*Vietnam Journal of Science and Technology* ***61*** *(2023) 875-888*

doi:10.15625/2525-2518/18427

# Polycyclic aromatic hydrocarbons (PAHs) in paddy soil around Nam Son landfill area, Ha Noi, Viet Nam

**Nguyen Thuy Ngoc[1], Truong Thi Kim[1, 2], Nguyen Thi Quynh[3], Phung Thi Vi[2], Pham Hung Viet[1, 2, *], Duong Hong Anh[1, 2, *]**

[1]*University of Science, Vietnam National University, Hanoi, 334 Nguyen Trai, Thanh Xuan, Ha Noi, Viet Nam*

[2]*Key Laboratory of Analytical Technology for Environment Quality and Food Safety Control (KLATEFOS), University of Science, Vietnam National University, Hanoi, 334 Nguyen Trai, Thanh Xuan, Ha Noi, Viet Nam*

[3]*Prefectural University of Kumamoto, Higashi-ku, Kumamoto, 862-8502, Japan*

[*]Emails: *1.phamhungviet@hus.edu.vn, 2.duonghonganh@hus.edu.vn*

Received: 14 June 2023; Accepted for publication: 22 August 2023

**Abstract.** The paddy soils were collected in paddy fields and the non-cultivated lands around the Nam Son domestic waste landfill in Hanoi. The average concentration of 16 US EPA priority PAHs in dry soil was 61.61 ng/g, with a range of 22.15 - 115.1 ng/g. The higher levels of PAHs concentration in soil samples were observed in paddy fields near the landfill in comparison with the fields far from the landfill. On the other hand, there was no difference in PAHs levels in paddy fields which were located near the landfill and along the irrigation water canal. Concentrations of 16 PAHs in paddy soils decreased in the order: 5 rings > 3 rings > 4 rings > 2 rings > 6 rings in this area. The PAH isomeric diagnostic ratios including Fluth/(Fluth+Pyr) ratio (average 0.43, a range of 0.17 - 0.61), BaA/(BaA+Chr) ratio (average 0.51, a range of 0.26-0.63), IcdP/(IcdP+BghiP) ratio (average 0.71, a range of 0.51 - 0.90) indicated that the potential main sources emitted PAHs in paddy soils from pyrogenic biomass combustion and coal burning. Compared with the risk threshold causing adverse impacts on the ecological environment from different countries in the world, concentrations of PAHs in the soil surrounding the Nam Son landfill area were still below the affected limit. However, environmental quality around the landfill area still needs to be regularly monitored to take timely measures to protect the environment in this area.

*Keywords:* rice paddy, soil, PAHs, GC/MS, Nam Son landfill.

*Classification numbers*: 2.4.2, 2.4.4, 5.2.1.

## 1. INTRODUCTION

Soc Son waste treatment complex (Nam Son landfill) with an area of more than 157 ha in three communes of Soc Son district has been operated since 1999. Currently, Nam Son landfill receives four-fifths of the solid waste amount in Hanoi (about 5000 - 5,500 tons per day) from

12 districts in central areas and five sub-districts of the city such as Me Linh, Soc Son, Thanh Tri, Gia Lam, and Dong Anh [1]. Due to the overloaded status of landfills for many years, especially from 2020 to the end of April 2021, Nam Son landfill must implement temporary solutions to remain operation daily and ensure the city's environmental safety. In the waste treatment complex, except the landfill sites, there is a leachate treatment plant and a component of a waste-to-energy power plant has just been operated since July 2022. Emission problems from the landfill are mainly odors and leachate as pollutants have not been completely removed. Domestic disposal waste contains many types of contamination at macro and micro levels. Contaminants can be classified into two main categories including biological waste and its microbial transformation (for example ammonia, dissolved organic carbon, short-chain aliphatic acids, phenols, and derivatives of abietic acid) and anthropogenic waste (such as toxic metals, hydrocarbons, chlorinated hydrocarbons, surfactant-derived compounds, phthalates, and pharmaceutical chemicals) [2]. In addition, burning domestic waste also has the potential to pollute the ambient air including inorganic gases such as CO, $SO_2$, $NO_x$, $H_2S$... and toxic organic substances such as volatile compounds (VOCs), benzene-toluene-xylene (BTX), polycyclic aromatic hydrocarbons (PAHs), and dioxins [3, 4]. Leachate contains various pollutants that can contaminate soil and water resources, and be hazardous for the aquatic environment and organisms in the soil [2, 5].

Polycyclic aromatic hydrocarbons (PAHs) are distributed widely in the environment due to their diffusion capacity in the atmosphere, deposition, and accumulation in the surrounding. The emission of PAHs originates from natural processes, fossil fuel combustion, and uncompleted biomass burning [6], [7],[8]. PAHs are classified as toxic persistent substances (TPS) because they have mutagenic and carcinogenic, teratogenic properties [8 - 10] and persistence in nature due to lipophilic and hydrophobic characteristics [9]. Out of sixteen PAHs on the priority monitoring list of the US-EPA, seven special substances are the potential to cause cancers in animals and humans including Benzo(a)anthracene (BaA), benzo(a)pyrene (BaP), benzo(b)fluoranthene (BbF), benzo(k)fluoranthene (BkF), chrysene (Chr), dibenzo(a)anthracene (DBA), and indeno(1,2,3-c,d)pyrene (InP). Other PAHs such as naphthalene (Nap), acenaphthylene (Acy), acenaphthene (Ace), fluorene (Flu), phenanthrene (Phe), anthracene (Ant), fluoranthene (Fluth), pyrene (Pyr), benzo[ghi]perylene (BghiP) are considered as non-carcinogens. Many studies on the presence of PAHs were reported in environmental samples in Hanoi such as water, sediment [11, 12], particles in the air [13], road dust [14 - 17], indoor dust [18], roadside soil [12], biological samples [19] and food [20, 21]. However, there are few studies concerning presence, distribution, and emission sources of PAHs in the farmland. Especially, the farming area is located neighboring an area that contains the potential for unwanted contaminants such as landfills. Crops that uptake PAHs from contaminated soil may be transferred to the human body via food chain [9]. In this study, soil samples around Nam Son municipal waste disposal site were collected and analyzed 16 typical PAHs in order to determine the pollution level for cropland and the PAHs origin in this area. To the best of our knowledge, this is the first study on organic matter pollution such as PAHs in paddy soil near the Soc Son solid waste treatment complex.

## 2. MATERIALS AND METHODS

### 2.1. Sample collection

The land around the Nam Son landfill area is grown with rice mainly in the south (Nam Son commune) and partly in the north (Bac Son commune). A total of 19 soil samples were

collected from September to October 2021. Of those 19 samples, 14 soils were collected in paddy fields where the rice plants were soon to be harvested, and 05 soils collected from non-cultivated fields or lawns were interspersed with paddy fields. In the paddy soils, five samples were taken in five small fields located next to an irrigation water channel (Fig. 1). Soil was collected using a stainless-steel sampler (d. 5 cm × l. 30 cm) with a depth of 25 cm from the soil surface. Double samples of each sampling site were taken. The samples were sent to the laboratory and mixed. After dried at room temperature, the soils were ground finely and sieved through a sieve with a pore size of 0.5 mm and stored at -18 $^{o}$C before extraction and clean-up steps.

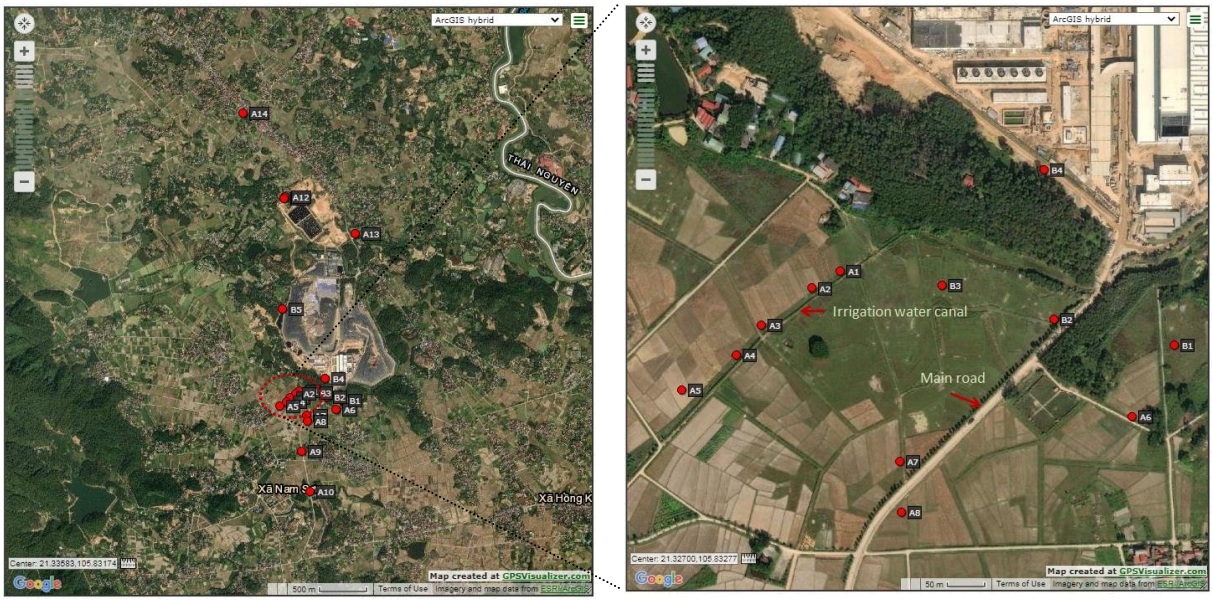


*Figure 1.* Location of sampling sites from Nam Son landfill area.

## 2.2. Chemical analysis

The soil sample extraction, clean-up and analysis were performed following our last research [22]. Approximately, 2 g of dried soil sample was weighed into a 100 ml glass stopper bottle. The samples were added with anhydrous sulfate salt and surrogate mixture - SR (PAH-Mix 33 including naphthalene-d8, acenaphthylene-d10, phenathrene-d10, chrysene-d12, and perylene-d10), and ultrasonicated and shaked with 40 ml dichloromethane for 2 hours. The extract was collected through an anhydrous sulfate layer into a round flask. The extraction step was repeated with dichloromethane solvent. The combined extract was concentrated and purified on a 1.5 g silica gel cartridge. The PAHs were eluted with 12 ml of the mixture of dichloromethane and hexane. The eluted solution was evaporated to 0.5 ml and added pyrene-d10 as the internal standard (IS) prior to chromatographic analysis (GC). All standard solutions such as SR, IS and 16 PAHs mixture were purchased from Dr. Ehrenstorfer, Germany. Sixteen PAHs on the priority monitoring list of the US-EPA and 05 surrogate standards were quantified by internal standard method on a gas chromatography-mass spectrometry (GC/MS-TQ 8050 NX, Shimazu, Japan) with a SH-Rxi-5Sil MS capillary column [30 m × 0.25 mm I.D., 0.25 µm film thickness, Shimadzu, Japan]. GC analysis conditions were as follows: split/splitless injection in 1 min; injection temperature was 260 $^{o}$C; carrier gas was helium (high purity, 99.999

%) with a flow rate of 1.2 ml/min; oven temperature program was initially set at 60 $^{o}$C (holding for 2 min), increased to 210 $^{o}$C at 30 $^{o}$C/min, and then increased to 310 $^{o}$C at 5 $^{o}$C/min and held for 15 min. The mass spectrometric detector was operated in electron impact mode at 70 eV, with ion source and detector temperatures were 230 °C and 300 $^{o}$C, respectively.

### 2.3. Quality assurance and quality control

Calibration curves of 16 PAHs were conducted with an internal standard method of 7 standard levels in a concentration range of 1 and 200 ng/ml and an IS concentration of 100 ng/ml. The 16 calibration curves all reached a correlation coefficient $R^2$ > 0.99. Quantity detection limits of PAHs in soil were from 0.07 ng/g to 0.22 ng/g. A surrogate standard was added in each sample in the beginning step to control the whole extraction procedure. Blank and recovery samples were implemented in each sample extraction batch. The recoveries of surrogate standards ranged from 55 % to 119 % in soil sample, and the recoveries of 16 PAHs were a range of 70 % and 94 %. Statistical analyses were performed in statistical software such as IBM SPSS Statistic 26, and Microsoft excel. For results below the detection limits, concentrations of PAHs were calculated as half of the limits of quantification [23].

## 3. RESULTS AND DISCUSSION

### 3.1. PAHs levels and spatial distribution in paddy soil

Sixteen PAHs in soil from paddy fields (n = 14) and non-cultivated fields (n = 5) were identified. The mean of 16 PAHs concentrations in paddy fields was 66.87 ng/g in dry soils with a range of 27.06 and 115.1 ng/g. The average concentration of sum 16 PAHs in non-cultivated fields was 46.89 ng/g in dry soils with a concentration range of 22.15 and 79.61 ng/g. As shown in Table 1, the average concentration of total PAHs in the field soil around this area was 61.61 ng/g, with a range of 22.15 and 115.1 ng/g. In which, the average concentration of seven PAHs on the probable carcinogenic potency for humans and animals according to US-EPA and IARC (International Agency for Researchon Cancer) [8, 24] was 27.96 ng/g (9.57 - 71.77 ng/g), accounting for 45 % of 16 analyzed PAHs. The correlation between the total concentrations of these PAH7 and PAHs were found to be relatively high ($R^2$ = 0.722), so that potentially carcinogenic PAHs and other PAHs may have the same initial sources.

As shown in Fig. 2, higher concentrations of PAHs were found in the sampling points right next to the landfill including sites B4, A1, A11, A12 and A13, except B5. While sites B4 and B5 are open land, sites A11, A12 and A13 are in paddy fields located in the northern landfill where small drainage ditches were flowing towards Bac Son commune. The sampling points B1, B2, and B3 with a PAHs concentration range of 22-54 ng/g were in the non-cultivated land right at the entrance to the landfill. Besides, the samples close to the landfill presented higher pollution than those far away from the landfill. For examples, levels of PAHs decreased in the order: A1 (114.7 ng/g) > A2 (72.14 ng/g) > A3 (65.07 ng/g) > A4 (61.07 ng/g) ~ A5 (61.91 ng/g), which was associated with their distances to the landfill and the direction of water flow from A1 to A5. It was worth noting that irrigation water canals from the northwestern lake can be considered as potential sources of pollutants, and consequently lead to their accummulation in the soil. In addition, paddy fields in Northern Viet Nam are designed as communicating vessels in order that water can be distributed from irrigation to fields more evenly and convenient.

*Table 1.* Average concentrations and ranges of 16 PAHs in soil surrounding Nam Son landfill area (ng/g dry weight).

| No. | PAH compound | Abr. | Number of Benzene rings | Paddy fields (n = 14) | Non-cultivated fields (n = 5) | All sites |
|---|---|---|---|---|---|---|
| 1 | Naphthalene | Nap | 2 | 11.04 (nd-26.16) | 8.36 (nd-19.12) | 10.33 (nd-26.16) |
| 2 | Acenaphthylene | Acy | 3 | 0.43 (nd-1.51) | 0.27 (nd-1.08) | 0.39 (nd-1.51) |
| 3 | Acenaphthene | Ace | 3 | 0.35 (nd-1.19) | 0.22 (nd-0.77) | 0.31 (nd-1.19 |
| 4 | Fluorene | Flu | 3 | 1.65 (0.36-3.44) | 1.34 (nd-2.86) | 1.57 (nd-3.44) |
| 5 | Phenanthrene | Phe | 3 | 8.86 (3.16-14.53) | 7.25 (5.53-8.22) | 8.43 (3.16-14.53) |
| 6 | Anthracene | Ant | 3 | 4.87 (0.51-12.55) | 4.08 (0.95 -8.03) | 4.66 (0.51 -12.55) |
| 7 | Fluoranthene | Fluth | 4 | 2.89 (0.28-6.90) | 1.49 (0.28-4.07) | 2.52 (0.28-6.90) |
| 8 | Pyrene | Pyr | 4 | 3.01 (1.42-4.96) | 2.23 (1.15-4.48) | 2.81 (1.15-4.96) |
| 9 | Benz[a]anthracene | BaA* | 4 | 3.19 (1.73-4.88) | 2.55 (1.71-3.48) | 3.02 (1.71-4.88) |
| 10 | Chrysene | Chr* | 4 | 3.35 (1.51-6.26) | 2.24 (1.88-2.55) | 3.06 (1.51-6.26) |
| 11 | Benzo[b]fluoranthene | BbF* | 5 | 8.43 (0.81-30.94) | 1.60 (0.60-3.38) | 6.63 (0.60-30.94) |
| 12 | Benzo[k]fluoranthene | BkF* | 5 | 4.85 (1.01 -13.05) | 5.01 (1.41-13.61) | 4.89 (1.01-13.61) |
| 13 | Benzo[a]pyrene | BaP* | 5 | 4.75 (0.28-12.72) | 3.62 (0.61-10.11) | 4.46 (0.28-12.72) |
| 14 | Indeno[1,2,3-cd]pyrene | IcdP* | 5 | 4.63 (1.75-13.75) | 3.36 (2.04-7.45) | 4.29 (1.75-13.75) |
| 15 | Dibenzo[a,h]anthracene | DahA* | 6 | 1.47 (0.25-4.76) | 1.97 (0.31-6.19) | 1.06 (0.25-6.19) |
| 16 | Benzo[ghi]perylene | BghiP | 6 | 3.11 (0.22-12.99) | 1.30 (0.33-4.00) | 2.63 (0.22-12.99) |
| | ∑PAH16: | | | 66.87 (27.06-115.1) | 46.89 (22.15-79.61) | 61.61 (22.15-115.1) |
| | ∑PAH7*: | | | 30.67 (9.57-71.77) | 20.36 (10.80-46.25) | 27.96 (9.57-71.77) |

*PAH*: probable carcinogenic PAHs; nd: not detected.*

The sampling points collected from paddy fields along the main road to the landfill recorded lower total PAHs concentrations of 30 - 40 ng/g for A6, A7, A9, and A10 and significantly higher PAHs concentration for the A8 sampling site (78.97 ng/g). Notably, high levels of PAHs were found at A14 which was quite far to the north of the landfill. In general, no statistically significant difference in PAHs concentrations ($p = 0.173$) were observed in soil from paddy fields and non-cultivated fields such as open land and lawns. However, there was a reliable difference in concentrations of PAHs in the soil of cultivating paddy fields in the sites near the landfill and far from the landfill ($p = 0.016$). There was no difference in PAH levels in the Paddy fields near the landfill and located along the irrigation water canal ($p = 0.305$). And there was a significant difference between paddy fields located along the canal and the field far from the landfill ($p = 0.05$). Thus, the paddy fields where were located near the landfill and

along the canal had similar concentrations of PAHs and irrigation water may be carrying sources of these pollutants [6, 25]. The specific emission sources of PAHs found in the land soil around the Nam Son landfill is presented in the below section.

Information on the presence of PAHs in agricultural land and especially paddy soil in Vietnam has been limited. A study by the T.T.Q. Hoa *et al*. [27] on PAHs pollution in the e-waste recycling area in Bui Dau village, Hung Yen recorded the amount of 16 PAHs in rice field soil in that area as 970 ng/g (390 - 5400 ng/g). The total of 16 PAHs concentration in the soil of the mangrove area at Dong Rui, Thien Yen, Quang Ninh reported by V.D. Toan et al. [7] was 692.6 ng/g (312.5 - 1407 ng/g). There was no study on contamination levels of PAHs on agricultural land in Ha Noi. Previous studies determined PAHs in the soil at some points in the inner city of Hanoi such as Co Nhue - Pham Van Dong streets [26] (10 PAHs with concentrations of 3.4 - 43.7 ng/g soil near traffic road) and Kim Nguu street [12] (16 PAHs with a concentration of 260 - 1350 ng/g soil for growing water spinach). Table 2 shows comparison of PAHs in soil from the farmland and paddy fields in some areas. In general, concentrations of PAHs in the paddy fields around Nam Son were lower than those found in soil from several studies in Vietnam, and in some countries such as China (Nansi Lake area, Shandong province [28], 16 PAHs showed concentrations of 515. 29 ng/g (57.49 - 2046.47 ng/g); Ningde city [29]: soil concentration in paddy fields 16 PAHs was 360 ± 372 ng/g and vegetable soil 16 PAHs was 489 ± 372 ng/g; on the outskirts of Guangzhou [25] the content of 13 PAHs in rice soil was measured at 562 - 934 ng/g; 16 PAHs in agricultural land in Deli, India ranged from 830 ng/g to 3880 ng/g [31]; 15 PAHs in paddy fields in 03 cities of Korea [30] such as Pohang (51.94 - 8106.21 ng/g), Ulsan (125.01 - 3106.27 ng/g) and Gyeonggi-do (19.53 - 672.93 ng/g).

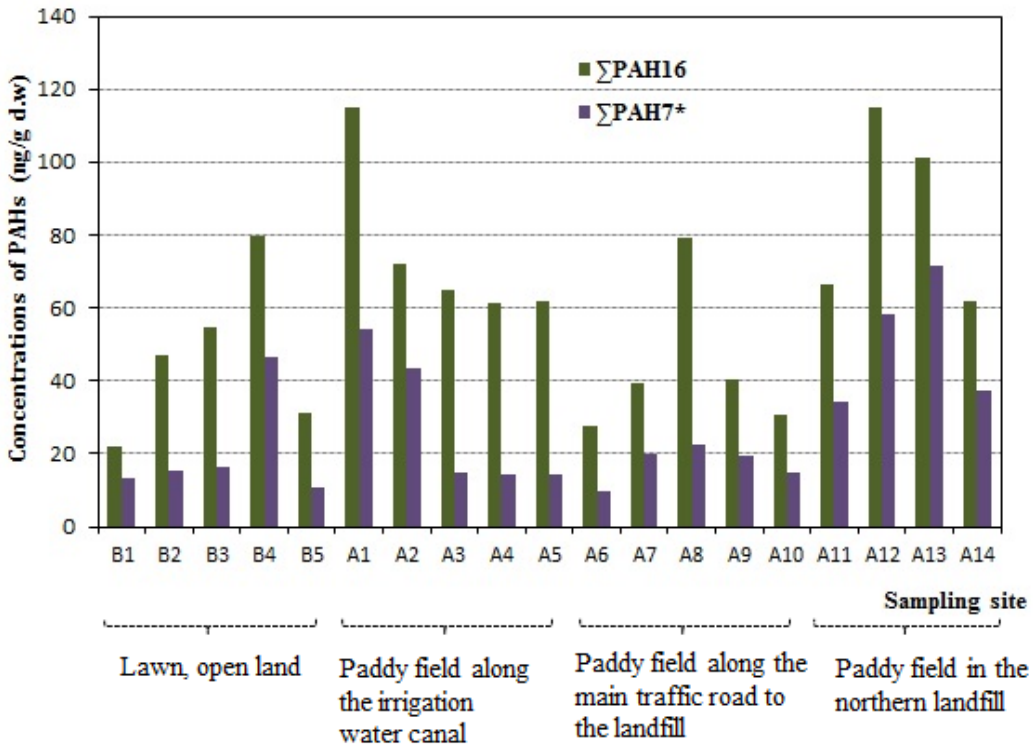


*Figure 2.* PAHs levels in sampling sites surrounding the Nam Son landfill area.

*Table 2.* Comparison of PAHs in soil from the farmland and paddy fields in some areas

| Country/City | Location | Soil type | No. of PAHs | Concentration (ng/g) | Reference |
|---|---|---|---|---|---|
| Viet Nam, Ha Noi | Nam Son landfill, Soc Son district | paddy field | 16 | 61.61 (22.15 - 115.1) | this study |
| Viet Nam, Ha Noi | Co Nhue - Phạm Van Dong street | near road | 10 | 3.4 - 43.7 | [26] |
| Viet Nam, Ha Noi | Kim Nguu street | near road for growing water spinach | 16 | 260 - 1350 | [12] |
| Viet Nam, Quang Ninh | Dong Rui, Thien Yen district | mangrove land | 16 | 692.6 (312.5 - 1407) | [7] |
| Viet Nam, Hung Yen | Bui Dau commune (e-waste recylcing) | paddy field | 31 | 1200 (530 - 6700) | [27] |
| | | | 16 | 970 (390 - 5400) | |
| China, Shangdong | Nansi lake | paddy field | 16 | 515.29 (57.49 - 2046.47) | [28] |
| China | Ningde | agriculture farm | 16 | 406 (7.3 - 1188) | |
| | | paddy field | 16 | 360 ± 372 | [29] |
| | | vegetable farm | 16 | 489 ± 372 | |
| China, Quangzhou | outskirt | paddy field | 13 | 562 - 934 | [25] |
| Korea | Gyeonggi-do | paddy field | 15 | 19.53 - 672.93 | [30] |
| | Ulsan | paddy field | 15 | 125.01 - 3106.27 | |
| | Pohang | paddy field | 15 | 51.94 - 8106.21 | |
| India | Delhi | agriculture farm | 16 | 830 - 3880 | [31] |

**3.2. Composition profiles of PAHs**

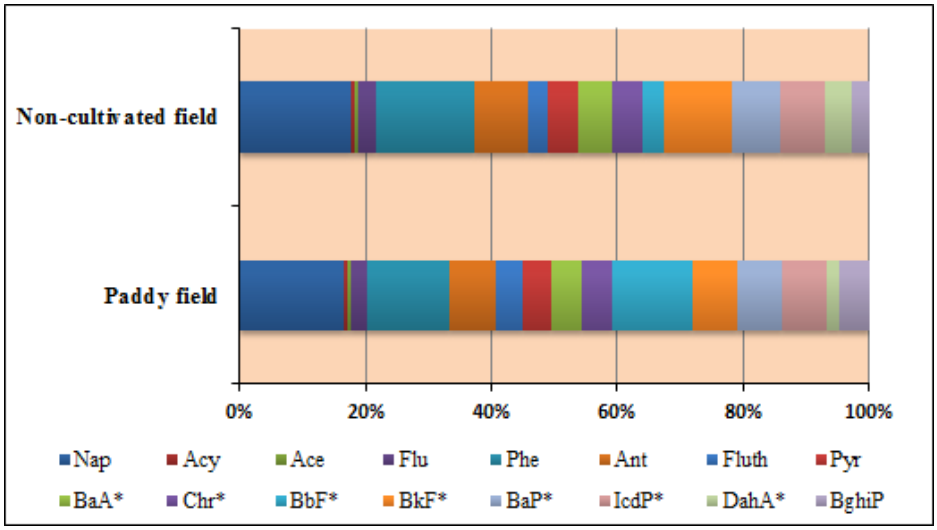


*Figure 3.* Distribution of PAHs in paddy fields and non-cultivated fields.

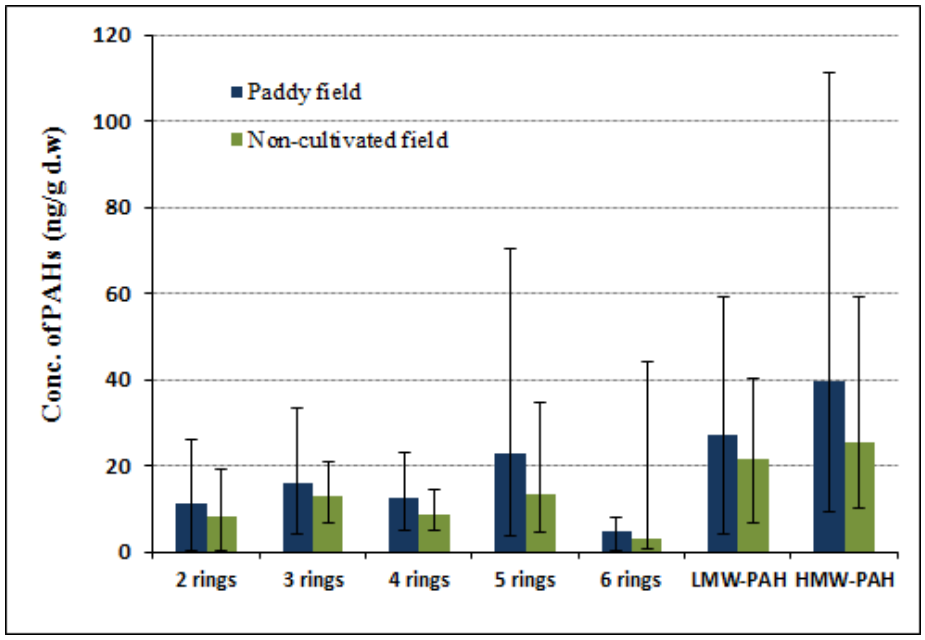


*Figure 4.* Levels of PAHs following benzene-ring groups in paddy fields and non-cultivated fields.

Among analyzed 16 PAHs in paddy soil surrounding the Nam Son landfill, the distribution pattern of PAHs was shown in figure 3 and the average percentages of each PAH in the rice-growing and non-cultivating paddy land were quite similar with not getting statistically difference ($p = 0.909$). The dominant components with the highest percentage (>10 %) were Nap, Phe, and BbF in paddy soils, and were Nap, Phe, and BkF in non-cultivated soils. BaP is the most carcinogenic PAH compound, accounting for 7.1 % and 7.8 % in rice and in non-cultivated field soils, respectively. Figure 4 revealed that the concentrations of analyzed PAHs with 2-3 aromatic rings in the molecule (LMW-PAH) were lower than PAHs containing 4-6 aromatic rings (HMW-PAH). PAHs with five aromatic rings showed higher concentrations with

the average value of 22.7 ng/g (3.86 - 70.45 ng/g) in paddy fields, accounting for 34 % of the total 16 PAHs; 16.6 ng/g (4.66 - 34.54 ng/g) in non-cultivated soil and occupied 29 % of the total 16 PAHs. The order of PAHs levels in soil decreased with the number of benzene rings in a molecule such as 5 rings > 3 rings > 4 rings > 2 rings > 6 rings. PAHs with 3 - 5 aromatic rings were always predominant in agricultural soils in previous studies and PAHs with 5 benzene-rings accounted for the highest percentage in some regions [29, 30]. The proportion of PAHs in the soil also depends on the climate and the structure of the soil in those areas [32].

### 3.3. Source identification

The emission sources of the PAHs in the environment were determined based on the ratio of some characterized PAHs or using emission source calculation models and softwares. In this study, we used the ratio between PAHs with 2 - 3 benzene rings (LMW-PAH), PAHs with 4-6 benzene rings (HMW-PAHs), and isomer pair ratios of some typical PAHs such as Ant/(Ant+Phe), Fluth/(Fluth+Pyr), BaA/(BaA+Chr) and IcdP/(IcdP+BghiP) [28 - 30] to estimate the source of PAHs in paddy soil around the Nam Son landfill area.

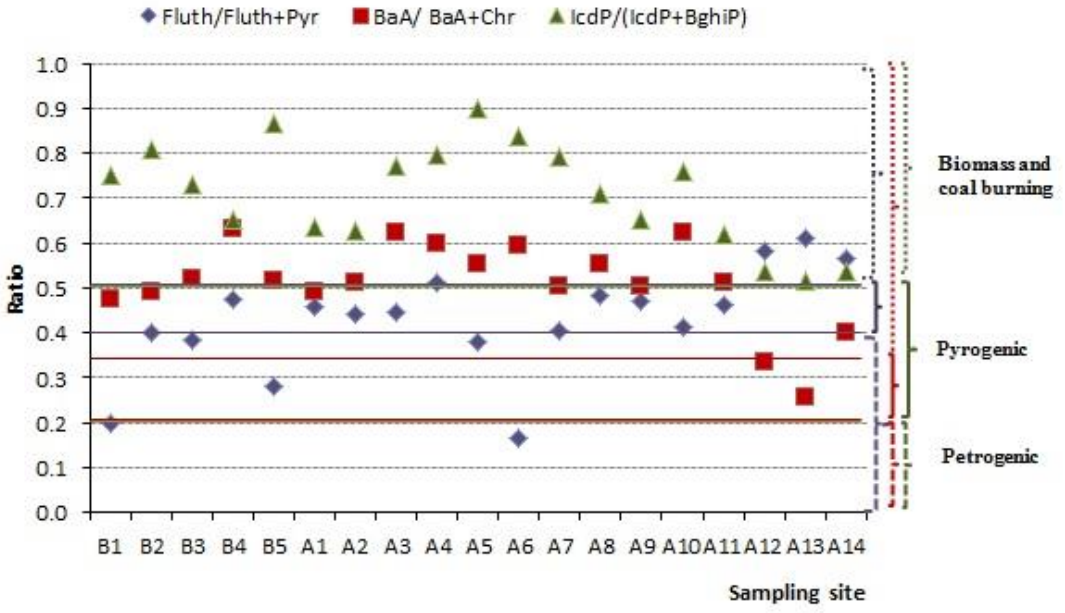


*Figure 5.* Plot of some specific PAHs isomer pair ratios and emission source.

Firstly, the ratio of LMW-PAHs/HMW-PAHs was used to preliminarily assess the origin of the PAHs. If this ratio > 1, the source of PAHs is related to petroleum, and if this ratio < 1, PAHs are generated from the combustion of petroleum products, wood, and coal [30]. The ratio of LMW-PAHs/HMW-PAHs in the cultivating paddy soil and the noncultivated paddy soil was 0.69 and 0.85 respectively. The result indicated that PAHs in the soil of the Nam Son landfill area primarily originated from the burning of fossil fuels and biomass materials. Considering the ratio of specific PAHs, most of the soil samples showed Ant/Ant+Phe ratio > 0.1, indicating that PAHs were not from nature. Figure 5 shows the results of the ratios of individual PAHs such as Fluth/(Fluth+Pyr), BaA/(BaA+Chr), and IcdP/(IcdP+BghiP to predict the PAHs emission sources. Almost ratios of Fluth/(Fluth+Pyr) were approximately from 0.4 to 0.5, revealing that

PAHs were generated from pyrogenic. Three sampling sites (B1, B5, and A6) had Fluth/(Fluth+Pyr) ratio clearly below 0.4 indicating PAHs sources from petroleum and other three sampling sites (A12, A13, and A14) PAHs predicted from biomass and coal burning with Fluth/(Fluth+Pyr) ratios were higher 0.5. The most value of BaA/(BaA+Chr) ratio was more than 0.35 (mean 0.51 in a range of 0.26 - 0.63) that predicted PAH main sources from biomass and coal burning. At two sampling points, the ratios were in the range of 0.2 - 0.35 indicating petroleum combustion as the other PAHs emission source in this studied area. Considering the IcdP/(IcdP+BghiP) ratio, it averaged 0.71 in the range 0.51 - 0.90 (all values > 0.5), representing that PAHs had origin from coal/wood/grass combustion sources. Thus, PAHs in the soil in this area were formed mainly from incomplete combustion of biomass materials such as open-burning rice straw and agricultural products. In addition, emissions from diesel and gasoline-powered motor vehicles were also the source of PAH emissions into the land in this area due to the large number of garbage trucks operating day and night. And the contamination of PAHs in the soil might come from air deposition and also from irrigation water for the area. The Nam Son landfill has just operated a component of a thermal power plant solid waste treatment. However, the time of soil sampling in this area before the thermal power plant is put into operation, so the possibility of emissions from the landfill is low. Based on specific PAHs ratios, other studies on PAHs in agricultural and rice soils in Korea and China also showed the similar sources of PAHs including biomass combustion including coal, wood, and grass [30]; the postharvest part of rice [33]; coal and coal/biomass, emissions from motor vehicles [29]. A study by P.T.Chau et al. on the emission characteristics of PAHs and nitro-PAHs in the smoke from open burning rice straw in the north of Vietnam recorded the PAHs levels such as 254.4 ± 87.8 µg/g for PM2.5 and 209.7 ± 89.5 µg/g for TSP [34]. Therefore, it was predicted that the PAHs in paddy soil around Nam Son landfill are mainly generated from biomass burning (such as rice straw, grass, trees, etc.) and partly from burning fossil fuels (petroleum products, coal, etc.) due to the use of agricultural machinery and motor vehicles. In addition, the levels of PAHs in the soil in this area may be affected by a variety of environmental factors such as wet and dry atmospheric deposition and irrigation water for the fields.

### 3.4. Ecological risk assessment

In this study, the concentration of PAHs in the field soil around Nam Son domestic solid waste treatment area was 61.61 ng/g and ranged from 22.15 ng/g to 115.1 ng/g. In the toxicity evaluation of PAHs, the toxic equivalent quantity (TEQ) is calculated when compared with the unique characteristic PAHs such as Benzo[a]pyren (BaP). The toxicity concentration of each PAHs is calculated based on the concentration of each PAH in the soil sample ($C_{PAHi}$) multiplied by the toxic equivalent factor (TEF). $TEQ_{BaP} = C_{PAHi} \times TEF_i$. The TEF factors were proposed by Nisbet and LaGoy in 1992 [35] and have been used until now. The average concentration of 16 PAHs ($\sum TEQ_{BaP}$) was 8.07 ng/g (1.57 - 20.78 ng/g) in paddy soils surrounding the dumping site, of which $\sum TEQ_{BaP}$ of 7 PAHs with carcinogenic potential accounted for 98.7 % and BaP was still the substance with the highest TEQ of 4.45 ng/g (0.27 - 12.71 ng/g). According to some safety levels and control values of some countries and organizations, soils are not polluted with PAHs if the concentration of PAHs in the range from 20 µg/kg to 50 µg/kg (Dutch government) and from 507.21 µg/kg to 781.44 µg/kg (US-EPA) [28]. According to the regulation of Western European countries, contaminated soil was classified as follows:contaminated soil (< 200 µg/kg), slightly contaminated soil (from 200 µg/kg to 600 µg/kg), moderately contaminated soil (600 µg/ kg to 1,000 µg/kg), and heavily contaminated soil (> 1,000 µg/kg) [28, 29]. The Canada environmental protection [16, 10] gives the soil quality $TEQ_{BaP}$ of 600 ng/g. The

archived results showed that the paddy soil surrounding the Nam Son landfill area has not been contaminated with PAHs compounds.

## 4. CONCLUSION

The study found 16 PAHs preferred by the US EPA priority list in paddy soil around the Nam Son landfill area. The total concentration of 16 PAHs in the paddy soil was lower than in some countries in the world. And the total toxic equivalent concentration of $TEQ_{BaP}$ in the field soil in this area was at a safe level in comparison with the soil quality recommended priority control values of some countries and international organizations. The source of PAH emission to the farmland in this area was predicted mainly from biomass (such as straw, grass, trees, etc.) burning and partly from the combustion of fossil fuels (such as petroleum products, coal, etc.) due to the use of agricultural machinery and vehicles. In addition, the presence of PAHs in the soil in this area was also attributed to the surrounding environment such as atmospheric deposition and irrigation water for the fields. Currently, Nam Son landfill has been only operated as a component of the waste treatment thermal power plant. Due to the time taken for soil sample collection in this area before the thermal power plant component was put into operation, the possibility of PAH contamination emitted from the disposal site was still low. And another reason for low PAHs levels in paddy soil may be sampling campaign had happen in the end of rainy season. However, the environment around the Nam Son landfill should be regularly monitored to give early warnings to farmers who are currently cultivating on the farmland around this area being potentially exposed by the PAHs in the near future once the built thermal power plant will be officially operated.

***Acknowledgements.*** This study is supported by the University of Science, Vietnam National University, Hanoi under the funding for strong research teams in 2021 and 2022.

***Credit authorship contribution statement.*** Nguyen Thuy Ngoc: Conceptualization, methodology, investigation, data curation, software, formal analysis, writing – original draft, writing – review and editing. Truong Thi Kim: investigation, data curation, software, validation, formal analysis. Nguyen Thi Quynh: investigation. Phung Thi Vi: writing – original draft, writing – review and editing. Pham Hung Viet: Conceptualization, methodology, supervision, writing – original draft, writing – review and editing. Duong Hong Anh: Conceptualization, methodology, writing – original draft, writing – review and editing.

***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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