Proceedings of the 7th World Congress on Civil, Structural, and Environmental Engineering (CSEE'22)
~~Lisbon, Portugal~~ Virtual Conference – April 10 – 12, 2022
Paper No. ICEPTP 113
DOI: 10.11159/iceptp22.113

Evaluating Site Investigation Data to Assess Polycyclic Aromatic Hydrocarbon (PAH) Soil Contamination on Brownfield Sites in Surrey, UK

E. E. Hellawell[1]*, T. O'Reilly[2] and S.J.Hughes[1]
[1]Department of Civil Engineering, University of Surrey
Guildford, GU2 7XH, UK
e.hellawell@surrey.ac.uk; sue.hughes@surrey.ac.uk
[2]Formerly Royal Holloway College, University of London
Egham, Surrey, KT20 0EX

Abstract **–** This paper describes the collection and preliminary analysis of polycyclic aromatic hydrocarbon (PAH) contamination data from soils on brownfield sites in south east England. The data were obtained during intrusive site investigations on development sites which were submitted to local government as part of the planning process between 1998-2019. The statistical distributions of the concentrations of the 16 principal PAHs found on 120 brownfield sites and over 1100 Made Ground soil samples in the study area are presented. The data showed low median values, but with high concentration outliers for all PAHs. The highest PAH concentrations were found for fluoranthene and pyrene. The mean value for benzo(a)pyrene (BaP), the most carcinogenic PAH, exceeded current UK guidance for residential use and the spatial location of BaP measurements showed no obvious source or distribution. Information on the soil samples from the borehole logs was used to compare the PAH profile of soil samples with particular PAH descriptors, e.g. clinker, ash. All had a similar PAH composition, which suggested a coal-based source. Diagnostic ratios were applied to the sample set, which indicated that almost all had a pyrogenic, non-traffic related, source. This was validated using the sample descriptions. A diagnostic ratio cluster was identified for soil samples described as slag, probably due to the high temperatures used in its formation. Overall, the PAH profile, soil descriptions and diagnostic profiles signified coal combustion as the source of PAH on these sites. This reflects the UK history of industrialisation with urban and domestic coal fuel use up to the 1980s. The study demonstrates the potential for local government datasets to provide greater information on contamination levels on brownfield sites as well as specific contamination data for parametric studies.

Keywords**:** brownfield site, contaminated land, site investigation, diagnostic ratios, polycyclic aromatic hydrocarbons, benzo(a)pyrene

1. Introduction

There is a current housing shortfall in the UK and a legacy of brownfield sites dating back to the 19th century industrialisation period. As this housing demand is mainly in urban areas, these brownfield sites are being targeted for new residential developments. This is challenging as any health risks to residents must firstly be identified and then addressed. Polycyclic aromatic hydrocarbons, PAHs are one group of contaminants often present on brownfield sites. PAHs are primarily formed from the incomplete combustion of pyrogenic materials such as coal or petroleum. Some PAHs, (e.g. benzo(a) pyrene and dibenzo(a,h)anthracene) are classified as mutagenic and carcinogenic to humans [1].

Information on PAHs within soils samples is collected on development sites by an intrusive site investigation. This costly site information is reviewed for risk assessment and the data sent to local government as part of the planning process. In this research, this untapped PAH data for a local government area have been extracted and analysed. Further information on the site history and soil sample descriptions have also been collected. The aim of this paper is to present the results of the PAH analysis for the region and to use descriptive evidence to investigate research methods for predicting the likely PAH source.

2. Method

The UK local government planning process requires the potential risk for any brownfield development site to be evaluated. Intrusive site investigation information for brownfield sites is submitted to local government, stored on a planning database and may be available on the planning website. This site investigation planning data for a local government borough in Surrey was obtained and interrogated. The study area is a suburban area, covering approximately 9,600 hectares. It lies 20km south west of London and is an affluent commuter area, with no dominant industry and where available brownfield land is now prioritised for residential development [2].

120 sites, with intrusive site investigation data, were identified within the borough. Information from the reports and desk studies was extracted and input into a database as detailed in Hellawell and Hughes [3]. Information collected included the site location, site history, geology, sample descriptions, sample locations and chemical analysis. Data from 132 site investigation reports detailing 1714 soil samples were collected, of which 1185 were classified as from Made Ground.

The soil samples were sent to commercial laboratories for analysis, as is standard in these investigations. Contamination data on the 16 priority PAH chemicals together with total PAH was collected and analysed for sites developed from 1998-2019. A significant number of the chemical results showed concentrations below the limit of detection for the laboratory method. In this case the most conservative approach of assigning the limit of detection was used in the analysis.

Information within the borehole log relating to descriptions of potential PAH was noted. The borehole log is the description made by the site engineer of the soil strata encountered as the borehole is excavated. This description details the soil formation, colour and any distinguishing geological or contaminating details. It is recorded in relation to the depth the soil sample was taken. This information was then categorised under the following sample headings: ash, clinker/coal, charcoal, slag, tarmac. This enabled comparison between chemical results and sample descriptions.

3. Results

The data for the concentrations of the 16 priority PAHs and the total PAH in Made Ground samples are shown in Fig.1. The box indicates the interquartile range and the median is shown within this box. The results show that the lowest concentrations were measured for the lowest molecular weight PAHs (naphthalene, acenaphthylene, acenaphthene and fluorene) and the highest concentrations were measured for fluoranthene and pyrene, which are heavier PAHs. The median values of all 16 PAHs were low, however a log scale was required to show the significance of outlier measurements (as indicated by dashed lines). The extreme outliers indicate that occasionally concentrations over 1000 times the median were measured.

The high outlier data affects the calculation of the mean concentration for the PAHs, resulting in relatively high values for naphthalene, fluoranthene and benzo(a)pyrene, as shown in Table 1. The latter is of concern as benzo(a) pyrene is the most carcinogenic PAH [1] and the mean value for BaP for this Made Ground dataset exceeds the current UK guidance value for residential site use of 5mg/kg [4]. The location of the BaP measurements and exceedances is plotted on a map of the study area in Fig. 2. This shows most of the sites were located in the more urban north of the borough, however there is no distinct pattern or source for sites with high BaP measurements.

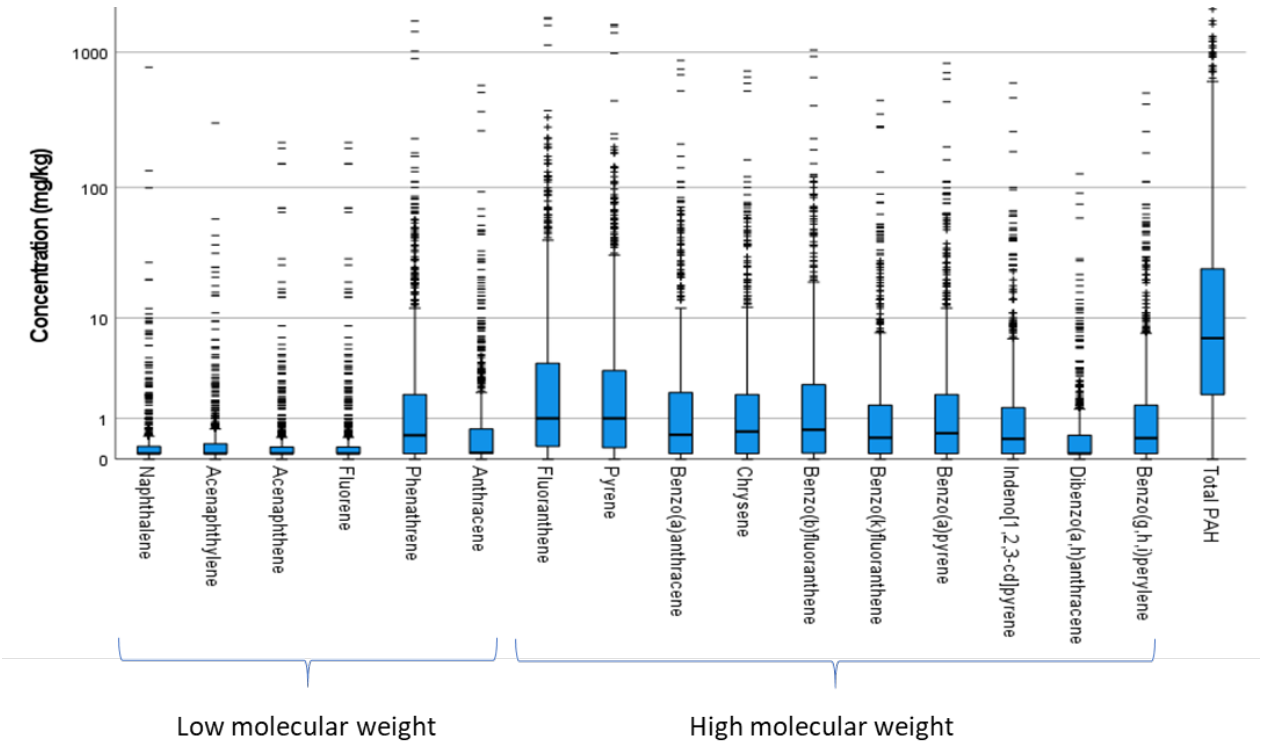

Fig. 1 Concentrations measured of the 16 priority PAHs and total PAH for Made Ground samples.

Table 1 Statistical data on PAHs concentrations (in mg/kg) measured in Surrey and for other studies.

Study Location		**Sample number**	**Naphthalene**	**Fluorene**	**Fluoranthene**	**Pyrene**	**Benzo(a)pyrene**	**Total PAH**
Surrey (Made Ground)	Mean	1185	14.2	2.0	18.6	16.2	10.0	112.9
	Median		0.1	0.1	1.0	1.0	0.7	7.0
Newcastle (urban) [5]	Mean	835-929	-	-	-	-	2.83	52.99
	Median		-	-	-	-	0.5	8.15
Newcastle (industrial) [5]	Mean	214-294	-	-	-	-	8.61	107.7
	Median		-	-	-	-	1	19
UK (urban) [6]	Mean	30	-	-	-	-	-	-
	Median		0.03		1.25	0.57	0.38	4.2
Glasgow [7]	Mean	20	0.132	0.11	1.729	1.763	0.971	11.93
	Median		0.068	0.038	1.125	1.124	0.657	8.33
London – south east [8]	Mean	76						18
	Median							14
Beijing (suburban) [9]	Mean	162	0.019	0.003	0.037	0.029	0.021	0.322
	Median		-	-	-	-	-	-
Ulsan Korea (urban) [10]	Mean	25	0.061	0.005	0.049	0.044	0.026	0.39
	Median		0.052	0.005	0.035	0.032	0.015	0.27

Table 1 also shows results obtained from different PAH studies in the UK and internationally on urban soils [5-10]. The PAH and BaP measurements in this Surrey study are only comparable in magnitude to the Newcastle study. Newcastle is a city in north east England, with a history of industrialisation predominantly based on coal. It would therefore be expected to have higher levels of PAH contamination than this study area of suburban Surrey. The data selection process of both these studies were similar, in using local government site data from predominantly brownfield sites. These results, therefore suggest that brownfield sites in suburban Surrey have similar PAH levels, indicating similar contaminating site histories, to former brownfield sites in industrial Newcastle.

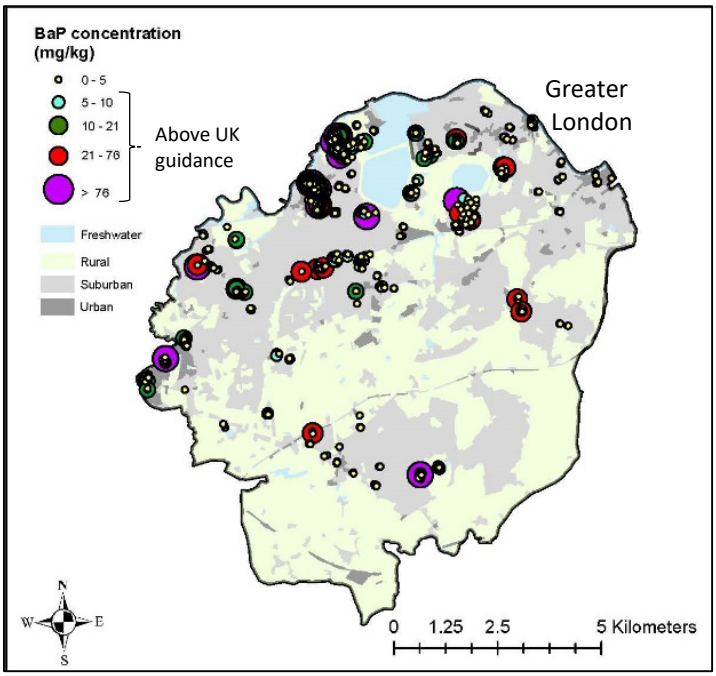

Fig. 2 Spatial location and exceedances of high benzo(a)pyrene measurement within the study area

Other UK investigations, shown in Table 1, used more uniform surface soil sampling techniques across their study area and did not focus only on brownfield sites. This resulted in lower mean and median PAH concentrations [6,7,8]. The results for studies in China and Korea [9,10] found PAH concentrations that were orders of magnitude lower than for the UK studies, probably reflecting the shorter industrial history of these areas and potentially alternative PAH sources.

Trends relating to PAH chemical concentrations and the sample descriptions from the borehole log were investigated. The aim of this borehole study was to find if the concentration and PAH chemicals encountered could be related to particular PAH markers/descriptions within the borehole log. Five descriptions relating to potential PAH sources were identified, namely: ash, clinker, charcoal, slag and tarmac. (Clinker is a solid residue found after coal has been burnt and slag is waste matter formed during metal smelting or refining). Fig. 3 shows the make-up of PAHs for soils containing the source descriptions. This showed that there were lower relative percentages of naphthalene, acenaphthylene, acenaphthene, fluorene. These are the lighter, lower molecular weight PAHs and considered more volatile. Fluoranthene and pyrene are the most abundant PAHs. This overall PAH distribution is similar to PAH emissions from domestic coal combustion as shown by Wild and Jones [6]. The relative concentrations of the PAHs were similar for the samples irrespective of the sample description. There are a few minor differences, which may be caused by differences in combustion temperature e.g. charcoal had slightly higher levels of pyrene and fluoranthene and lower levels of naphthalene and slag had higher levels of benzo(a)pyrene.

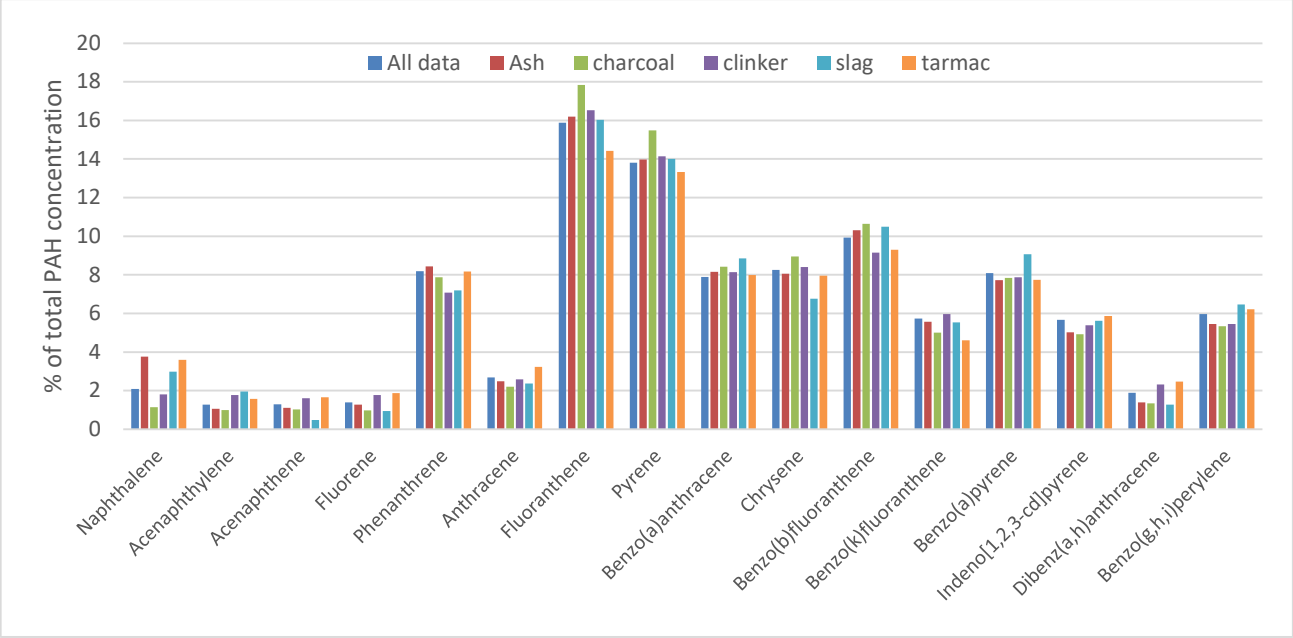

Fig. 3 Percentage of total PAH concentration for the key 16 PAHs for soil sample descriptions.

PAH isometric or diagnostic ratios have been applied in soils, sediments and dust to characterise the PAH source [11]. These aim to distinguish pyrogenic and petrogenic sources based upon the thermodynamic stability of the PAH components. Fig.4 shows the results of plotting two diagnostic ratios for all Made Ground soil samples then highlights the results for samples with soil strata descriptions. (In this analysis all samples with a concentration at the limit of detection were removed.) Fig. 4a shows most of the sample results lie within the pyrogenic (top right) quadrant of the plots. This implies that high temperature combustion of grass/wood/ coal is the likely source of the PAHs within the sample set. This diagnostic ratio analysis is verified by Fig. 4b where the sample descriptions ash, clinker, charcoal and slag are detailed and all lie within the pyrogenic quadrant. Fig. 4b also shows a cluster for samples described as containing slag. The production of slag is likely to be at a very high temperature and the data suggests this results in less chrysene (as shown for slag in Fig. 3) and hence a high BaA/(BaA +Chry) ratio.

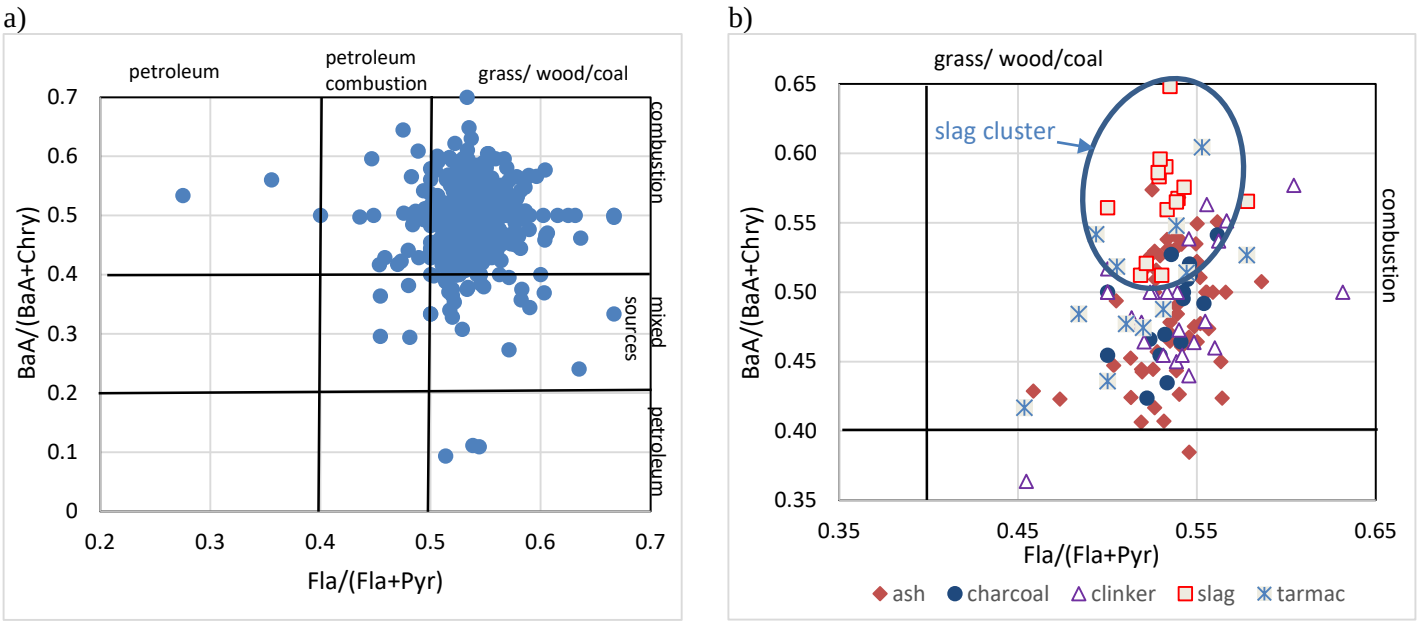

Fig. 4 Diagnostic ratios for source identification for a) all Made ground samples and b) samples with a PAH description. BaA = benzo(a)anthracene, Chry = chrysene; Fla = fluoranthene, Pyr = pyrene.

Another PAH marker, cited by Pandey et al [12] for identifying traffic related sources, is the ratio of benzo(a)pyrene to benzo(ghi)perylene. High concentrations of benzo(ghi)perylene (BghiP) are indicative of petroleum/diesel burning and hence low values of this ratio (BaP/BghiP < 0.6) are considered to show a traffic-based source. Fig. 1 shows for Made Ground samples, the measured benzo(ghi)perylene concentrations are lower than for benzo(a)pyrene. The mean ratio of BaP/BghiP for all the Made Ground samples was 1.4, with only 2.7% of samples having values < 0.6. Hence this ratio determines most of the samples to be from a non-traffic source. This is confirmed by samples within the dataset with a pyrogenic log description. For these samples, the diagnostic ratio BaP/BghiP was determined to be 1.6.

4. Conclusions

This paper describes a proof of concept study to high-light the potential use of local government data sources for parametric studies which in turn, can inform developers on contamination levels in a local area. The results provide valuable data on the PAH levels found on brownfield sites in south-east England. Although the median values for the PAH concentrations are low, high outliers were commonly detected, which for the most critical PAH, benzo(a)pyrene were shown to be distributed on sites across the study area. The descriptive sample data collected in this research provided validation of the diagnostic ratios used for source identification. Overall the sample descriptions, PAH distribution and diagnostic ratio results indicated a pyrogenic coal-based source for PAH on the brownfield sites in this area, reflecting the UK history of industrialisation, urban and domestic coal fuel use.

Acknowledgements

The authors would like to thank NERC and the University of Surrey for funding this Daphne Jackson Research Fellowship.

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