), emission factor of the air pollutant I is determined as follows:

$$EF_i = ER_{i/CO2} * EF_{CO2} \quad (6)$$

where, i: Air pollutant; $ER_{i/CO}$ or $ER_{i/CO2}$: Emission ratio of air pollutant I to reference CO or $CO_2$; $ER_{CO/CO2}$: Emission ratio between CO and $CO_2$; $EF_{CO2}$: Emission factor of $CO_2$.

The emission ratio of air pollutant I to reference CO ($ER_{i/CO}$) is calculated using Equation (7):

$$ER_{i/CO} = \frac{\Delta_i}{\Delta_{CO}} \quad (7)$$

$$ER_{\frac{CO}{CO2}} = \frac{\Delta_{CO}}{\Delta_{CO2}} \quad (8)$$

where, $\Delta_i = i_a - i_b$: net pollutant i (in concentration units) from burning; $\Delta CO = CO_a - CO_b$: net CO (in concentration units) from burning; $\Delta CO_2 = CO_{2a} – CO_{2b}$: net $CO_2$ (in concentration units) from burning.

Note that CO or $CO_2$ is used as the reference species depending on MCE in equation (2).

In our study, $CO_2$ emission factor ($EF_{CO2}$) and CO emission factor ($EF_{CO}$) from RSOB in Vietnam of Pham et al., were used for inventory using the carbon balance method [16].

### *2.4. Statistical analysis*

The collected data and monitored results were synthesized and statistically analyzed by the Microsoft excel. Then the analysis results were compared to the Vietnamese standards and regulations for assessing the air pollutant emissions from RSOB.

## 3. Results

### *3.1. Rice production, reuse and disposal of rice straw in Hoa Vang district*

*3.1.1. Rice production*

From 2019 to 2023, Hoa Vang district has had an average rice cultivation area of 4,467 hectares/year, with a productivity of more than 27,680 tons of rice/year. In 2023, rice cultivation area of Hoa Vang was 4,300.36 hectares, with a productivity of 27,127 tons of rice. Because the weather in the Central region of Vietnam can be divided into 2 distinct seasons: dry season and rainy season and to minimize the negative impact of weather on rice crop (especially the flood season from September to November), the Central region in general and Hoa Vang district in particular rice is cultivated in two different crops including Winter-Spring (from December to April of the following year) and Summer-Autumn (from April to August).

From Figure 2, rice cultivation area in Hoa Vang tends to decrease during 2019 - 2023 due to the conversion impacts from agricultural land to residential land and also industrial land, the combined impacts of climate change, epidemics, and natural disasters, so the farmers have reduced rice cultivation. The reduction rice cultivation areas resulted in a decrease of rice production. Rice production in 2021 was 1,300 tons higher than that in 2020. Rice production in 2022 decreased sharply by nearly 5,500 tons in comparison with that in 2021. However, rice production in 2023 tended to increase again, nearly 2,800 tons compared to in 2022 due to the rice productivity in 2023 (6.31 tons/ha) was higher than that in 2022 (5.52 tons/ha).

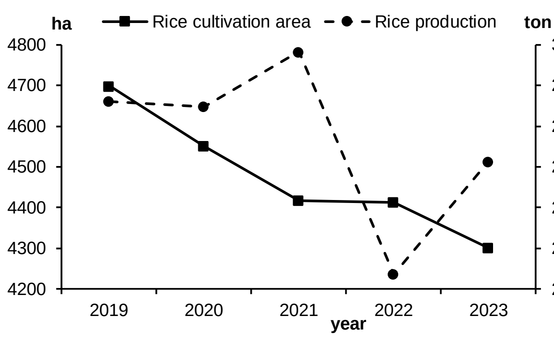



***Figure 2.*** *Rice cultivation area and production during 2019 - 2023*

*3.1.2. Rice straw generation*

At each experimental site, to determine the rice straw generated by area, 2 standard plots were selected randomly with an area of 1m$^2$ each. Rice straw in each standard plot was collected and weighted, then the average value of rice straw per 1m$^2$. was determined (Table 5).

***Table 5.*** *Rice straw generation*

| No. | Sampling site | Rice straw per 1 m$^2$ |
|---|---|---|
| 1 | Hoa Khuong | 1.10 kg |
| 2 | Hoa Chau | 1.20 kg |
| 3 | Hoa Phong | 1.10 kg |
| | Average | 1.13 kg |

The investigate results showed that all rice farmers have cultivated 2 rice crops. From the average rice straw per 1 m$^2$ in Table 5 and the rice cultivation area, the rice straw generation in Hoa Vang is shown in Figure 3. The rice straw has decreased gradually from 2019 to 2023 due to the decreasing rice cultivation area.

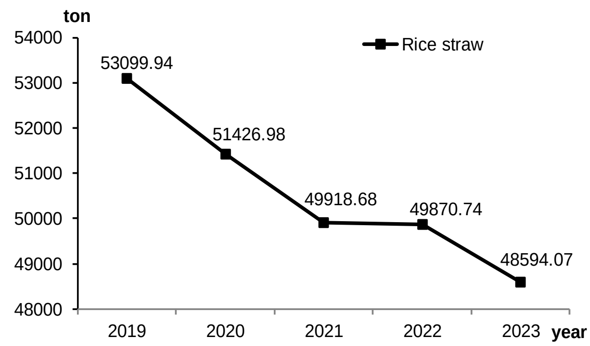



***Figure 3.*** *Rice straw generation during 2019 - 2023*

*3.1.3. Reuse and disposal of rice straw in Hoa Vang district*

In Hoa Vang district, rice was harvested by the combine harvesters. After harvesting, rice straw was in rows on the field. Rice straw was dried directly on the field, after drying, part of this rice straw was rolled for reuse (72.7%) including mushroom cultivation, food and bedding for livestock..., and the remains (27.3%) was burned directly on the field (Figure 4).

The reused rice straw was mainly for mushroom cultivation (67.3%), whereas the remains (32.7%) for cooking, food and bedding for livestock....

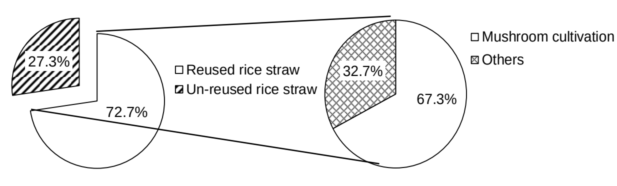



***Figure 4.*** *Reused ratio of rice straw*

*3.1.4. Rice straw burning*

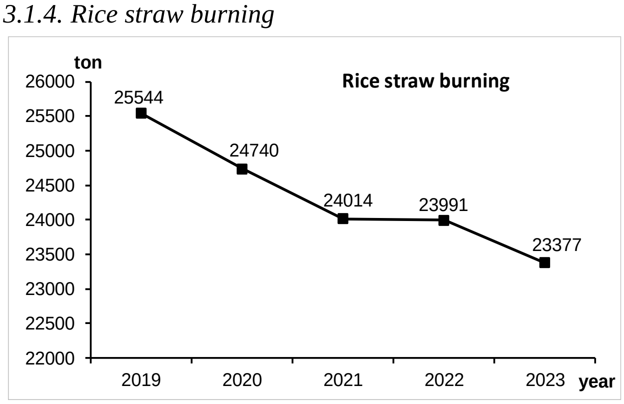



***Figure 5.*** *Rice straw burning during 2019 – 2023*

Applying formula (1) and rice straw generation presents in section 3.1.2, rice straw burning was determined in Hoa Vang district as shown in Figure 5.

During 2019 - 2023, rice straw burning has decreased due to the reduction of rice cultivation area. However, rice straw open burning in 2023 was 23,377 tons, quite high, this wasted the resources and resulted in air pollution.

### *3.2. Air pollutant emissions from RSOB in Hoa Vang district*

To determine the modified combustion efficiency (MCE), in each monitoring site, rice straw in the area of 100m$^2$ was burnt, simultaneously CO and $CO_2$ were quickly measured. The results are presented in Table 6.

***Table 6.*** *MCE of rice straw open burning in Hoa Vang district*

| Burning site | Burning area (m$^2$) | CO (mg/m$^3$) | $CO_2$ (mg/m$^3$) | MCE | Combustion process |
|---|---|---|---|---|---|
| Hoa Khuong | 100 | 628.1 | 5421 | 0.896 | Smoldering |
| Hoa Chau | 100 | 1007.8 | 8307 | 0.892 | Smoldering |
| Hoa Phong | 100 | 802.6 | 7101 | 0.898 | Smoldering |
| Average | 100 | 812.8 | 6943 | 0.895 | Smoldering |

The MCE results in Table 6 show that the combustion process was smoldering so CO is used as a reference species [9]. Referring to the emission factors of CO = 73.6 g/kg and $CO_2$ = 1,160.9 g/kg from rice straw burning in Hanoi city, Vietnam of Pham et al. [16] and net pollutants from rice straw burning, the emission coefficients of $SO_2$, $NO_2$, $PM_{10}$ and $PM_{2.5}$ were determined by the carbon balance method (Table 7).

***Table 7.*** *Emission factor of air pollutants developed by net concentration from burning*

| Parameter | | Monitoring site | | | | EF (g/kg RS) | |
|---|---|---|---|---|---|---|---|
| | | Hoa Khuong | Hoa Phong | Hoa Chau | Average | This study* | Other studies |
| CO | ΔCO | 620 | 796 | 999 | 805 | | 73.6 ± 46.2[b]; 93 ± 10[d] |
| $CO_2$ | $\Delta CO_2$ | 5130 | 6827 | 8021 | 6659 | | 1,247.5 ± 190[a]; 1,160.9 ± 80.9[b]; 1761 ± 30[c]; 1177 ± 140[d] |
| | $ER_{CO/CO2}$ | 0.1209 | 0.1165 | 0.1246 | 0.1207 | | |
| $SO_2$ | $\Delta SO_2$ | 5.5 | 6.5 | 7.1 | 6.4 | 1.11 ± 0.10 | 1.4 ± 0.3[a]; 1.4 ± 1.1[b]; 20.3 ± 1.5[c]; 0.51 ± 0.32[d] |
| | $ER_{SO2/CO}$ | 0.0087 | 0.0081 | 0.0070 | 0.0079 | | |
| $NO_2$ | $\Delta NO_2$ | 2.1 | 2.9 | 3.4 | 2.8 | 0.49 ± 0.01 | 1.3 ± 0.3[a]; 1.1 ± 0.9[b]; 0.49 ± 0.21[d] |
| | $ER_{NO2/CO}$ | 0.0034 | 0.0037 | 0.0034 | 0.0035 | | |
| $PM_{10}$ | $\Delta PM_{10}$ | 83 | 134 | 164 | 127 | 21.77 ± 2.63 | 13.6 ± 2.4[a]; 9.4 ± 3.5[d] |
| | $ER_{PM10/CO}$ | 0.1339 | 0.1684 | 0.1641 | 0.1578 | | |
| $PM_{2.5}$ | $\Delta PM_{2,5}$ | 32 | 67 | 78 | 59 | 9.97 ± 2.37 | 12.1 ± 2.1[a]; 34 ± 17.6[b]; 8.3 ± 2.2[d] |
| | $ER_{PM2.5/CO}$ | 0.0516 | 0.0842 | 0.0780 | 0.0733 | | |

*Note: * Data shows mean ± SD (Spread burning);*
*[a] P.T.H. Phuong et al. (Spread burning) [15] ;[b] P.C. Thuy et al. (Small piles in field) [16]*
*[c] T. Zhang et al [18]; [d] Kim Oanh et al. (Spread burning) [19]*

The $SO_2$ EF of our study (1.11 ± 0.10 g/kg) is similar to the $SO_2$ EF measured in the Mekong Delta, Vietnam (1.4 ± 0.3 g/kg) [15] and in Hanoi, Vietnam (1.4 ± 1.1 g/kg) [16]. The $NO_2$ EF in this study (0.49 ± 0.01 g/kg) is similar to the $NO_2$ EF measured in Thailand (0.49 ± 0.21 g/kg) [19] but nearly half of the $NO_2$ EF measured in Hanoi, Vietnam (1.1 ± 0.9 g/kg) [16] and the Mekong Delta, Vietnam (1.3 ± 0.3 g/kg) [15]. The $PM_{2.5}$ EF in this study (9.97 ± 2.37 g/kg) is similar to the survey results in the same conditions of spread rice straw burning in the Mekong Delta, Vietnam (12.1 ± 2.1 g/kg) [15] and in Thailand (8.3 ± 2.2 g/kg) [19], but much lower than that measured in Hanoi, Vietnam (pile rice straw burning) (34 ± 17.6 g/kg). Thus, the burning condition (Rice straw is spread or in piles on the field) affects the pollutant EF from RSOB.

This study was conducted to inventory the air pollutant emissions from RSOB and assess the impacts of these air pollutants on the human's health. The detailed inventory results of air pollution emissions from RSOB in Hoa Vang district from 2019 to 2023 are shown in Table 8.

The inventory results showed that the air pollutants gradually decreased from 2019 to 2023 due to the decrease of rice cultivation area in Hoa Vang district. In 2023, $CO_2$ emissions were the highest (27,138.1 tons), followed by CO (1,720.5 tons), CO emissions were high due to incomplete combustion (MCE < 0.9), whereas $PM_{10}$, $PM_{2.5}$, $SO_2$ and $NO_2$ emissions were 508.87, 233.17, 25.90 and 11.42 tons, respectively.

***Table 8.*** *Air pollutant emissions from RSOB*

| Pollutants (ton/year) | EF (g/kg DS) | Year | | | | |
|---|---|---|---|---|---|---|
| | | 2019 | 2020 | 2021 | 2022 | 2023 |
| CO | 73.6$^{(*)}$ | 1880.1 | 1820.8 | 1767.4 | 1765.7 | 1720.5 |
| $CO_2$ | 1160.9$^{(*)}$ | 29654.5 | 28720.2 | 27877.9 | 27851.1 | 27138.1 |
| $SO_2$ | 1.11 | 28.30 | 27.41 | 26.61 | 26.58 | 25.90 |
| $NO_2$ | 0.49 | 12.48 | 12.08 | 11.73 | 11.72 | 11.42 |
| $PM_{10}$ | 21.77 | 556.05 | 538.53 | 522.74 | 522.24 | 508.87 |
| $PM_{2.5}$ | 9.97 | 254.79 | 246.76 | 239.53 | 239.30 | 233.17 |

*$^{(*)}$ Emission factors referred from P.C. Thuy et al. [16]*

### 3.3. Assessment of air pollution from RSOB

#### *3.3.1. Dispersion of air pollutants from RSOB*

To assess the air pollution dispersion, $PM_{10}$, $PM_{2.5}$, $CO_2$, CO, $NO_2$, $SO_2$ were monitored at 5m, 10m, 50m, 100m, 150m and 200m away from the burning site in the downstream of wind direction. The highest $PM_{10}$ concentration at 5m measured in Hoa Chau, Hoa Phong and Hoa Khuong communes was 179 μg/m$^3$, 145 μg/m$^3$ and 102 μg/m$^3$, respectively. From 50m to 100m, the $PM_{10}$ concentration in Hoa Chau commune decreased by 44%, Hoa Phong commune decreased by 45% and Hoa Khuong commune decreased to the background concentration. From 100m to 150m in Hoa Chau commune, the $PM_{10}$ concentration decreased by 41%, while in Hoa Phong commune decreased to the background concentration. From 150m to 200m, the $PM_{10}$ concentration in Hoa Chau commune decreased to the background concentration (Figure 6). The safe range to avoid the effects of $PM_{10}$ emission from RSOB was 200m.

The highest $PM_{2.5}$ concentration at 5m measured in Hoa Chau, Hoa Phong and Hoa Khuong communes was 89 μg/m$^3$, 76 μg/m$^3$ and 45 μg/m$^3$, respectively. From 50m to 100m, the $PM_{2.5}$ concentration in Hoa Chau commune decreased by 41%, in Hoa Phong commune decreased by 42%, and in Hoa Khuong commune decreased to the background concentration. From 100m to 150m, the $PM_{2.5}$ concentration in Hoa Chau commune decreased by 39%, and in Hoa Phong commune decreased to the background concentration. From 150m to 200m, the $PM_{2.5}$ concentration in Hoa Chau commune decreased to the background concentration (Figure 7). The $PM_{2.5}$ monitoring results showed that the farther away from the burning site, the higher rate of air pollutant reduction due to the influence of wind diffusion. In Hoa Phong commune, the wind speed was the highest (2.87 m/s), so the rate of air pollutant reduction was the highest among the three sites.

The rate of air pollutant reduction in Hoa Chau commune was lower than that in Hoa Phong and Hoa Khuong communes because the rice straw generation (1.20 kg/m$^2$) in Hoa Chau commune was larger than that in Hoa Phong commune (1.10 kg/m$^2$) and Hoa Khuong commune (1.10 kg/m$^2$), and an additional reason was the lowest wind speed in Hoa Chau commune (2.01 m/s).

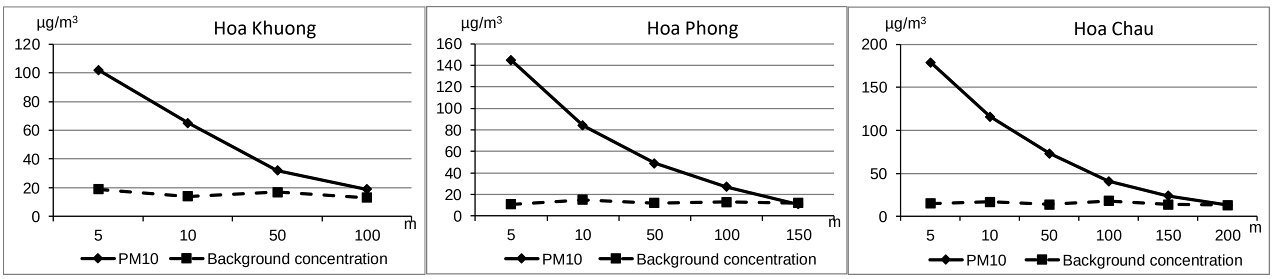



***Figure 6.*** *$PM_{10}$ concentration in Hoa Khuong, Hoa Phong and Hoa Chau commune*

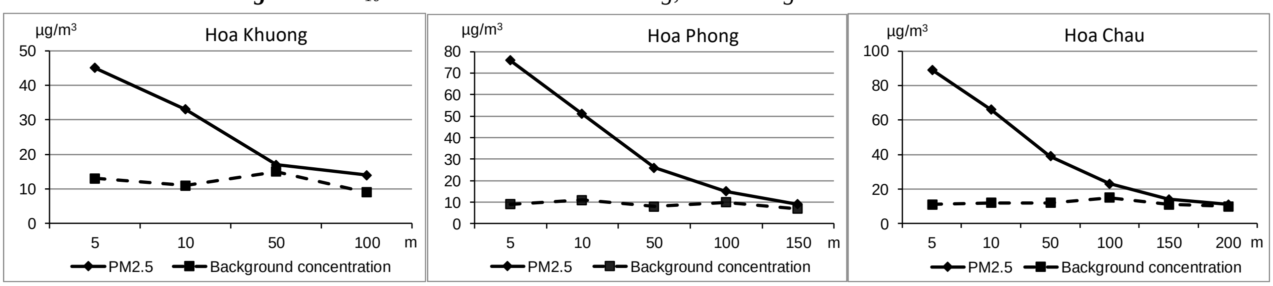



***Figure 7.*** *$PM_{2.5}$ concentration in Hoa Khuong, Hoa Phong and Hoa Chau commune*

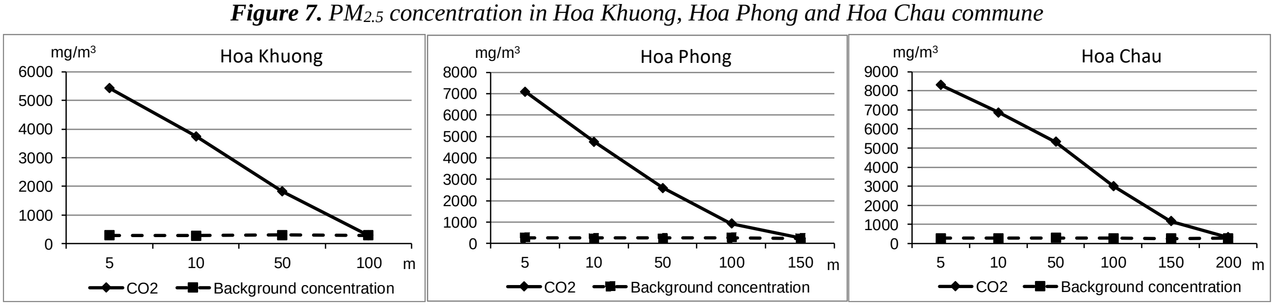



***Figure 8.*** *$CO_2$ concentration in Hoa Khuong, Hoa Phong and Hoa Chau commune*

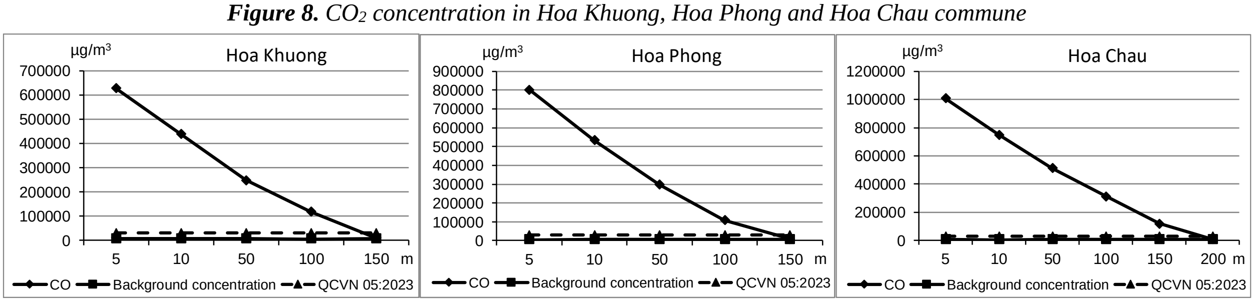



***Figure 9.*** *CO concentration in Hoa Khuong, Hoa Phong and Hoa Chau commune*

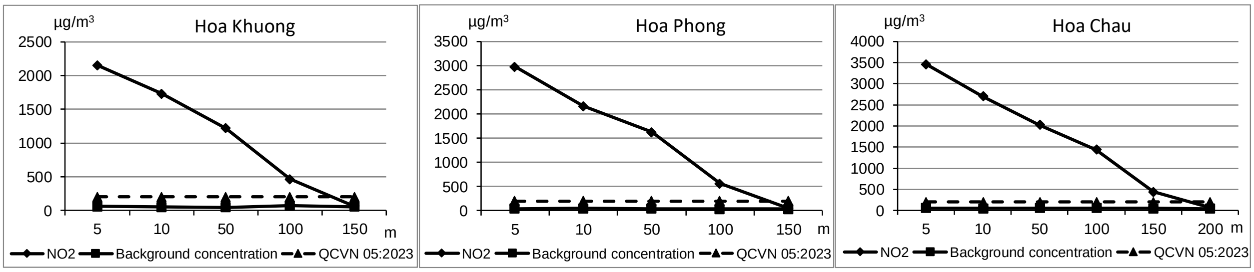



***Figure 10.*** *$NO_2$ concentration in Hoa Khuong, Hoa Phong and Hoa Chau commune*

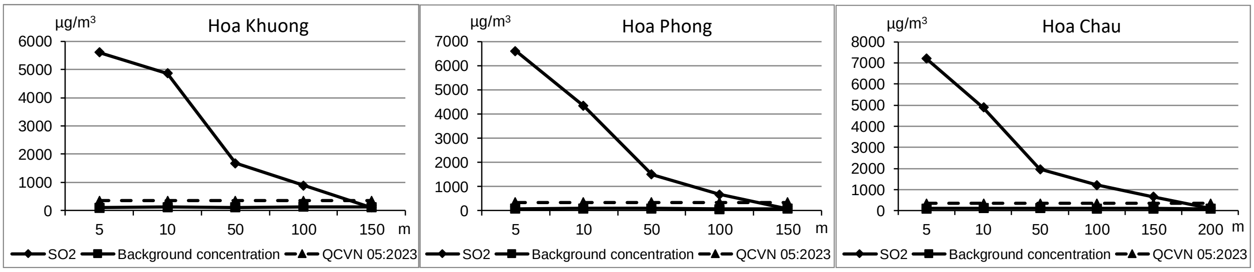



***Figure 11.*** *$SO_2$ concentration in Hoa Khuong, Hoa Phong and Hoa Chau commune*

The highest CO concentration at 5m measured in Hoa Chau, Hoa Phong and Hoa Khuong communes was 1,007,760 µg/m$^3$, 802,560 µg/m$^3$ and 628,140 µg/m$^3$, respectively, which were 34, 28, and 21 times higher than that of QCVN 05:2023/BTNMT. From 100m to 150m, the CO concentration in Hoa Chau commune decreased by 62%, was still 4 times higher than that of QCVN 05:2023/BTNMT, while in Hoa Phong and Hoa Khuong communes, it decreased to the background concentration and was lower than that of QCVN 05:2023/BTNMT. From 150m to 200m, the CO concentration in Hoa Chau commune continued to decrease to the background concentration and was below the permissible limit of QCVN 05:2023/BTNMT (Figure 9).

The highest $NO_2$ concentration at 5m in Hoa Chau, Hoa Phong and Hoa Khuong communes was 3,461 µg/m$^3$, 2,974 µg/m$^3$ and 2,152 µg/m$^3$, respectively, which were 17.3 times, 14.9 times and 10.8 times higher than that of QCVN 05:2023/BTNMT. From 100m to 150m, the $NO_2$ concentration in Hoa Khuong and Hoa Phong communes decreased to the background concentration and was lower than that of QCVN 05:2023/BTNMT, whereas the $NO_2$ concentration in Hoa Chau commune decreased by 69% but still exceeded QCVN 05:2023/BTNMT by 2.01 times. The $NO_2$ concentration at 200m in Hoa Chau commune decreased to the background concentration and were below QCVN 05:2023/BTNMT (Figure 10).

The highest $SO_2$ concentration at 5m in Hoa Chau, Hoa Phong and Hoa Khuong communes was 7,207 µg/m$^3$, 6,605 µg/m$^3$ and 5,609 µg/m$^3$ respectively, which were 20.6, 18.8 and 16.0 times higher than that of QCVN 05:2023/BTNMT. From 100m to 150m, the $SO_2$ concentration in Hoa Khuong and Hoa Phong communes decreased to the background concentration and was below QCVN 05:2023/BTNMT. From 150m to 200m, in Hoa Chau commune, the $SO_2$ concentration decreased to the background concentration and was within the limit of QCVN 05:2023/BTNMT (Figure 11).

The monitoring results in the 3 sites in Hoa Vang district demonstrated that the main wind direction was Northwest, so people live at the downstream of this wind direction will often be affected by air pollutant emissions from RSOB and at a distance of 200m, the air pollutants gradually decrease to the background concentration.

*3.3.2. The impacts of RSOB on human health*

The survey results on the local residents in Hoa Vang district on the impacts of RSOB showed that 87% limited visibility, 81% smoke, 77% horrible odor, 72% stuffiness, and 35% affected traffic (Figure 12). Above 70% of local residents responded that the ambient environment was affected by odors, dust and smoke. The impacts of RSOB on traffic was less significant (35%), because the rice fields are quite far from the local traffic systems.

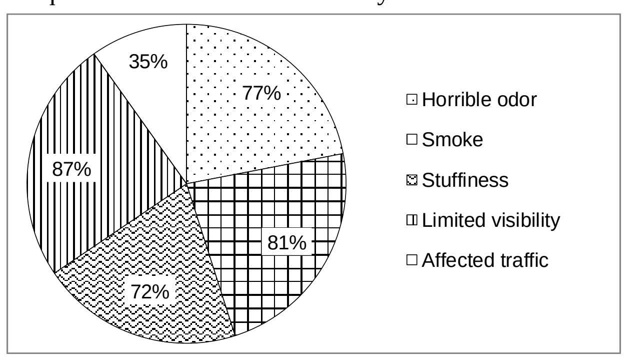



***Figure 12.*** *The environmental effects from RSOB*

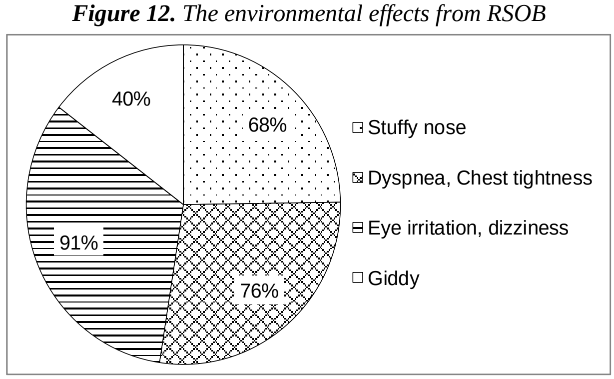



***Figure 13.*** *Impacts of RSOB on human health*

In addition to the environmental effects, RSOB also had a significant impact on the local residents' health. The responses from survey included eye irritation, blurred vision or dizziness (91%), difficulty breathing, chest tightness (76%); stuffy nose (68%) and giddy (40%) (Figure 13). From the above analyses, in the long-term effects, RSOB can cause chronic diseases, serious diseases such as bronchitis, respiratory diseases, lung diseases and vision loss.

This study showed that RSOB after rice harvesting emitted air pollutants, which also contributed to greenhouse gas emissions, affected the environment and human health, so it is necessary to promote propaganda to the farmers about the harmful effects of rice straw burning. Rice straw after harvesting should be collected by straw rollers and reused for mushroom cultivation, animal feed, fertilizer, bedding for livestock and poultry or reused rice straws as raw materials for industrial production such as paper, plywood, biochar, etc. Rice straw should be considered as a link in the rice industry chain to find reasonable ways elevating the values of this largely neglected resource.

## 4. Conclusions

In Hoa Vang district, the rice straw tended to decrease due to the shrinking rice cultivation area, of which 73% was reused in mushroom growing, livestock feeding, composting..., the remaining 27% was not reused and burned. The amount of rice straw burned in 2019 and 2023 was 25,544 and 23,377 tons, respectively.

The inventory results of air pollutant emissions from RSOB in 2023 in Hoa Vang district showed that $CO_2$ were the highest (27,138 tons/year), followed by CO (1,720 tons/year), then $PM_{10}$, $PM_{2.5}$, $SO_2$ and the lowest was $NO_2$. Burning conditions (rice straw is spread evenly or in piles on the field) affected the emission factor of air pollutants from RSOB on the field.

The assessment results of the air pollution dispersion showed that the highest pollutant concentrations from RSOB at 5m downstream of the wind direction with $PM_{10}$, $PM_{2.5}$ and $CO_2$ were 179 $\mu g/m^3$, 89 $\mu g/m^3$ and 8,307 $mg/m^3$ respectively, whereas CO, $SO_2$ and $NO_2$ were 1,007,760 $\mu g/m^3$, 7,207.6 $\mu g/m^3$ and 3461.1 $\mu g/m^3$, respectively, which were 34, 21 and 17 times higher than that of QCVN 05:2023/BTNMT. At 200m, the air pollutant concentrations gradually decreased to the background concentrations. 100% local residents were aware of the impacts of RSOB to the environment and their health, so it is necessary to promote propaganda to the farmers about the harmful effects of rice straw burning and also apply scientific and technological measures to increase the collection and reuse rice straw.

Further research is needed to determine the carbon content of rice straw, then the emission factors of $CO_2$ and CO can be developed more accurately for determining the emission factors of other air pollutants from rice straw burning in Da Nang city, Vietnam.

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