Polish Journal of Environmental Studies Vol. 7, No. 5 (1998), 267-272

Soil Contamination with Polycyclic Aromatic Hydrocarbons (PAHs) in Poland - a Review

E. Wcisło

Institute for Ecology of Industrial Areas
40-833 Katowice, ul. Kossutha 6, Poland

Received 13 May, 1998
Accepted 15 July, 1998

Abstract

The purpose of this paper is to provide a summary of data on PAH content in soils in Poland, published in literature over the last 20 years. This paper presents a preliminary assessment of soil contamination by PAHs for different land use patterns.

A review of available literature highlights the need to continue research on PAH contamination levels in environmental media in Poland, including surface soil. Results of such research would be important in order to better define exposure estimates in the general population and to examine the relationship between levels of PAHs in the environment and the subsequent development of health effects.

Keywords: PAHs, soil contamination, Poland, contaminated areas

Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a class of organic chemicals consisting of two or more fused-benzene rings. PAHs are components of most fossil fuels and are ubiquitous in the natural environment [1, 2]. Natural sources include release in forest fires and from volcanic eruptions. Most environmental PAHs are products of incomplete combustion or pyrolysis of fossil fuels [1,3, 4]. Stationary fuel sources are responsible for over 97% of PAH emissions [5]. Other important sources include automobile and truck emissions [6]. Hazardous waste sites can be a concentrated source of PAHs on a local scale. It is estimated that in Poland nearly 21 tons of one PAH alone, benzo(a)pyrene, are emitted into the air from especially burdensome industrial plants every year [7].

The study of these compounds is due mainly to their carcinogenic and widespread occurrence in environmental components, including surface soils. Most of the PAHs are introduced into soil from atmospheric depostion after local and long-range transport, which is supported by the presence of PAHs in soil of regions remote from any industrial activity [8]. Other potential sources of PAHs in soil include disposal from public sewage tretment, irrigation with coke oven effluent, leachate from bituminous coal storage sites, and use of soil compost and fertilizers [9, 10, 11, 12, 13, 14].

Although PAHs are described as carcinogenic, only the following are considered as possible human or animal carcinogens [6]: benz(a)anthracene, benzo(a)pyrene, benzo (b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz (a,h)anthracene, indeno(l,2,3-cd)pyrene. The general population may be exposed to these compounds by inhalation of the compounds in tobacco smoke and contaminated air, as well as ingestion of contaminated food. Populations living in the vicinity of hazardous waste sites may be at greater risk of potential exposure to PAHs than the general population through inhalation, ingestion and direct contact with contaminated media [6].

Benzo(a)pyrene (BaP) is the most thoroughly studied of PAHs. Some PAHs are included in the "priority pollutants" lists developed by the United States Environmental Protection Agency (US EPA) and the European Community (EC). Some European countries have developed soil quality criteria for selected PAHs or their sum [15]. Critical limits for soil set in the Netherlands, Finland, Denmark, the United Kingdom, Belarussia, Moldavia, Russia and Ukraine are based on an effect-based approach: effects on ecosystem and/or effects on human beings.

Level of Soil Contamination with PAHs - Results and Discussion

Analytical difficulties and lack of any standardized methods for determining polycyclic aromatic hydrocarbons in soil have caused few research institutions in Poland to investigate these compounds in soil. The studies have been carried out haphazardly and have usually covered rather not extensive areas. The studies of some larger areas concerned soil used for agricultural purposes in the Katowice, Lodz, Czestochowa, Lublin and north and eastern provines [14, 16, 17, 18, 19, 20]. It should be emphasized that some results were obtained over ten or even twenty years ago using semiquantitative analytical methods [21, 22, 23, 24, 25]. The studies have often covered only the determination of benzo(a)pyrene [21, 25, 26]. The sum of PAHs under study regarded different kinds and numbers of compounds - from six [23] to sixteen numbers of compounds [14, 17, 18, 19, 27]. For these reasons interpreting results is very difficult or sometimes even impossible at all.

Tables I and 2 present data concerning the concentrations of PAHs in surface soil from uncontaminated and contaminated areas in Poland, respectively.

No soil quality values for PAHs have been established in Poland. The only recommendations on levels of some PAHs in soils exist in Poland, published by the Polish State Environmental Inspectorate [28]. In fact, they are the requirements for remediation activity in Poland. Polish researchers have referred the results to the levels found in the unpolluted areas or reference values proposed in different countries. The "Dutch List" has been used most often for these purposes [29].

In the 1980's concentrations of from 25 to 30 µg/kg were recognized as general "background" of soil contamination with BaP in Poland [25]. It was proposed to treat BaP content in soil from 300 to 1000 µg/kg as high and above 1000 µg/kg as very high soil contamination [25]. The Institute of Soil Science and Plant Cultivation in Pulawy proposed classification of agricultural soil contaminated with 16 PAHs [18]. According to this classification, PAH content in agricultural soil below 200 µg/kg can be considered "background values". The sum of PAHs (600-10,000 µg/kg) corresponds to the contaminated soil with different levels of contamination and over 10,000 µg/kg - corresponds to very high contaminated soils where reclamation is needed.

Concentrations of BaP in soil in clean regions of Poland ranged mostly from 2 to about 30 µg/kg and seldom exceeded 70 µg/kg (Table 1). The sum of PAHs found in uncontaminated soil in Poland in most cases did not exceed 600 µ^g.

Soil contamination with PAHs increases considerably in industrial and urban areas (Table 2). PAH concentrations in

Table 1. PAH concentrations in uncontaminated soils.

Place of sampling	PAH concentrations (µg/kg)		Method of analysis	References
	Sum	BaP		
Rural areas Beskidy: light sandy soil heavy loamy soil	–	 1.5-6.5 50-78	liquid column chromatography, UV spectrophotometry	[22]
Eastern and central provinces	–	3.4-75	TLC, spectrofluorimetry	[25]
Western regions of Poland	–	25-30	TLC, spectrofluorimetry	[25]
Szczawnica - Nowy Sącz province	58[a]	–	liquid column chromatography, UV spectrophotometry	[23]
Bierna - Bielsko-Biała province	71.3[b]	2.9	liquid column chromatography, UV spectrophotometry	[30]
Miedźna (arable soils) - outskirts of the Katowice province	98-1038[c] (M = 388)	2-77 (M = 29)	HPLC, UV detection	[16]
Białowieża - Białystok province	190.3[c]	8.2	HPLC, UV detection	[16]
Gogolin - Opole province	498.1[c]	21.0	HPLC, UV detection	[16]
Wisła - Bielsko-Biała privince	579.6[c]	37.4	HPLC, UV detection	[16]
Martąg - Elbląg province	317[c]	30.1	HPLC, UV detection	[16]
Przewale - Zamość province	481.6[c]	16.0	HPLC, UV detection	[16]
Agricultural soils in Poland	G = 150[d]	G = 15	HPLC, UV detection	[18]
Wilków - Lublin province (agricultural soils)	81-645 (M = 180)[d]	–	HPLC, UV detection	[31]

Abbreviations and symbols - see below Table 2.

Table 2. PAH concentrations in contaminated soils.

Place of sampling	PAH concentrations (μg/kg)		Method of analysis	References
	Sum	BaP		
1	2	3	4	5
Surroudings of industrial plants				
Vicinity of petrochemical complex, Płock	–	11,000-15,000	TLC, UV spectrophotometry	[21]
5 km from petrochemical complex, Płock	–	< 2,000	TLC, UV spectrophotometry	[21]
200 m from bitumic mass production plant	–	734.6	TLC, spectrofluorimetry	[25]
300 m from chemical works	–	515.4	TLC, spectrofluorimetry	[25]
Coking plant, Zabrze town	–	520-1,300	liquid column chromatography, UV spectrophotometry	[22]
Areas under influence of coal mine and power plant "Turów"	–	1.1-580.0	HPLC, UV detection	[32]
Protective zone around bituminous mass production plant - Strupiń Duży, Chełm province	4,000-12,000[e]	–	HPLC, UV detection	[27]
Lagoon soils - Czechowice Oil Refinery	A = 31,140[f]	50-33,100 (A = 3,780)	HPLC, UV detection	[33]
Allotments				
Zabrze town	–	93.6-853.0	liquid column chromatography, UV spectrophotometry	[24]
Kraków city	382-3,411[a]	60-337	liquid column chromatography, UV spectrophotometry	[23]
Bytom - Bobrek town	–	1,000-2,600	HPLC, UV detection	[26]
Agricultural soils				
Bytom-Bobrek town	–	400	HPLC, UV detection	[26]
Mysłowice region	65-2,913 (G = 264)[e]	–	HPLC, UV detection	[17]
Tarnowskie Góry region	62-12,760 (M = 817)[e]	–	HPLC, UV detection	[14]
Zabrze town	705-29,143 (M = 3,716)[c]	41-3,991 (M = 323)	HPCL, UV detection	[16]
Sławków town	217-5,244 (M = 1,392)[c]	9-626 (M =96)	HPLC, UV detection	[16]
Łódź province	60-650 (M = 166)[e]	–	HPLC, UV detection	[18]
Częstochowa provice	M = 800[e]	–	HPLC, UV detection	[19]
The proximity of the industrialised town Puławy - Lublin province	70-2,787 (G = 217)[d]	–	HPLC, UV detection	[31]

1	2	3	4	5
Soil contaminated by mobile sources				
150 m from engine-house	–	8,046	TLC, spectrofluorimetry	[25]
Airport - 2 km from runway	–	456.7	TLC, spectrofluorimetry	[25]
100 m from heavy traffic road 50 m from heawy traffic road	– –	11.4-13.4 19.3-23.6	TLC, spectrofluorimetry	[25]
Road environs	~ 5,000[b]	500-600	liquid column chromatography, UV spectrophotometry	[22]
Vicinity of road (8,000 cars/day)	–	7.1-10.6	Liquid column chromatography, UV spectrophotometry	[34]
Vicinity of road	~ 330-800[g]	36.9-129.3	GC	[35]
Kraków city - heavy traffic roads side	840-2,030[h]	60-250	HPLC, fluorescent detection	[36]
Industrial cities				
Upper Silesian Industrial Region	~ 2,800[b]	400-980	liquid column chromatography, UV spectrophotometry	[22]
Gliwice town (Łabędy district)	1,085.1[b]	150.75	liquid column chromatography, UV spectrophotometry	[30]
Zabrze town	3,357-4,186[i]	250-366	HPLC, UV detection	[37]
Łaziska town	3,615-4,684[i]	266-427	HPLC, UV detection	[37]
Katowice city	11,994-12,194[i]	903-982	HPLC, UV detection	[37]
Bytom town	7,246-7,905[i]	406-455	HPLC, UV detection	[37]

Abbreviations and symbols for Table 1 and 2:

PAH - polycyclic aromatic hydrocarbon
BaP - benzo(a)pyrene
GC - gas chromatography
HPLC - high performance liquid chromatography
TLC - thin layer chromatography
A - arithmetic mean
M - median
G - geometric mean

[a] - 6 PAHs: pyrene, fluoranthene, chrysene, benz(a)anthracene, benzo(a)pyrene, benzo(ghi)perylene

[b] - 10 PAHs: pyrene, fluoranthene, chrysene, benz(a)anthracene, benzo(e)pyrene, benzo(a)pyrene, benzo(ghi)perylene, perylene, anthantrene, anthracene

[c] - 7 PAHs: fluoranthene, pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, indeno(1,2,3-cd)pyrene

[d] - 13 PAHs: fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenz(ah)anthracene, benzo(ghi)perylene, indeno(l,2,3-cd)pyrene

[e] - 16 PAHs: naphtalene, acenaphtylene, acenaphtene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenz(ah)anthracene, benzo(ghi)perylene, indeno(1,2,3-cd)pyrene

[f] - 6 PAHs: fluoranthene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene, indeno(l,2,3-cd)pyrene

[g] - 8 PAHs: fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(a)pyrene, benzo(ghi)perylene, phenanthrene, perylene

[h] - 7 PAHs: phenanthrene, anthracene, pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene

[i] - PAHs: acenaphthene, fluorene, phenanthrene, anthracene, fluranthene, pyrene, benz(a)anthracene, chrysene, benzofluoranthenes, benzo(a)pyrene, dibenz(ah)anthracene, benzo(ghi)perylene, indeno(l,2,3-cd)pyrene

soils effected by emission from anthropogenic sources are up to hundreds times higher than concentrations found in reference areas. The highest sum of PAH concentrations was reported in industrial soils at the lagoon located at the Czechowice Oil Refinery (mean - over 30,000 µg/kg) [33]. The maximum PAH concentration in agricultural soils reached 30,000 µg/kg [16]. In soils of contaminated areas higher contents of BaP were also found. Soil from industrial cities contained BaP levels tenfold higher than soil from reference areas. The maximum BaP concentration (33,100 µg/kg) [33], determined in industrial soil, was up to about one thousand times higher than its natural content. A review of literature allows only a preliminary assessment of soil contamination by PAHs in Poland, and points out that there is a need to continue research on PAH contamination levels in environmental media in Poland, including surface soil. Results of such research would be important in order to better define exposure estimates in the general population and to examine the relationship between levels of PAHs in the environment and the subsequent development of health effects. Especially, more information on PAH contamination of soil and plants grown in contaminated soil would be helpful in indentifying the risk for populations living at industrial sites. Establishing mandatory risk-based soil quality limits for PaHs and standardized analytical methods for their determination could be very useful for land management and would allow risk assessors to determine the potential and actual risk of soil contamination to man or the environment.

Acknowledgements

This work was partly sponsored by the Ministry of Health, Germany (Project: Gzyl J., Kucharski R., Sas-Nowosielska A., Piesak Z., Wcisto E., 1994: Present Methods in Soil Protection in Poland and Comparison with German and International Standards).

References

1. ELLENHORN M.J.. BARCELOUX D.G. Polycyclic Aroma tic Hydrocarbons, in: Ellenhorn M.J. & Barceloux D.G. (Eds): Medical Toxicology: Diagnosis and Treatment of Poisoning. Elsevier, New York, NY, pp 952-954, **1988.**
2. Polynuclear Aromatic Hydrocarbon (PAH) Toxicity. Case Studies in Environmental Medicine. Agency for Toxic Sub stances and Disease Registry, Atlanta, GA, **1993.**
3. Polycyclic Aromatic Hydrocarbons: Evaluation of sources and effects. Washington, D.C.: National Research Council. Natio nal Academy Press, ES/l-ES/7, **1983.**
4. HOLBROOK D.J. Carcinogenesis, in: Haddad L.M. & Win chester J.F. (Eds): Clinical Management of Poisoning and Drug Overdose, 2nd ed, W.B. Saundcrs Co, Philadelphia, PA, pp 508-521, **1990.**
5. PIKE S., Polycyclic Aromatic Hydrocarbons, in: Sullivan J.B. & Krieger G.R. (Eds): Hazardous Materials Toxixology: Cli nical Priciples of Environmental Medicine, Williams & Wilkins, Baltimore, MD, pp 1151-1154, **1992.**
6. Toxicological Profiles for Polycyclic Aromatic Hydrocarbons. Agency for Toxic Substances and Disease Registry. TP-90-20, **1990.**
7. Environment Protection Information and Statistical Papers. Central Statistical Office, Warszawa **1997.**
8. THOMAS W. Accumulation of airborne trace pollutants by arctic plants and soil. Water Sci. Technol. **18,** 47, **1986.**
9. PERWAK J., BYRNE M., COONS S. et al. An exposure and risk assessment for benzo(a)pyrene and other polycyclic aro matic hydrocarbons. Vol. IV. Benzo(a)pyrene, acenaphtylene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene, chrysene, dibenz(a,h)anthracene, and indeno(l,2,3-cd)pyrene. Washington, D.C.: US Environ mental Protection Agency, Office of Water Regulations and Standards. EPA 440/4-85-020-V4, **1982.**
10. SANTODONATO J. Polycyclic organic matter. J. Environ. Pathol. Toxicol. 5, **1, 1981.**
11. STAHL R.G., LIEHR J.G., DAVIS E.M. Characterization of organic compounds in simulated rainfalls from model coal piles. Arch. Environ. Contam. Toxixol. **13,** 179, **1984.**
12. WHITE CM., LEE M.L. Identification and geochemical sig nificance of some aromatic components of coal. Geochim. Cosmochim. Acta. **44,** 1825, **1980.**
13. JONES K.C., STRATFORD J.A., WATERHOUSE K.S., VOGT N.B. Organic contaminants in Welsh soils. Environ. Sci. Technol. **23,** 540, **1989.**
14. MALISZEWSKA-KORDYBACH B. The persistence of poly cyclic hydrocarbons in soils. Qualifying Thesis. Institute of Soil Science and Plant Cultivation, Pulawy **1993** (in Polish).
15. van de PLASSCHE E., BASHKIN V., GUARDANS R., JO HANSSON K., VRUBEL J. Ah overview of critical limits for heavy metals and POPs. Background Document for the Work shop on Critical Limits and Effects-based Approaches for He avy Metals and Persistent Organic Pollutants. UN ECE Con vention on Long-Range Transboundary Air Pollution. Task Force on Mapping. Bad Harzburg, Germany, **1997.**
16. DZIEWIECKA B., LUKASIK K., WCISLO E. A method for evaluation of agricultural areas contaminated with polycyclic aromatic hydrocarbons. Internal Report. Institute for Ecology of Industrial Areas, Katowice **1993** (in Polish).
17. MALISZEWSKA-KORDYBACH B., OLESZEK W. Quanti tative determination of polycyclic aromatic hydrocarbons in the cultivated soils of the Myslowice municipality by means of HPLC. Proceedings for XVII^{lh} Scientific Seminar: Chroma tographic methods for determintion of organic compounds, Katowice **1993** (in Polish).
18. KABATA-PENDIAS A., PIOTROWSKA M., MOTOWICKA-TERELAK T., MALISZEWSKA-KORDYBACH B., FILIPIAK K., KRAKOWIAK A., PIETRUCH CZ. Guidelines for assessment of soil contamination - heavy metals, sulphur and PAHs. Biblioteka Monitoringu Srodowiska, Warszawa **1995** (in Polish).
19. TERELAK H., PIOTROWSKA M, MOTOWICKA-TERELAK T., STUCZYNSKI T., MALISZEWSKA-KORDY BACH B., BUDZYNSKA K., PIETRUCH CZ. Ecological status assessment of agricultural lands in the Czestochowa province. Internal Report. Institute of Soil Science and Plant Cultivation, Pulawy **1995** (in Polish).
20. MALISZEWSKA-KORDYBACH B. Soil contamination with organic compounds in Poland - on the basis of polycyclic aromatic hydrocarbons. Proceedings of the Conference: Prote ction and use of agricultural lands in Poland. Institute of Soil Science and Plant Cultivation, Pulawy **1997** (in Polish).
21. SIEWNIAK M. Studies on air and soil pollution in the sur roundings of petrochemical complex in Plock. Zeszyty Naukowe Szkoly Glownej Gospodarstwa Wiejskiego Akademii Rolniczej - Warszawa, **53,** 1, **1975** (in Polish).

22. MASLOWSKI J. Investigation on the dynamics of benzo(a)pyrene concentrations in soil. D.Sc Thesis. Institute for Ecology of Industrial Areas, Katowice **1981** (in Polish).
23. MIKOLAJEK A., BRANDYS J., LIPNIAK M. Polycyclic aromatic Hydrocarbons (PAHs) in the soil of allotments in the city of Cracow. Roczniki PZH, **XXXVI(2),** 125, **1985** (in Polish).
24. MARCHWINSKA E., KUCHARSKI R., GZYL J., KARPINSKA B., LEWANDOWSKI W., SKIBA K., NOWINSKA Z., JAROSZ W., PIESAK Z. Contamination of vegetables in al lotments of the Katowice provice. Internal Report. Institute for Ecology of Industrial Areas, Katowice **1983** (in Polish).
25. GORSKA E., GORSKI T. Benzo(a)pyrene in the soil and potatoes. Bromatologia i Chemia Toksykologiczna, **XIII (3),** 257, **1980** (in Polish).
26. WYZGOLIK B., SYPIEN-WYZGOLIK J., MANKO T. Ac cumulation of polycyclic aromatic hydrocarbons in soils in the vicinity of coking plants. Proceedings of the Scientific Con ference: The effects of coking industry impact on the environ ment. Polish Academy of Sciences. Institute of Environmental Engineering. Friedrich Ebert Fundation, Zabrze **1992** (in Po lish).
27. MAL1SZEWSKA-KORDYBACH B., OLESZEK W., STUCZYNSKI T. HPLC applied for the determination of polycyc lic aromatic hydrocarbons (PAHs) in soils on the example of soils from the protective zone around the bituminous mass production plant. Proceedings of XVI"[1] Scientific Seminar: Chromatographic methods for determination of organic com pounds, Katowice **1992** (in Polish).
28. Guidance for the assessment of soil and groundwater contami nation with petroleum products and other chemical substances in remediation process. The Polish State Environmental Prote ction Inspectorate, Warszawa **1994** (in Polish).
29. VROM, Leidraad Bodembescherming. Afl. 10, The Nether lands **1995.**
30. DUTKIEWICZ T., LEBEK G., MASLOWSKI J., MIELZYNSKA D., RYBORZ S. Polycyclic aromatic hydrocarbons in the environment. State Scientific Publishers, Warszawa **1988** (in Polish).
31. MALISZEWSA-KORDYBACH B., SMERCZAK B. The content of polycyclic aromatic hydrocarbons (PAH) in agricu ltural soils in Lublin district. Roczniki Gleboznawcze. T. **XL VIII (1-2), 95, 1997** (in Polish).
32. TRACZEWSKA T., PAWLACZYK-SZPILOWA M. Deter mination of polycyclic aromatic hydrocarbons (PAHs) in the region of the "Turow" power plant. Czlowiek. Populacja. Srodowisko. Dolnosla.skie Centrum Diagnostyki Medycznej "Dolmed", 4, (23), Wroclaw **1987** (in Polish).
33. WCISLO E., KUPERBERG M., TEAF C. Risk assessment for the Czechowice Oil Refinery Lagoons. Internal Report. Insti tute for Ecology of Industrial Areas, Katowice **1997.**
34. DZIEWIECKA B., WCISLO E., BARON R. Evaluation of air and soil contamination with polycyclic aromatic hydrocarbons in the vicinity of roads. Internal Report. Institute for Ecology of Industrial Areas, Katowice **1989** (in Polish).
35. LIPNIAK M., ZASTE.PA P., GAWLIK M. Concentration of some polycyclic aromatic hydrocarbons (PAHs) and metals in the soils in Cracow. Roczn. PZH, **XLV (1-2),** 97, **1994** (in Polish).
36. JUSZKIEWICZ A., MEUS M. Soil contamination with poly cyclic aromatic hydrocarbons in the vivinity of heavy traffic roads. Proceedings of the Discussion Forum: Problems with Polluted Areas in Central and Eastern Europe. Risk Abate ment Center for Central and Eastern Europe, Katowice **1998** (in Polish).
37. BODZEK D., LUKS-BETLEJ K., MALISZEWSKA-KORDYBACH B., OLESZEK W. A preliminary studies on the effect of air pollution on the contamination of the soil by polycyclic aromatic hydrocarbons. Org. Geochemistry, Poster session of the 16'" International Meeting on Organic Geoche mistry, Stavanger, p. 691, **1993.**