Check for updates

Polycyclic aromatic hydrocarbon concentrations in soils of greenhouses located in Aksu Antalya, Turkey

Bihter Olgun and Güray Doğan

ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs) are hydrophobic organic compounds that are generally absorbed on organic fraction of soils. It is known that some PAHs, which can pass to air, soil, water and food as a result of natural or anthropogenic processes, have carcinogenic, toxic and mutagenic effects on humans and animals. One of the important steps that is identified in the transition takes place during agricultural production. Greenhouses are commonly used as a type of agricultural production especially during the winter season in mid and temperate climates. Greenhouse cultivation is abundant in Antalya Aksu Region in Turkey. Two sampling campaigns (autumn and winter) were carried out to sample the soils in 53 glass and polyethylene covered greenhouses. The samples were analysed with gas chromatography-mass spectrometry (GC/MS) for 16 PAHs. The result showed that four ring PAHs were dominant in the region. In the winter season, PAHs concentrations increase because of low volatility of motor vehicle exhaust related PAHs in the atmosphere and of coal and wood combustion emissions used in the heating of greenhouses and surrounding village houses. The cross plots of diagnostic ratios also confirmed coal and wood combustion and traffic emissions in the region.

Key words | agriculture, diagnostic ratios, greenhouse, PAHs

Bihter Olgun
Güray Doğan (corresponding author)
Department of Environmental Engineering,
Akdeniz University,
07058 Antalya,
Turkey
E-mail: *gdogan@akdeniz.edu.tr*

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are one of the most important classes of persistent organic pollutants (POPs) (Khaiwal *et al.* 2008). PAHs are released to the environment from domestic, industrial, mobile and natural sources. Domestic sources are largely related to the combustion of organic substances such as coal, oil, gas, garbage, tobacco and charred meat (Smith & Harrison 1998). Mobile sources include emissions from vehicles such as aircraft, railways, automobiles, off-road vehicles and machinery (Khaiwal *et al.* 2008). The most important industrial sources of PAHs are primary aluminum production, coke production, creosote and wood protection, waste incineration, cement production, petrochemical and related industries, bitumen and asphalt industry, rubber tire production and commercial heat/energy production (European Commission 2001). Non-anthropogenic combustion of forests and volcanic eruptions are the natural sources of PAHs (Baumard *et al.* 1999; Khaiwal *et al.* 2008).

Generally, when PAHs are first released into the atmosphere, they are either attached to a particle or retained in the gaseous form. Then they are dispersed in multiple environments, such as air, water, soil and sediment, as governed by their physical and chemical properties and environmental and meteorological conditions (Palm *et al.* 2004; Kim *et al.* 2009). In the atmosphere, PAHs can be transported long distances before they deposit on soils, vegetation, seas and surface waters by precipitation or by dry deposition (Wild & Jones 1995; Van Jaarsveld *et al.* 1997).

Physical and chemical properties of PAHs determine the propagation to the environment. PAHs are low volatile and low soluble compounds. Their solubility decreases with increasing number of rings (Skupinska *et al.* 2004). Soil is an important environment for the accumulation of PAHs. In soil, PAHs are hydrophobic. In particular, PAH compounds tend to get adsorbed unto the organic fraction of soil (Tremblay *et al.* 2005). It is known that transfer of low molecular weight PAHs from soil matrix is faster than high molecular weight PAHs (Venny *et al.* 2012).

PAHs are persistent in the environment and can pose a risk to humans, animals and plants (WHO 1998). Living organisms are exposed to PAHs through inhalation, oral and skin exposure. These exposures cause death of

doi: 10.2166/wst.2020.114

Downloaded from http://iwaponline.com/wst/article-pdf/81/2/283/679854/wst081020283.pdf
by guest

organisms (Diggs *et al.* 2012), negative systematic, immunological and lymphoreticular, neurological, developmental, and genotoxic effects (ATSDR 1995). Exposure to high concentrations of PAH containing contaminants is known to cause symptoms such as eye irritation, nausea, vomiting, diarrhea, skin irritation and inflammation (Unwin *et al.* 2006).

Agricultural land, a vital resource, plays a key role in food and biomass production. Agricultural areas are at risk of PAH contamination mainly due to anthropogenic activities (Gan *et al.* 2009). It is known that the exposure of these compounds, which can pass into vegetables and fruits via air, water and soil and direct contact, has significant effects on human and animal exposures. Therefore, it is important to determine the concentrations and sources of these compounds in the soil.

The province of Antalya in Turkey is one of the most important agricultural centers. Due to the favorable climatic conditions, greenhouse cultivation is intensive. Located approximately 10 km from Antalya city center, the Fettahlı district of Aksu is an area where greenhouse cultivation is concentrated. The aim of this study is to determine the PAH concentrations in agricultural soil of greenhouses in Aksu-Fettahlı region, Turkey. Sixteen PAHs were identified as priority pollutants by EPA in the agricultural soil of the greenhouses in the region. The 16 PAHs were analyzed from the greenhouse soils, the results of which form the database on PAH pollution in the region. The data set obtained was compared and evaluated with national and international studies.

MATERIALS AND METHODS

Sampling location and sampling program

Antalya is located on the Mediterranean coast of Turkey and in 2017, Antalya province has a population of 2.36 million (Antalya Governorship 2020). Tourism and agricultural activities are the major sources of income. Open and greenhouse cultivations are done at different altitudes of the region. On coastal regions, greenhouse cultivation is dominant. Just for Antalya, greenhouse cultivation is done on an area of approximately 278 million m^2 and 3.2 million tons of vegetables are produced each year (Republic of Turkey Ministry of Agriculture and Forestry 2017).

In this study, soils from greenhouses of the Fettahlı village of Aksu located on the northwestern part of Antalya were sampled and analyzed for PAHs. The farmers in the region may cultivate the greenhouses one or two times a year depending on market needs. If the farmer chooses to cultivate the greenhouse twice, the first cultivation takes place in September and the second in February. If the farmer chooses to cultivate the greenhouse only once, cultivation is carried out in October. However, the preliminary work has to be done before the cultivation process. To eliminate the effect of cultivation time, two sampling campaigns were carried out in the region. The first and the second samplings were conducted in September 2017 and in February 2018, respectively. According to data obtained from Turkish State Meteorological Service, the ambient average monthly temperature observed from Aksu Station in September 2017 and February 2018 were 25 °C and 11 °C, respectively.

Approximately, 52% of the produced vegetables are tomatoes (Turkish Statistical Institute 2017). Since tomato production in greenhouses in the Antalya region is the major vegetable, in order to depict the effect of seasonal variation of atmospheric emissions and production process on the same vegetable, in both campaigns, soil samples were taken from tomato–cultivated greenhouses. A total of 53 greenhouses together with five reference points sampling were carried out in each campaign. Reference points are chosen from places around greenhouses where greenhouse emissions and waste do not come into direct contact. To determine the effect of greenhouse cover type, samples were taken from glass and polyethylene covered greenhouses. As shown in Figure 1, the sampling was done in an area of approximately 5.83 km^2. The town is on the Antalya-Isparta intercity highway. The Antalya International Airport is located just 5 km south of the region and welcomes over 15 million tourists every year. Fettahlı town is on the landing and take-off route. Wood and coal is combusted in the region for household heating and greenhouse heating. Therefore, the area is under the influence of various sources of pollutants.

Soil extraction and analysis

Soil extraction

Before extraction, soil samples were sieved through a No. 10 (2 mm) sieve. Five grams of soil samples were taken from the sieved sample. A 1: 1 mixture of Acetone: Hexane and 1 μL of PAH recovery standard (Acenaphthene-d10, Chrysene-d12, Pyrene-d12, Phenanthrene-d10) were added to the soil samples and kept in 50 mL conical tubes for 24 h. Then, soil samples were placed in an ultrasonic bath at 15 °C for 60 min. The volume of the samples was reduced

Downloaded from http://iwaponline.com/wst/article-pdf/81/2/283/679854/wst081020283.pdf
by guest



Figure 1 | Sampling area (blue dots and green dots represent polyethylene and glass covered greenhouses, respectively; red dots represent reference points). Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/wst.2020.114.

to 5 mL on a rotary evaporator, and the final volume was reduced to 1 mL under nitrogen flow. One milliliter of the extract was filtered through a cartridge of florisil, silica or alumina. A 1:1 20 mL of hexane and acetone was added to the cartridge in ratio and passed through the cartridge. The collected fraction volume was reduced to 5 mL on a rotary evaporator. The final volume was reduced to 1 mL with the solvent being hexane under a nitrogen stream. The extract was added to the vials for gas chromatography-mass spectrometry (GC/MS) for analysis.

Analysis and quality control

The samples were analyzed by Agilent 7890/5975 gas chromatography-mass spectrometer. The GC/MS furnace temperature program was started at 50 °C for 1 min and increased to 200 °C in 25 °C/min increments. 200 °C for 0 min, 8 °C/min increase to 310 °C temperature was maintained at this temperature for 12 min. High purity helium gas (3 mL/min) was used as carrier gas. For the 16 PAH compounds, the internal standard calibration method was used for calibration. For GC/MS calibration, 4-point calibration was performed at a concentration of 1, 25, 50 and 100 ng/mL. $R^2 > 0.99$ values for each PAH compound were calculated.

A two-step quality control procedure was applied before using the data for further analysis. In the first step, the recovery percentiles of the four compounds (Acenaphthene-d10, Chrysene-d12, Pyrene-d12, Phenanthrene-d10) were checked. If the recovery of the standards were not between ±25% then the sample was omitted from the analysis. In the second part of the quality control analysis, the binary correlation between the PAH compounds were calculated. The plots of correlations which have statistically significant Pearson correlation coefficient, R, values of above 0.8, were prepared. A linear trend line and a corresponding 95% confidence interval trend line were drawn. The data points outside the 95% confidence interval lines were re-investigated.

Health risk analysis and diagnostic ratio calculations

The incremental lifetime cancer risk (ILCR) was used to estimate the exposure risk for PAHs. The soil concentration was obtained by converting concentrations of PAHs according to the toxic equivalents of benzo[a]pyrene (BaP), employing the toxic equivalency factor (Σ7cPAHs = 0.001[Chysene] + 0.01[Benzo(k)fluoranthene] + 0.1[Benzo(a)anthracene] + 0.1 [Benzo(b)fluoranthene] + 0.1[Indeno(1,2,3-cd)pyrene] + [Dibenzo(a,h)anthracene] + Benzo(a)pyrene).

Downloaded from http://iwaponline.com/wst/article-pdf/81/2/283/679854/wst081020283.pdf
by guest

Table 1 | The relationship between health risk level, ILCR and BaPeq (Wang *et al.* 2018)

Significance	ICLR	BaPeq (ng g^{-1})
Little to no risk	$<10^{-6}$	<70
Potential low risk	10^{-6}–10^{-5}	70–700
Exceeds the critical value	10^{-5}–10^{-4}	700–7000
Potential high risk	$>10^{-4}$	>7000

ILCR values and health risk levels are shown in Table 1 (Wang *et al.* 2018).

There are specific PAH indicators of different emission sources. Relationship between PAH concentrations can be used to determine the contribution of different emission sources. A basic approach for this is to use diagnostic relationships. Most diagnostic relationships involve PAH pairs with the same molar mass and similar physicochemical properties (Mackay *et al.* 2006). In recent years, cross plots of different diagnostic ratios are becoming more useful to identify sources (Yunker *et al.* 2002; Wang *et al.* 2004; Biache *et al.* 2014; Cetin, 2016). In this study, two cross plots using Anthracene (Ant), Phenanthrene (Phe), Fluoranthene (Flu), Pyrene (Py), Benzo(a)anthracene (BaA) and Chrysene (Chr) were prepared to identify the major combustion sources that are used for heating the greenhouses and the village in the region (Li *et al.* 2017).

RESULTS

PAH concentrations

Soil samples taken from greenhouses located in Fettahlı region were analyzed for PAHs. The results of autumn and winter campaigns and effect of cover material (glass or polyethylene) on PAH concentrations were investigated. After the quality control, results of 87 greenhouse samples and eight reference point samples were used for the following discussions. The descriptive statistics of PAH values obtained in greenhouses and reference points are given in Tables 2 and 3, respectively.

The concentrations of the measured PAHs in greenhouses ranged from 0.01 ng/g to 80.54 ng/g with an average of total PAHs found as 65.65 ± 100.8 ng/g. The highest observed PAHs in greenhouses were Fluoranthene, Pyrene, Phenanthrene, Chrysene and Benzo(b)fluoranthene. The average value of the seven carcinogenic PAHs concentration was 5.65 ± 8.89 ng/g with a maximum value of 53.20 ng/g. These values indicate that the PAHs level in the region has little to no incremental lifetime cancer risk ($<10^{-6}$) (Wang *et al.* 2018).

The average total PAH concentration to the reference soils was 44.57 ± 32.8 ng/g. The highest concentration was found to be 7.33 ± 6.05 ng/g. Similar to the greenhouses, the highest observed PAHs in reference soils were

Table 2 | PAH concentrations in greenhouse soils in Antalya region, Turkey (ng/g)

Rings	Compound	Mean	Median	Maximum	Minimum	N[a]
2-ring	Naphthalene	1.18 ± 0.96	0.96	5.33	0.02	76
3-ring	Acenaphthylene	0.67 ± 0.66	0.50	2.55	0.01	73
	Acenaphthene	1.54 ± 1.4	0.81	4.94	0.27	23
	Fluorene	0.73 ± 0.69	0.50	4.75	0.10	84
	Phenanthrene	7.82 ± 11.11	3.22	61.16	0.01	85
	Anthracene	1.08 ± 1.71	0.46	9.63	0.02	86
4-ring	Fluoranthene	10.33 ± 14.4	4.57	64.89	0.14	87
	Pyrene	8.08 ± 12.27	2.98	57.40	0.04	87
	Benzo(a)anthracene	5.82 ± 10.63	1.71	68.61	0.01	87
	Chrysene	7.75 ± 12.9	3.00	80.54	0.02	85
5-ring	Benzo(b)fluoranthene	7 ± 12.28	2.63	73.96	0.05	86
	Benzo(k)fluoranthene	1.55 ± 2.49	0.58	12.73	0.01	85
	Benzo(a)pyrene	3.23 ± 4.8	1.30	28.72	0.01	87
	Dibenzo(a,h)anthracene	1.29 ± 2.16	0.46	12.96	0.01	85
6-ring	Indeno(1,2,3-cd)pyrene	3.47 ± 5.6	1.44	32.37	0.03	87
	Benzo(ghi)perylene	4.1 ± 6	1.80	33.16	0.06	87
	Σ7cPAH	5.65 ± 8.89	2.19	53.20	0.03	87
	Σ16PAH	65.65 ± 100	26.92	553.70	0.79	87

[a]N represents number of valid data points above method detection limit.

Downloaded from http://iwaponline.com/wst/article-pdf/81/2/283/679854/wst081020283.pdf
by guest

Table 3 | PAH concentrations in reference soils in Antalya region, Turkey (ng/g)

Rings	Compound	Mean	Median	Maximum	Minimum	N[a]
2-ring	Naphthalene	1.04 ± 0.91	0.82	2.62	0.23	7
3-ring	Acenaphthylene	0.51 ± 0.49	0.47	1.06	0.01	6
	Acenaphthene	0.54 ± 0.31	0.46	0.88	0.28	3
	Fluorene	0.42 ± 0.19	0.33	0.81	0.26	7
	Phenanthrene	4.66 ± 4.23	3.44	14.57	1.38	8
	Anthracene	0.57 ± 0.69	0.32	2.17	0.08	8
4-ring	Fluoranthene	7.33 ± 6.05	5.94	21.65	2.96	8
	Pyrene	6.67 ± 6.6	4.58	22.40	2.33	8
	Benzo(a)anthracene	3.65 ± 2.09	3.63	7.13	0.99	8
	Chrysene	4.26 ± 2.02	5.15	6.45	1.41	8
5-ring	Benzo(b)fluoranthene	4.59 ± 2.88	5.20	9.87	1.00	8
	Benzo(k)fluoranthene	1.16 ± 0.76	1.14	2.70	0.24	8
	Benzo(a)pyrene	2.31 ± 1.13	2.44	3.73	0.69	8
	Dibenzo(a,h)anthracene	0.83 ± 0.57	0.78	1.95	0.14	8
6-ring	Indeno(1,2,3-cd)pyrene	2.56 ± 1.62	2.52	5.57	0.58	8
	Benzo(ghi)perylene	3.48 ± 2.26	3.21	7.76	0.81	8
	Σ7cPAH	3.91 ± 2.18	4.04	7.33	1.01	8
	Σ16PAH	44.57 ± 32.8	40.44	111.33	13.39	8

[a]N represents number of valid data points above method detection limit.

Fluoranthene, Pyrene and Phenanthrene. PAH levels in reference points were lower than those observed in greenhouses (Figure 2). Acenaphthene, Fluorene, Phenanthrene, Anthracene, Benzo(a)anthracene and Chrysene are observed to be more than 50% higher in greenhouses. These compounds are tracers of biomass-coal combustion and unburned petroleum products (Aydın *et al.* 2014). Considering that the greenhouses are heated with coal and wood during winter season, the accumulation of these compounds could be attributed to winter heating.

Seasonal variation of PAHs for different cover types are given in Figure 3. A statistically significant difference was observed between autumn and winter average concentrations for Acenaphthylene, Fluorene, Phenanthrene, Fluoranthene, Benzo(a)pyrene, Chrysene and Benzo(ghi) perylene compounds in glass covered greenhouses. In polyethylene covered greenhouses, however, only the average concentrations of Acenaphthylene, Fluorene and Phenanthrene compounds in autumn and winter were statistically different. Acenaphthylene and Fluorene are used in paints

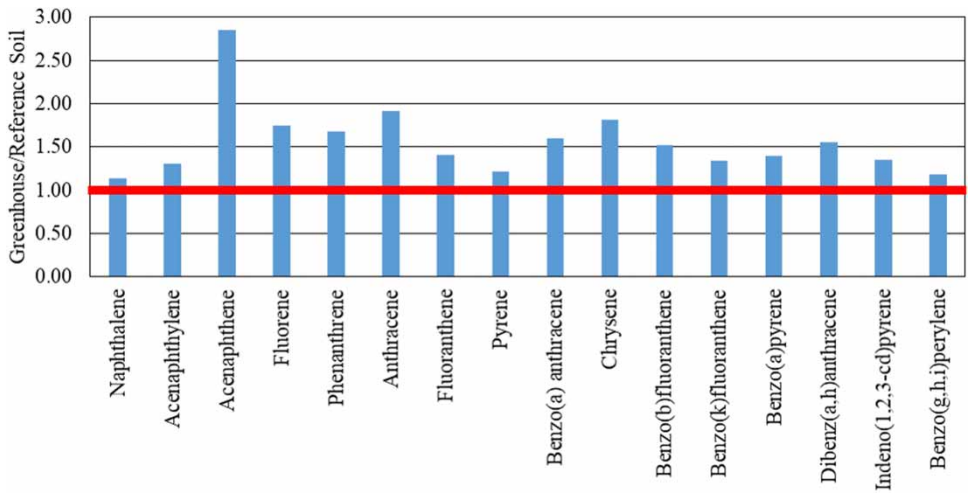


Figure 2 | Ratio of PAH concentrations in greenhouse soils to reference soils.

Downloaded from http://iwaponline.com/wst/article-pdf/81/2/283/679854/wst081020283.pdf
by guest

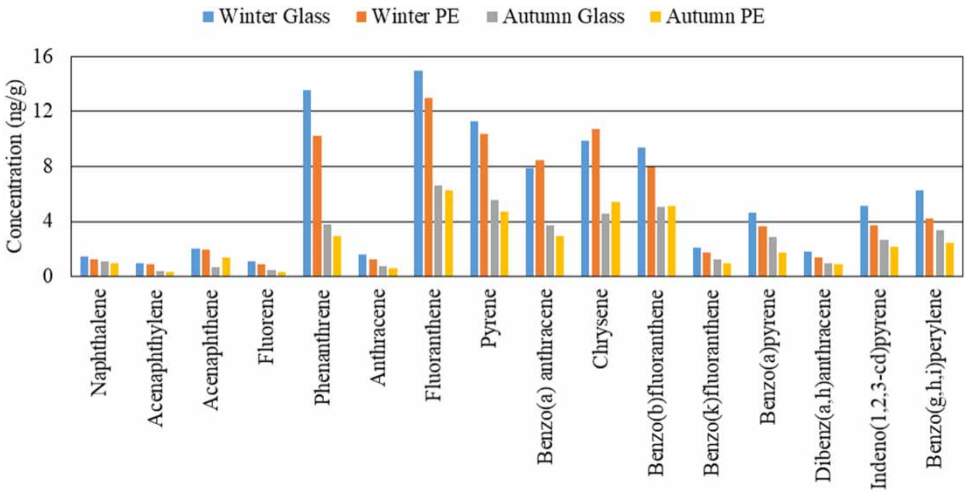


Figure 3 | PAH concentrations in winter and autumn for glass and polyethylene covered greenhouses in Antalya, Turkey.

and plastics (Abdel-Shafya & Mansour 2016). Fluorene is also a tracer of coal combustion (Tian *et al.* 2009; Wang *et al.* 2009; Cao *et al.* 2011; Lin *et al.* 2013) and Fluorene together with Chrysene and Phenanthrene are identified as fingerprints of wood combustion (Cao *et al.* 2011). Benzo(a) pyrene and Benzo(ghi)perylene are typical tracers of exhaust emissions from gasoline-powered vehicles (Tian *et al.* 2013). Chrysene (Tian *et al.* 2013) and Benzo(ghi)perylene are also enriched in diesel exhaust (Callen *et al.* 2012; Cristale *et al.* 2012). Temperature and ventilation control are two essential parameters in greenhouses. Temperature control is needed to control the growth of vegetables. The

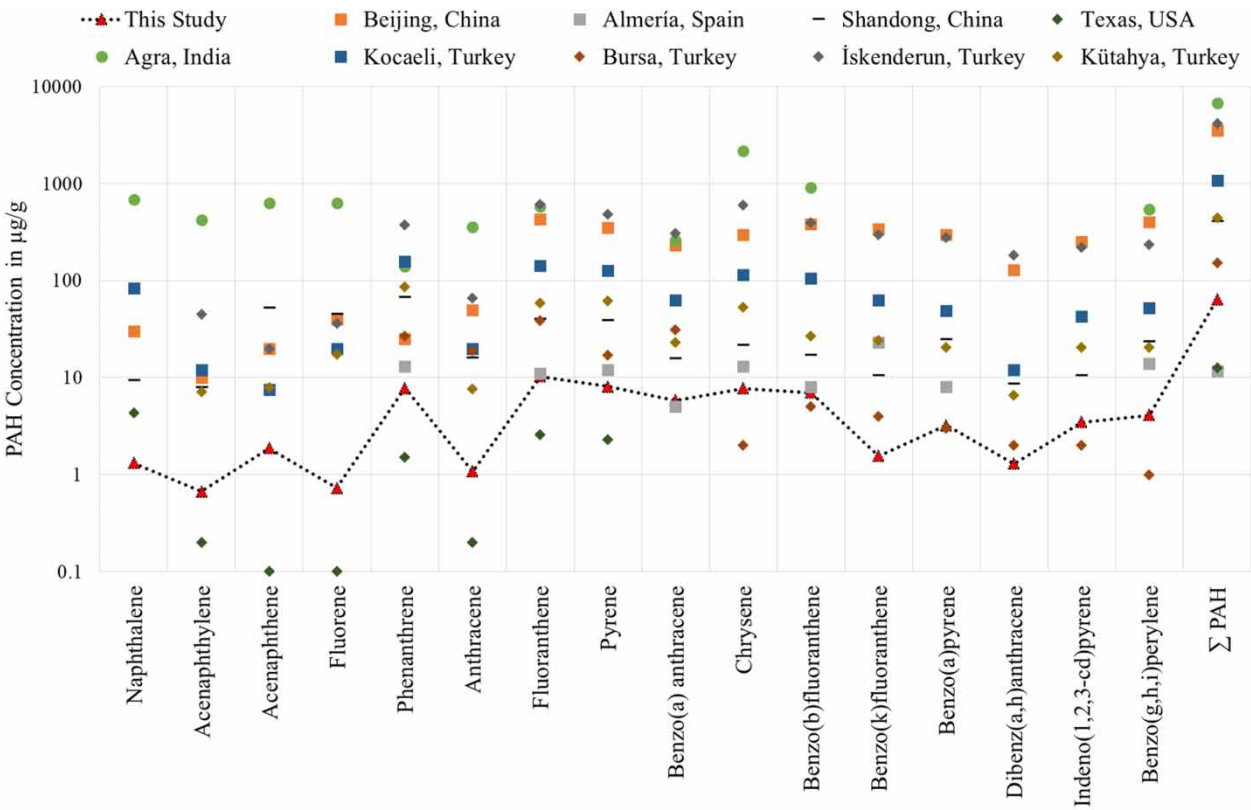


Figure 4 | Comparison of PAH concentrations in Antalya region, Turkey with similar studies across the globe.

Downloaded from http://iwaponline.com/wst/article-pdf/81/2/283/679854/wst081020283.pdf
by guest

optimum temperature for tomatoes to grow is reported as 15.5–18 °C (Aggie Horticulture 2020). The ventilation of greenhouses is needed to decrease temperature, to control the humidity and to refresh air in the greenhouse (Department of Primary Industries 2007). Since the average temperature observed in the autumn campaign was around 25 °C, ventilation vents of the greenhouses were generally open and greenhouses were not equipped with stoves. However, during the winter campaign, all the greenhouses were equipped with stoves and ventilation vents were closed. Although, concentrations of some compounds were observed higher in winter because of low volatility of PAHs, which were emitted from outside sources; the concentrations of other compounds were observed higher in winter because of higher greenhouse activities and lower ventilation of greenhouses during winter.

Comparison with the literature

In the literature, three studies on greenhouse soils were found. To increase the number of datasets, two studies on agricultural land around the world and the studies carried out in the soils of industrial regions of Turkey were reviewed (Figure 4). Studies in greenhouse soils were previously conducted in Beijing (Ma *et al.* 2003) and Shangdong (Chai *et al.* 2017), China and Almería, Spain (Plaza-Bolanos *et al.* 2012). In Texas, USA (De La Torre-Roche *et al.* 2009) and in Agra, India (Masih & Taneja 2006), the soils were farmlands. The levels of PAHs in soils obtained in this study are relatively lower than the other studies that were conducted on agricultural areas, with an only exception of Texas, USA. In Texas, 2–3 ring PAH levels were observed lower than this study. However, four and higher ring PAHs were higher than those observed in Antalya. The observed difference between concentrations obtained in Texas and Antalya could be because of petroleum refining in the Texas area (De La Torre-Roche *et al.* 2009). Almería and Antalya are under the influence of similar climatic conditions and the PAH levels are also comparable. The PAH concentrations in soils conducted in other parts of Turkey (Falay *et al.* 2013; Cetin 2016; Karaca 2016; Dumanoglu *et al.* 2017) are higher than the concentrations obtained in this study because all other sites were industrial areas.

Diagnostic ratios

Cross plots of diagnostic ratios can be used to predict the possible sources of PAHs in soils. Cross plots of diagnostic ratios are given in Figure 5. Anthracene (Ant) to sum of Anthracene (Ant) and Phenanthrene (Phe) versus Fluoranthene (Flu) to sum of Fluoranthene (Flu) and Pyrene (Py) plot indicates that biomass and coal combustion are the major sources. However, signatures of petroleum combustion and petroleum are also observed in the greenhouses. Benzo(a)anthracene (BaA) to sum of BaA and Chrysene (Chr) versus Flu/(Flu + Py) showed that biomass and coal combustion are the major sources together with petroleum combustion. As stated earlier, the greenhouses and village houses in the region are heated with either coal or wood during winter and village is located nearby an intercity highway. Therefore, major sources identified with diagnostic ratios seem to be reasonable.

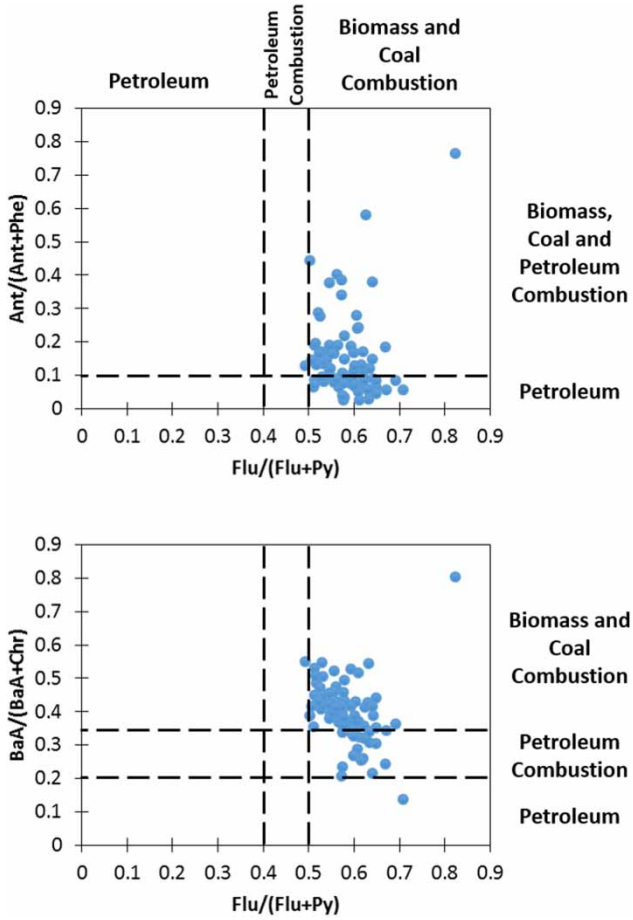


Figure 5 | Cross plots of PAH diagnosis ratios.

Greenhouse production in Antalya began in the 1940s and grew after the 1970s (Yilmaz *et al.* 2005). Currently, tomatoes produced in the province have been exported to 30 countries (Fresh Plaza 2017). There has been a huge

Downloaded from http://iwaponline.com/wst/article-pdf/81/2/283/679854/wst081020283.pdf
by guest

effort to control the pesticides and other chemicals on exported fresh fruits and vegetables in Antalya. Agricultural cooperatives work closely with government offices to let farmers be aware of not using POPs and other chemicals. This could be one of the important reasons of observing low concentrations of PAHs in the soil. However, incomplete combustion product emissions to the atmosphere for heating of the greenhouses and surrounding village houses increases the PAH content of the soil. Atmosphere seems to be the major path for pollution transport to the soil rather than the cultivation process and irrigation water which is groundwater. Therefore, to decrease the amount of PAHs in soil, atmospheric emissions should be decreased by means of using cleaner heating sources. However, the site should be further investigated to evince the degradation mechanism of PAHs from soil by means of groundwater analysis and atmospheric analysis.

CONCLUSIONS

Greenhouse soil concentrations of PAHs were investigated in a town located 10 km from downtown Antalya. Among the 16 PAHs ranging from two to six rings, four ring PAHs were found to be dominant. The seasonal variation of PAHs indicates the contribution of PAH deposition as a result of greenhouse activities (greenhouse heating, plastics and paint) and transportation of especially motor vehicle and household heating emissions from nearby village and intercity highway. PAH concentrations in the area were found to be lower than or comparable with the other greenhouse studies in the world. The diagnostic ratios also confirm the biomass and coal combustion sources and motor vehicle exhaust emissions in the region. However, to determine human health risk related to PAHs and groundwater contamination, air and groundwater PAH concentrations should be assessed in future studies by means of sampling air and groundwater.

ACKNOWLEDGEMENTS

This work was supported by Akdeniz University Scientific Research Project Office with project number FYL-2018-3645. We would like to thank Mihriban Civan, Sema Yurdakul, Ebru Nur Dokumacı and Tuba Ayaz for the analysis and Ayça Erdem and Merve Özkaleli Akçetin for their help during the sampling.

REFERENCES

Abdel-Shafya, H. I. & Mansour, M. S. M. 2016 A review on polycyclic aromatic hydrocarbons: source, environmental impact, effect on human health and remediation. *Egyptian Journal of Petroleum* **25** (1), 107–123. doi:10.1007/s11356-019-06043-8.

Aggie Horticulture 2020 *Greenhouse Tomato Culture*. Available from: https://aggie-horticulture.tamu.edu/greenhouse/hydroponics/tomato.html (accessed 22 February 2020).

Antalya Governorship 2020 *Nüfus-Demografi (Demographics-Population)*. Available from: http://www.antalya.gov.tr/nufus (accessed 21 February 2020).

ATSDR, Agency for Toxic Substances and Disease Registry 1995 *Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs)*. Department of Health and Human Services, Public Health Service, Atlanta, GA, USA.

Aydin, Y. M., Kara, M., Dumanoglu, Y., Odabasi, M. & Elbir, T. 2014 Source apportionment of polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) in ambient air of an industrial region in Turkey. *Atmospheric Environment* **97**, 271–285. doi:10.1016/j.atmosenv.2014.08.032.

Baumard, P., Budzinski, H., Garrigues, P., Dizer, H. & Hansen, P. D. 1999 Polycyclic aromatic hydrocarbons in recent sediments and mussels (*Mytilus edulis*) from the Western Baltic Sea: occurrence, bioavailability and seasonal variations. *Marine Environmental Research* **47** (1), 17–47. doi:10.1016/S0141-1136(98)00105-6.

Biache, C., Mansuy-Huault, L. & Faure, P. 2014 Impact of oxidation and biodegradation on the most commonly used polycyclic aromatic hydrocarbon (PAH) diagnostic ratios: implications for the source identifications. *Journal of Hazardous Materials* **267**, 31–39. doi:10.1016/j.jhazmat.2013.12.036.

Callen, M. S., Lopez, J. M. & Mastral, A. M. 2012 Apportionment of the airborne PM10 in Spain. Episodes of potential negative impact for human health. *Journal of Environmental Monitoring* **14**, 1211–1220. doi:10.1039/c2em10802j.

Cao, Q. M., Wang, H. & Chen, G. Z. 2011 Source apportionment of PAHs using two mathematical models for Mangrove sediments in Shantou coastal zone, China. *Estuaries and Coast* **34**, 950–960. doi:10.1007/s12237-011-9397-3.

Cetin, B. 2016 Investigation of PAHs, PCBs and PCNs in soils around a heavily industrialized area in Kocaeli, Turkey: concentrations, distributions, sources and toxicological effects. *Science of the Total Environment* **560**, 160–169. doi:10.1016/j.scitotenv.2016.04.037.

Chai, C., Cheng, Q. Q., Wu, J., Zeng, L. S., Chen, Q. H., Zhu, X. W., Ma, D. & Ge, W. 2017 Contamination, source identification, and risk assessment of polycyclic aromatic hydrocarbons in the soils of vegetable greenhouses in Shandong, China. *Ecotoxicology and Environmental Safety* **142**, 181–188. doi:10.1016/j.ecoenv.2017.04.014.

Cristale, J., Silva, F. S., Zocolo, G. J. & Marchi, M. R. 2012 Influence of sugarcane burning on indoor/outdoor PAH air

Downloaded from http://iwaponline.com/wst/article-pdf/81/2/283/679854/wst081020283.pdf
by guest

pollution in Brazil. *Environmental Pollution* **169**, 210–216. doi:10.1016/j.envpol.2012.03.045.

De La Torre-Roche, R. J., Lee, W.-L. & Campos-Díaz, S. I. 2009 Soil-borne polycyclic aromatic hydrocarbons in El Paso, Texas: analysis of a potential problem in the United States/Mexico border region. *Journal of Hazardous Materials* **163** (2–3), 946–958. doi:10.1016/j.jhazmat.2008.07.089.

Department of Primary Industries 2007 *Ventilation of Greenhouses*. Available from: https://www.dpi.nsw.gov.au/agriculture/horticulture/greenhouse/structures-and-technology/ventilation (accessed 22 February 2020).

Diggs, D. L., Harris, K. L., Rekhadevi, P. V. & Ramesh, A. 2012 Tumor microsomal metabolism of the food toxicant, benzo(a)pyrene, in Apc^{Min} mouse model of colon cancer. *Tumor Biology* **33** (4), 1255–1260. doi:10.1007/s13277-012-0375-6.

Dumanoglu, Y., Gaga, E. O., Gungormus, E., Sofuoglu, S. C. & Odabasi, M. 2017 Spatial and seasonal variations, sources, air-soil exchange, and carcinogenic risk assessment for PAHs and PCBs in air and soil of Kutahya, Turkey, the province of thermal power plants. *Science of the Total Environment* **580**, 920–935. doi:10.1016/j.scitotenv.2016.12.040.

European Commission 2001 *Ambient Air Pollution by Polycyclic Aromatic Hydrocarbons (PAH)*. Position Paper.

Falay, E. O., Tuna, G., Altiok, H., Kara, M., Dumanoglu, Y., Bayram, A., Tolunay, D., Elbir, T. & Odabasi, M. 2013 Spatial variation of polycyclic aromatic hydrocarbons (PAHs) in air, soil and tree components in Iskenderun Industrial Region, Turkey. *International Journal of Chemical, Environmental & Biological Sciences* **1** (2), 263–276.

Fresh Plaza 2017 Turkey: Antalya tomatoes reach 30 countries around the world. https://www.freshplaza.com/article/2186624/turkey-antalya-tomatoes-reach-countries-around-the-world/ (accessed 22 February 2020).

Gan, S., Lau, E. V. & Ng, H. K. 2009 Remediation of soils contaminated with polycyclic aromatic hydrocarbons (PAHs). *Journal of Hazardous Materials* **172** (2–3), 532–549. doi:10.1016/j.jhazmat.2009.07.118.

Karaca, G. 2016 Spatial distribution of polycyclic aromatic hydrocarbon (PAH) concentrations in soils from Bursa, Turkey. *Archives of Environmental Contamination and Toxicology* **70** (2), 406–417. doi:10.1007/s00244-015-0248-2.

Khaiwal, R., Ranjeet, S. & Rene, V. G. 2008 Atmospheric polycyclic aromatic hydrocarbons: source attribution, emission factors and regulation. *Atmospheric Environment* **42** (13), 2895–2921. doi:10.1016/j.atmosenv.2007.12.010.

Kim, S.-K., Lee, D. S., Shim, W. J., Yim, U. H. & Shin, Y.-S. 2009 Interrelationship of pyrogenic polycyclic aromatic hydrocarbon (PAH) contamination in different environmental media. *Sensors* **9** (12), 9582–9602. doi:10.3390/s91209582.

Li, Y., Long, L., Ge, J., Yang, L., Cheng, J., Sun, L., Lu, C. & Yu, X. 2017 Presence, distribution and risk assessment of polycyclic aromatic hydrocarbons in rice-wheat continuous cropping soils close to five industrial parks of Suzhou, China. *Chemosphere* **184**, 753–761. doi:10.1016/j.chemosphere.2017.06.055.

Lin, T., Qin, Y. W., Zheng, B. H., Li, Y. Y., Chen, Y. & Guo, Z. G. 2013 Source apportionment of polycyclic aromatic hydrocarbons in the Dahuofang Reservoir, Northeast China. *Environmental Monitoring and Assessment* **185**, 945–953. doi:10.1007/s10661-012-2605-1.

Ma, L. L., Chu, S. G. & Xu, X. B. 2003 Organic contamination in the greenhouse soils from Beijing suburbs, China. *Journal of Environmental Monitoring* **5** (5), 786–790. doi:10.1039/b305901d.

Mackay, D., Shiu, W., Ma, K. & Lee, S. 2006 *Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals*. CRC Press, Boca Raton, FL, USA.

Masih, A. & Taneja, A. 2006 Polycyclic aromatic hydrocarbons (PAHs) concentrations and related carcinogenic potencies in soil at a semi-arid region of India. *Chemosphere* **65**, 449–456. doi:10.1016/j.chemosphere.2006.01.062.

Palm, A., Cousins, I., Gustafsson, O., Axelman, J., Grunder, K., Broman, D. & Brorstrom-Lunden, E. 2004 Evaluation of sequentially-coupled POP fluxes estimated from simultaneous measurements in multiple compartments of an air-water-sediment system. *Environmental Pollution* **128** (1–2), 85–97. doi:10.1016/j.envpol.2003.08.023.

Plaza-Bolanos, P., Padilla-Sanchez, J. A., Garrido-Frenich, A., Romero-Gonzalez, R. & Martinez-Vidal, J. L. 2012 Evaluation of soil contamination in intensive agricultural areas by pesticides and organic pollutants: south-eastern Spain as a case study. *Journal of Environmental Monitoring* **14** (4), 1182–1189. doi:10.1039/c2em10993j.

Republic of Turkey Ministry of Agriculture and Forestry 2017 *Örtü Altı Yetiştiricilik (Greenhouse Cultivation)*. Available from: https://www.tarimorman.gov.tr/Konular/Bitkisel-Uretim/Tarla-Ve-Bahce-Bitkileri/Ortu-Alti-Yetistiricilik (accessed 17 March 2019).

Skupinska, K., Misiewicz, I. & Kasprzycka-Guttman, T. 2004 Polycyclic aromatic hydrocarbons: physicochemical properties, environmental appearance and impact on living organisms. *Acta Polonise Pharmaceutica-Drug Research* **61** (3), 233–240.

Smith, D. J. T. & Harrison, R. M. 1998 Polycyclic aromatic hydrocarbons in atmospheric particles. In: *Atmospheric Particles* (R. Harrison & R. Van Grieken, eds), IUPAC Series on Analytical and Physical Chemistry of Environmental Systems, West Sussex, UK, pp. 253–294.

Tian, F. L., Chen, J. W., Qiao, X. L., Wang, Z., Yang, P., Wang, D. G. & Ge, L. K. 2009 Sources and seasonal variation of atmospheric polycyclic aromatic hydrocarbons in Dalian, China: factor analysis with non-negative constraints combined with local source fingerprints. *Atmospheric Environment* **43**, 2747–2753. doi:10.1016/j.atmosenv.2009.02.037.

Tian, Y. Z., Li, W. H., Shi, G. L., Feng, Y. C. & Wang, Y. Q. 2013 Relationships between PAHs and PCBs, and quantitative source apportionment of PAHs toxicity in sediments from Fenhe reservoir and watershed. *Journal of Hazardous Materials* **248**, 89–96. doi:10.1016/j.jhazmat.2012.12.054.

Tremblay, L., Kohl, S. D., Rice, J. A. & Gagne, J. P. 2005 Effects of temperature, salinity, and dissolved humic substances on the

Downloaded from http://iwaponline.com/wst/article-pdf/81/2/283/679854/wst081020283.pdf
by guest

sorption of polycyclic aromatic hydrocarbons to estuarine particles. *Marine Chemistry* **96** (1–2), 21–34. doi:10.1016/j.marchem.2004.10.004.

Turkish Statistical Institute 2017 *Örtüaltı Üretimi (Greenhouse Production)*. Available from: http://www.tuik.gov.tr/PreTablo.do?alt_id=1001 (accessed 17 March 2019).

Unwin, J., Cocker, J., Scobbie, E. & Chambers, H. 2006 An assessment of occupational exposure to polycyclic aromatic hydrocarbons in the UK. *Annals of Occupational Hygiene* **50** (4), 395–403. doi:10.1093/annhyg/mel010.

Van Jaarsveld, J. A., VanPul, W. A. J. & DeLeeuw, F. 1997 Modelling transport and deposition of persistent organic pollutants in the European region. *Atmospheric Environment* **31** (7), 1011–1024. doi:10.1016/S1352-2310(96)00251-8.

Venny Gan, S. & Ng, H. K. 2012 Current status and prospects of Fenton oxidation for the decontamination of persistent organic pollutants (POPs) in soils. *Chemical Engineering Journal* **213**, 295–317. doi:10.1016/j.cej.2012.10.005.

Wang, X. J., Chen, J., Zhang, Z. H., Piao, X. Y., Hu, J. D. & Tao, S. 2004 Distribution and sources of polycyclic aromatic hydrocarbons in soil profiles of Tianjin area, People's Republic of China. *Bulletin of Environmental Contamination and Toxicology* **73** (4), 739–748. doi:10.1007/s00128-004-0488-8.

Wang, D. G., Tian, F. L., Yang, M., Liu, C. L. & Li, Y. F. 2009 Application of positive matrix factorization to identify potential sources of PAHs in soil of Dalian, China. *Environmental Pollution* **157**, 1559–1564. doi:10.1016/j.envpol.2009.01.003.

Wang, C., Zhou, S., Song, J. & Wu, S. 2018 Human health risks of polycyclic aromatic hydrocarbons in the urban soils of Nanjing, China. *Science of the Total Environment* **612**, 750–757. doi:10.1016/j.scitotenv.2017.08.269.

Wild, S. R. & Jones, K. C. 1995 Polynuclear aromatic-hydrocarbons in the United-Kingdom environment – a preliminary source inventory and budget. *Environmental Pollution* **88** (1), 91–108. doi:10.1016/0269-7491(95)91052-M.

World Health Report 1998 *Life in the 21st Century: A Vision for all*. Geneva: World Health Organization.

Yilmaz, I., Sayin, C. & Ozkan, B. 2005 Turkish greenhouse industry: Past, present, and future. *New Zealand Journal of Crop and Horticultural Science* **33** (3), 233–240. doi:10.1080/01140671.2005.9514355.

Yunker, M. B., Macdonald, R. W., Vingarzan, R., Mitchell, R. H., Goyette, D. & Sylvestre, S. 2002 PAHs in the Fraser River basin: a critical appraisal of PAH ratios as indicators of PAH source and composition. *Organic Geochemistry* **33** (4), 489–515. doi:10.1016/S0146-6380(02)00002-5.

First received 20 November 2019; accepted in revised form 27 February 2020. Available online 11 March 2020

Downloaded from http://iwaponline.com/wst/article-pdf/81/2/283/679854/wst081020283.pdf
by guest