Contaminated Urban Soils

ENVIRONMENTAL POLLUTION

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To my father
who always asked
whether I was getting on well with writing of the book
and who died
shortly after it was completed

"In the fury of the moment I can see Master's hand
in every leaf that trembles, in every grain of sand."
B. Dylan

Foreword

With more than 50% of the world's population already living in towns and cities, migration from rural areas continuing at an alarming rate in developing countries and suburbanisation using more and more land in developed countries, the urban environment has become supremely important with regard to human health and wellbeing. For centuries, urbanisation has caused relatively low level soil contamination mainly by various wastes. However, from the time of the Industrial Revolution onwards, both the scale of urban development and the degree of soil contamination rapidly increased and involved an ever widening spectrum of contaminants. With constraints on the supply of land for new urban development in many countries, it is becoming increasingly necessary to re-use previously developed (brownfield) sites and to deal with their accompanying suites of contaminants. It is therefore essential to fully understand the diversity and properties of urban soils, to assess the possible risks from the contaminants they contain and devise ways of cleaning up sites and/or minimizing hazards.

The author, Helmut Meuser, is Professor of Soil Protection and Soil Clean-up at the University of Applied Sciences, Osnabrück and is one of Europe's foremost experts on contamination from technogenic materials in urban soils. He has many years' experience of research in Berlin, Essen, Osnabrück, other regions of Germany, and several other countries. In this book he has applied his wide-ranging experience to provide a comprehensive review of the subject of contaminated urban soils. One of the book's great strengths is the inclusion of data and other information from studies in urban areas across the world with widely differing climatic conditions, soils and types of industrial and residential development. Commencing with a brief consideration of the geographical basics of urbanization, he goes on to cover in detail the causes and sources of the different types of contaminants found in the soils of towns and cities. These include inputs of heavy metals and organic pollutants in dusts arising from industrial emissions, roads and railways, construction sites, excavations for pipelines, river flooding, horticultural and agricultural sources, derelict land, accident sites and various types of fill.

Particular emphasis is placed on man-made (or 'technogenic') substrates which, together with dust deposits are the most important sources of contaminants in the urban environment. These technogenic materials include construction debris, demolition waste (such as concrete, brick, tarmac, steel), slags, coal ash, mining wastes, municipal solid wastes and sludges and are dealt with in considerable detail. A key for the identification of these materials in field excavations is provided which will be particularly helpful for surveyors, planners, construction engineers and environmental health specialists in assessing brownfield sites. The characteristics and contamination potential of these technogenic materials are considered in detail and followed by a classification of 'anthropogenic' soils. These comprise the 'Anthrosols' developed from cultivated natural soils and 'Technosols' formed on deposited materials. Having discussed the origins and classification of these urban soils and their constituents, the book then progresses goes to the main physical and chemical properties of soils which influence their contamination potential, especially the mobility and bioavailability of heavy metals and organic pollutants. These physical properties include surface sealing, erosion and deflation, compaction, skeleton enrichment, movement of the water table and subsidence. The chemical properties include total concentrations of contaminants, pH, carbon content and biological activity, texture and binding compounds and nutrient materials. Pedogenic processes such as humus formation, pedoturbation, weathering, aggregation and redox (gleying) are also considered in the context of their effects on the behaviour of the range of contaminants.

The book concludes with a major chapter on the assessment of the hazards posed by urban soils and a short, final chapter on the outlook for the future for contaminated urban soils. One of the most important parts of the hazard assessment chapter is the range of soil quality standards in use in different countries and their respective cut-off values for the safe maximum concentrations of many of the most important contaminants. These provide a valuable guide to the concentration levels which are considered hazardous for certain urban land uses and in some countries these are the basis of statutory clean-up regulations. It is likely that these quality standards will be expanded to include more potentially hazardous substances and that the safe maximum levels will be amended in the light of developments in toxicological research. The outlook for the future for contaminated urban soils chapter stresses the need for more attention to be paid to the subject, especially as the contamination potential of urban land increases with time and with the accelerating pace of urbanisation. The greatest contamination risks lie with derelict industrial sites and technogenic substrates, but garden and allotment soils (Anthrosols) used for growing vegetables can also pose a risk to health where they have been contaminated by the addition of various materials including the long-term deposition of pollutant-containing dusts.

This book provides a very thorough and concise review of contaminated urban soils. With its international scope based on examples from the USA, China, India, Germany, the Netherlands, the United Kingdom, France, and other countries it will be particularly relevant to professionals involved in urban planning, construction and environmental health in these and other countries. Likewise, it has also been designed to be a state of the art textbook for use in advanced university courses around the world in Environmental Science, Urban Geography, Landscape Architecture, Waste Management, Ecology and Soil Science. This one volume contains material which is otherwise only partially covered in several existing textbooks and even then not in such a comprehensive way and so it is highly recommended to both students and lecturers as well as practitioners dealing with contaminated land.

February 2010 Brian J. Alloway

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Contents

Abbreviations

AC	air capacity
ADI	acceptable daily intake
Ag	silver
AMD	acid mine drainage
As	arsenic
ASM	artisinal and small scale mine
Au	gold
AWC	available water capacity
Ba	barium
BCR	Community Bureau of Reference Protocol
Be	beryllium
BTEX	benzene, toluene, ethylbenzene, xylene
Br	bromide
C	carbon
Ca	calcium
Cd	cadmium
CEC	cation exchange capacity
CEC_{eff}	effective cation exchange capacity
CEC_{pot}	potential cation exchange capacity
Cl	chloride
CN	cyanide
Co	cobalt
Cr	chromium
Cs	caesium
Cu	copper
DDT	dichlorodiphenyltrichloroethane
DHA	dehydrogenase acitvity
DM	dry matter
DOC	dissolved organic carbon
DTPA	diethylenetriaminepentaacetic acid
EC	electrical conductivity
EDTA	ethylenediaminetetraacetic acid
Eh	rodox potential

EPA	Environmental Protection Agency (USA)
F	fluoride
Fe	iron
H	hydrogen
HCB	hexachlorobenzene
Hg	mercury
I	iodine
K	potassium
K_{oc}	Freundlich constant
Mg	magnesium
Mn	manganese
MSW	municipal solid waste
N	nitrogen
Na	sodium
Ni	nickel
O	oxygen
P	phosphorus
PAH	polycyclic aromatic hydrocarbons
PAH_{EPA}	polycyclic aromatic hydrocarbons (EPA list)
Pb	lead
PCB	polychlorinated biphenyles
PCDD	polychlorinated dibenzodioxins
PCDF	polychlorinated dibenzofurans
PCE	perchloroethylene
PCP	pentachlorophenol
PM	periculate matter
Pt	platinium
qCO_2	metabolic quotient
Ra	radon
Rh	rhodium
S	sulfur
Sb	antimony
Se	selenium
SIR	substrate-induced respiration
Sn	tin
TE	toxicity equivalent
Te	technetium
TC	total carbon
TCDD	tetrachlorodibenzodioxin
TCE	tetrachloroethylene
TIC	total inorganic carbon
TOC	total organic carbon
Tl	thallium
TPH	total petroleum hydrocarbons
TPV	total pore volume

V	vanadium
VHC	volatile organic hydrocarbons
WRB	World Reference Base
Zn	zinc

Chapter 1
Introduction

Many publications which deal with soils in urban environments begin with sentences such as "there is still very little knowledge about soils of the urban environment "or" up to now soil sciences have dealt almost exclusively with soils in agricultural and forested environments." Is this true?

Without a doubt the branch urban soil sciences is still very young compared to the classical soil sciences which traditionally deal with the rural environment. Basically municipal svoils have only been a topic since the middle of the 1970s, particularly in the USA, Germany and Russia. For example, at the Conference of the International Society of Soil Sciences (ISSS) in 1986 in Germany municipal soils in the area of Berlin (West) were presented in detail (Blume 1986). The first well-founded books on this topic dated from the period of the early 1990s, i.e. the books of Bullock and Gregory (1991), which focussed on anthropogenically disturbed soils in United Kingdom and of Craul (1992), which centred on municipal soils in cities in the USA. In the 1990s numerous books of international authors appeared. Most of these were published in the respective national language (Hiller and Meuser 1998; Kollender-Szych et al. 2008).

Generally speaking, the proportion of publications on soils used for urban, industrial and mining purposes has increased in trade journals. This is a consequence of a growing number of research projects in different regions of the world, which varied in their motivation to make urban soils their subject. The ever pressing issues of urbanisation, of land use but, above all, of contamination pushed urban environments increasingly into the focus of science. Working groups formed in various urban agglomerations such as in the Ruhr district (Germany) and in Moscow (Russia), which dealt intensively with the urban locations whose characteristics deviated so strongly from soils of rural environments. Increasing attention was given to urban soils in countries which, by tradition, had experience in soil science research (e.g. in France, in Poland, in Russia, in the USA) and in countries which made the recording and assessment of contaminated locations the focal point (e.g. in Germany and The Netherlands).

We owe it to the initiative of Burghardt (2000) that the first international conference of a newly formed working group of the ISSS, which was devoted to soils of urban and industrial environments and of areas used for traffic, mining and

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military purposes (SUITMA), took place in Essen (Germany) in the year 2000. Further conferences in Nancy (France) in 2003, Cairo (Egypt) in 2005, Nanjing (China) in 2007 and New York (USA) in 2009 followed this one. These conferences documented in an impressive way in how many countries research into urban soils has been carried out. In the meantime investigations into urban soils are being carried out in numerous urban agglomerations. More recently, this is also taking place in developing countries such as China.

Today it can thus be stated that in the meantime a lot of knowledge has been gained on urban soils. The aim of this book is to document the status of the knowledge on hand and to supplement this with the results of the author's own long-term studies in order to provide a comprehensive picture of the physical-chemical qualities of urban soils and, in particular, of their contamination.

In order to place the trigger of the increasing problems in urban environments, the ongoing urbanisation, into its overall historical and economic context, the book begins with a short outline of the basic geographic elements of the urbanisation problem (chapter 2). Chapter 3 deals intensively with the manifold causes of contaminated urban soils such as the influence of dust deposition through industry and traffic, use of fertiliser and sludge but also the influence of former industrial locations and depositions of contaminated materials. The latter aspect leads to the contamination potential of technogenic substrates such as construction debris, slag, ash, garbage, mining waste and various sludges. In Chapter 4 light is shed on these. The aim of the determination key integrated into this Chapter is to give the soil scientists the possibility to recognise such materials when working on site. The different urban soils are presented by means of examples, separated according to Anthrosols and Technosols and assessed with regard to their soil-physical and soil-chemical properties (Chapter 5). The extent and effect of the contamination are strongly influenced by physical and chemical factors. For this reason in Chapter 6 physical characteristics of urban soils such as sealing, compaction and deflation and also chemical characteristics such as pH value, carbon content and chemical binding forms are presented and discussed in relation to the contamination problem in each case. In addition, the nutrient relationships and pedogenesis issues of urban soils are taken up. Chapter 7 deals with the assessment of urban soils. At first, approaches such as the assessment of soil functions, which is presented by means of selected partial functions, are dealt with. However, the assessment of contaminated urban soils is usually carried out on the basis of limit values. For this reason, after a description of the different relevant contaminant pathways, quality standard catalogues and guidelines from numerous countries are presented and discussed comparatively. An outlook including future scenarios complete the book in Chapter 8.

References

Blume, H.-P. (Ed.). (1986). *Landscapes, soils and land use of the Federal Republic of Germany.* Guidebook Tour G and H: Soilscape of Berlin(West) – natural and anthropogenic soils and

environmental problems in the metropolitan area. Hamburg, Germany: XIII Congress of the International Society of Soil Science.
Bullock, P., & Gregory, P. J. (Eds.). (1991). *Soils in the urban environment*. Oxford: Blackwell.
Burghardt, W. (2000). *First international conference on soils of urban, industrial, traffic and mining areas. Preface*. Proceeding Vol. 1. Paper presented at 1st international conference on Soils of Urban, Industrial, Traffic and Mining Areas, Essen, Germany.
Craul, P. J. (1992). *Urban soil in landscape design*. New York: Wiley.
Hiller, D. A., & Meuser, H. (1998). *Urban soils.* Berlin: Springer (in German).
Kollender-Szych, A., Niedzwiecki, E., & Malinowski, R. (2008). *Urban soils (Gleby miejskie).* Academia Rolnicza W Szczecinie, Szczecin (in Polish).

Chapter 2
Geographical Basics

Abstract For a better understanding of the current existence of contaminated urban soils some geographical aspects are initially introduced after a definition of the most important terms of reference for this book. The historical development of city growth and its relation to soil contamination is described taking particular consideration of soil contamination of ancient times and the influence of the Industrial Revolution in Europe. Furthermore, the process of urbanization in less developed and developing countries in Africa and Asia and its impact on soil losses and degradation forms a part of this chapter. The theoretical scheme of city structure and urban land-use types in association with their contamination pattern are also points of consideration.

Keywords City structure • Historical development • Industrial revolution • Urbanization • Urban land-use types • Urban sprawl

2.1 Definitions

Soils are defined as dynamic natural bodies composed of mineral and organic solids, gases, liquids and living organisms which have properties resulting from integrated effects of climate, organisms, parent material and topography over periods of time and which can serve as a medium for plant growth (Brady and Weil 2008).

Urban soils are soils in urban and suburban areas consisting of anthropogenic deposits with natural (mineral, organic) and technogenic materials, formed and modified by cutting, filling, mixing, intrusion of liquids and gases, sealing and contamination (Burghardt 1994; Stroganova et al. 1998). According to the definition urban soils are related to specific areas, namely urban and suburban areas. In this sense, industrial, traffic and mining areas may also belong to the areas of concern. Currently, the abbreviation SUITMA for Soils of Urban, Industrial, Traffic, Mining and Military Areas is frequently used.

Contaminated or polluted soils are soils with physical, chemical and biological materials that can potentially have adverse impacts on human health or environmental

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media. The materials must be undesirable substances which are normally not or to a less extent present in the environmental media like soils (Asante-Duah 1996). The terms ‘contaminated’ and ‘polluted’ always involve the assessment of measured concentrations in comparison with either empirical determined thresholds or with background values resulting from naturally occurring concentrations (bedrock concentrations) and non-site-related, ubiquitous concentrations (see Section 3.2).

In this book the term ‘contaminated’ will not relate to thresholds and man-made quality standards, since the defined thresholds and quality standards applied by environmental agencies vary from country to country (see Section 7.4.2). The non-site related concentrations do not seem to be a suitable level either due to the dependence on site factors such as topography, climate, etc. Alternatively, naturally occurring concentrations based on the continental earth crust could be taken, but in the case of exceeded values an adverse impact on human health is not inevitably present.

In urban geography city size classification includes different definition approaches. Based on the United Nations definition, inhabitants of towns range between 10,000 and 100,000 people, in cities a population of 100,000 to 1 million is supposed. If the population exceeds 1 million inhabitants and the population density is higher than 2,000 inhabitants km^{-2}, it is called a metropolis (UN 1993). The terms metropolis, metropolitan area and agglomeration are used synonymously. In this book the terms agglomeration and (big) city are mostly used but not clearly separated.

A metropolis of global scale reveals particular characteristics such as presence of international authorities, economic institutions and private enterprises, broadcasting houses, publishing houses and telecommunication centres of international reputation, as well as famous cultural buildings like theatres and museums, beneficial traffic connections like international airports or big harbours. Moreover, such cities are globally well-known and they have frequently capital status. It should be noted that the boundaries of all areas defined above are politically determined and can subsequently change with reference to urban expansion.

The increase in share of urban population in relation to the total population in the area of concern is termed urbanisation. It is characterized by an increase in the amount of cities, in the population density and in rural-to-city migration. It leads to spatial expansion of city areas and the establishment of agglomerations.

2.2 Historical Development of Urbanization

In Europe and North America the process of intensified urbanization started during the Industrial Revolution. Inventions and innovations in originally agriculture-based countries led to a conversion process from the primary sector to the secondary industrial sector. The possibility to smelt iron and other ores with hard coal instead of charcoal, the invention of blast furnaces and other heavy industry equipment powered by steam machines initiated a complete transformation of the industrial status quo. Mechanization in factories and general acceleration of production processes resulted in an increase in produced goods but also in an increasing demand on resources and employees. The coal mining and metal processing industries expanded and population migration into urban and industrial areas occurred.

The process started in the late eighteenth century, firstly in the United Kingdom. In 1850 labour forces in the industry sector already made up 48% of the population. In the nineteenth century countries such as France, Germany and Belgium followed. Between 1870 and 1914 the era of Industrial Revolution can be understood, if the rapid increase of coal and steel production is taken into consideration (Kiesewetter 2006). For instance, in the United Kingdom in 1870 125,500 t of hard and lignite coal were mined, in 1913 292,000 t were registered. In Germany coal mining resulted in 26,400 t in 1870, 43 years later 190,100 t. Between 1860 and 1914 steel production in the United Kingdom rose from 150,000 to 7,790,000 t and in Germany from 50,000 to 18,960,000 t (Table 2.1). In 1900 in Western European countries the labour force of the industrial sector ranged from 29% to 39% of the population. Some decades later in North America same tendencies were observed. To a less extent in Eastern European countries and in some Asian countries a comparable historical development took place.

After the first World War the tertiary sector, the services sector, became more significant, in particular in European and North American countries. Ultimately, in 1990 71% of the labour force was employed in the tertiary sector in USA, 69% in United Kingdom, 64% in France, and 57% in Germany. This sector was strongly connected with improved living standards and a wasteful lifestyle, causing more land consumption particularly in the city periphery. Both the development of industry during the epoch of the Industrial Revolution and the development of the services sector led to increasing urbanization in the developed countries. In the former socialist countries in Europe the development of the tertiary sector started with some delay, but the tendencies were rather similar (Kiesewetter 2006).

Table 2.1 Development of coal production from 1870 to 2005 and steel production from 1860 to 2007 in different European countries in 1,000 t (Data from different sources, e.g. Kiesewetter 2006, UN 2009, European Navigator 2006, UK Steel 2008)

	Coal production					
Country	1870	1890	1913	1960	1992	2005
Belgium	13,700	20,400	24,400	27,100	218	uv
France	12,200	25,100	37,600	57,700	uv	uv
Germany	26,400	70,200	190,100	132,600	72,200	28,000
United Kingdom	125,500	185,500	292,000	196,700	84,900	20,500
	Steel production					
Country	1860	1890	1913	1958	2007	
Belgium	3	240	2,470	6,007	10,700	
France	42	570	4,690	14,633	19,300	
Germany	50	2,260	18,960	22,785	48,600	
United Kingdom	150	3,640	7,790	uv	14,300	

uv = unknown values

The growth of area occupied by the city can be historically recognized in the capital of Russia, Moscow, with 10,500,000 inhabitants. In 1495 the town covered the area within the Kremlin walls, an area of 0.2 km^2, only. The growth slowly continued in the Middle Ages, achieving 18.7 km^2 between 1630 and 1640. Just before the Industrial Revolution in 1864 the territory of Moscow covered 72.1 km^2. Rapid growth took place during the following decades and when the Moscow Ring Railroad was completely finished in 1917 the territory made up 212.1 km^2. At the end of the 1960s 356.7 km^2 were occupied by the agglomeration, continuing urban sprawl. Today, the modern city of Moscow covers an area of 1,091.0 km^2.

Intensive soil surveys corresponded with the historical development. It was almost impossible to detect the original soil of Moscow, mainly soddy-podsolic soils and glacial, glaciofluvial and mantle deposits, in the upper horizons. Above the buried natural soil deposited material with a thickness of approximately 2 m and composed of clayey texture with a high humus content and timber and saw residues was present. This dates back to the twelfth to sixteenth century, when the city was constructed of wood. This layer was overlaid by another anthropogenic horizon which was mainly sandy and poor in humus that was enriched with construction rubble such as bricks and stones. The layer relates to the seventeenth to nineteenth century, when intensive construction activities occurred. Finally, a modern cultural horizon containing modern construction debris like asphalt and concrete covered the last one. The anthropogenically deposited layers ranged in ancient Moscow between 2 and 3 m, in wet depressions it was possible to find thicknesses of 7–10 m and the maximum thickness was 20 m.

Research projects in downtown Moscow demonstrated that a historical contamination has to be taken into account when assessing the current contamination level. In deep soil layers related to the fifteenth to nineteenth centuries an accumulation of trace elements such as arsenic, copper, lead, and zinc has been found, reflecting metal working, leather treatment and other commercial activities of former times. Copper, for instance, ranged between 43 and 359 mg kg^{-1}, lead between 13 and 265 mg kg^{-1}, and zinc between 76 and 265 mg kg^{-1}, exceeding clearly the background levels. Table 2.2 presents a soil profile considering the depth 0–220 cm that was possible to relate to the period of time in which the artificial deposits happened. In addition, the upper layer seemed to be strongly influenced, resulting from current contamination sources.

The relatively high contaminant level is confirmed when considering areas of long-term anthropogenic use. In the catchment area of the Russian capital Moscow some areas established by mankind for a long time have been analyzed in detail. For example, the Rozhdestvenskiy Convent, established in 1386, supplied very high values in subsoils (Pb: 33–373 mg kg^{-1}, Zn: 55–492 mg kg^{-1}). It was possible to detect similar results in the Zachat'evskiy Convent, established in 1623 (Pb: 40–873 mg kg^{-1}, Zn: 36–597 mg kg^{-1}) as well as the Yusupovskiy Park, established in the seventeenth century (Pb: 131–245 mg kg^{-1}, Zn: 41–151 mg kg^{-1}). Obviously, lead and zinc are typical parameters, proving the long-term human influence, while Cd, Cu, Co, Ni, and V revealed low results at the same sites (Stroganova et al. 1998).

Table 2.2 Heavy metal content (mg kg^{-1}) in deposited, cultural layers of a soil profile in downtown Moscow associated with the period of time of depositing (Data from Stroganova et al. 1998)

Depth, cm	Century	As, mg kg^{-1}	Cr, mg kg^{-1}	Cu, mg kg^{-1}	Ni, mg kg^{-1}	Pb, mg kg^{-1}	Zn, mg kg^{-1}
0–25	Beginning of the 20th	74	98	197	24	1,321	1,552
25–70	18th–19th	36	90	149	29	242	192
70–100	18th	16	61	88	24	103	151
100–115	18th	13	50	64	12	146	128
115–145	17th–18th	25	92	43	23	152	107
145–160	17th	33	92	80	28	265	256
160–170	17th	16	83	83	35	55	134
170–195	17th	18	91	81	36	54	104
195–220	16th	15	81	359	29	89	398

Metal extraction method: HNO_3

The described context that soils function as records of urban development was also found outside of Europe. In Nanjing (China) with a population of 5,300,000 soils were sampled at every 5 cm for heavy metal determination purposes. Charcoal from several layers was found and dated using ^{14}C to recognize archaeological horizons termed cultural layers. All cultural layers started about 1,700 years ago above the original loess indicated high concentrations of Cu, Pb and Zn but not of Co, Cr and Ni. The lead content varied from 100 mg kg^{-1} to more than 2,000 mg kg^{-1}, Cu varied from about 100 mg kg^{-1} to more than 5,000 mg kg^{-1}, Zn from 70 mg kg^{-1} to more than 2,000 mg kg^{-1}. There were several historical periods in which heavy metals accumulated, such as ancient ore smelting and use of materials containing heavy metals for handicraft manufacture. It was concluded that the source of Pb in cultural layers might come from lead ores of former times. Similar interpretation was made related to copper and zinc (Zhang et al. 2005a).

In the vicinity of areas with long-term metal mining processes the accumulation of metals in soils can reach the highest levels by far. Such historical accumulation areas are, for example, in Eastern Turkey (Ergani Maden Copper Mine close to the river Tigris), where copper was extracted 9,000 years ago. Other examples of ancient mining activities like the copper ore mining and smelting regions of Iran, Iraq and Israel were reported. In the Bronze Age, 4,600 years ago, tin and copper were extracted and smelted together with charcoal. Later on, 2,000 years ago, iron smelting became widespread. The metal extraction activities reached their peak in Roman times in the form of weapon manufacturing (bronze, iron) as well as the production of more peaceful things such as ornaments (copper, gold, silver), plumbing and coffins (lead), coinage (bronze), etc. Moreover, some minerals were used as pigments in order to colour ceramics and glass (cobalt, nickel). The soil contamination derived from historical ore mining processes, however, was usually limited to the small-scale sites of extraction and processing (Evans 2005).

The different sources of contaminants which are deposited onto the soil surface have an impact on the long-term contaminant uptake of long living plants like old trees. Accordingly, trees can be witnesses of historical development as well. The lead content in wood of the American beech trees in Virginia, USA showed an increasing trend, in particular a sharp increase in the late 1800th century, when the industrialization began (increase from less than 100 to more than 450 μg kg^{-1}). The high level continued, indicating a visible second peak in the 1950s (300–400 μg kg^{-1}) when leaded petrol was burnt in vehicles. After the 1990s with the beginning of unleaded gasoline utilization, the Pb values in the wood of the trees were reduced again reaching values less than 300 μg kg^{-1} (Pierzynski et al. 2005).

Another witness of historical development is the type and distribution of anthropogenic artefacts present in soil profiles. Human behaviour has left its fingerprint in urban history, and in turn contamination. Beginning in the Middle Ages inhabitants of urban areas threw organic garbage, litter and other organic materials away next to their houses. This permanent activity produced waste materials without any consideration of sanitation. Organic material was incorporated into the soil, together with some mineral artefacts.

The production of urban wastes changed drastically in the eighteenth century, the beginning of the period of the Industrial Revolution. Industrial waste was increasingly thrown away, often causing soil contamination based on the kind of material such as ash and slag. The opportunity to use hard coal for smelting iron led to an expansion of iron production for domestic articles and particularly for machinery and manufacture. The mechanized production opened the way for the establishment of large-scale factories, which were built first in the United Kingdom and some years or decades later in many countries all over the world. The flourishing industry needed more and more metals extracted, resulting in increasing prospecting for mineral resources. Hence, the exploitation was intensified, especially in the nineteenth century, causing large devastated areas in the developing countries like Belgium, France, Germany and the United Kingdom, on the one hand, and increasing worldwide exploitation in countries which supply raw materials, on the other hand. Consequently, soil contamination caused by metal extraction took place in the developing countries to a greater extent and, additionally, in, for instance, African countries whose economies were originally based on agriculture (and still are today) (Evans 2005).

Increasing urbanisation since the Industrial Revolution changed the residential areas considerably as well. Construction operations led to the production of construction debris and wastes that were deposited close to the buildings after the humic topsoil had been excavated. The stockpiled topsoil, however, returned after building operations. In city areas only little natural soil remained, instead mixtures of soil and construction debris were refilled. If the area was not redeveloped well, apart from construction rubble foundations, concrete floors and underground cellars can be discovered as well, leading to rehabilitation difficulties later on (see Section 5.4.1). Industrial wastes in urban areas have been masked by distinct anthropogenic influences of the period after the First World War. The frequent land use changes associated with excavation and fill operations altered the soil below the surface time and time again.

Long-term urban utilization led to increasing contaminant values. Different contaminant inputs such as waste additions, long-term application of ash and

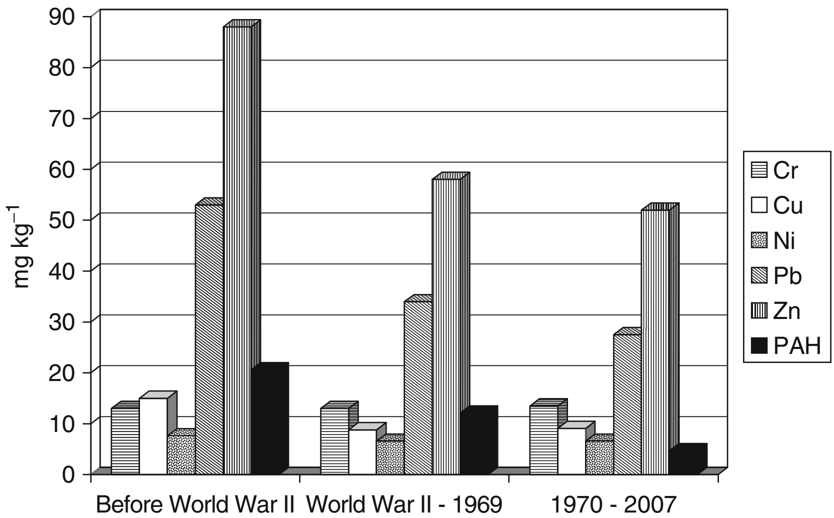

Fig. 2.1 Topsoil concentration of some contaminants related to the age of buildings constructed nearby in Münster, Germany. Investigated areas of different land-use types: 285. Sampling depth: ranging from 0–10 to 0–35 cm. Metal extraction method: aqua regia

problematic organic manures and the atmospheric deposition left their fingerprints in the long course of time. In the past, it was documented that the lead concentrations in garden topsoils increased with the age of the houses present. In Münster (Germany) with its population of 270,000 soil contamination maps were produced taking the age of residential and industrial areas into consideration. The city is designated as an administrative area and to a less extent as an industrially influenced city but intensive vehicle traffic and emissions of some industrial complexes may enhance the topsoil concentration in any case. Residential areas were separated into three classes, firstly constructive phases before the Second World War, secondly between the Second World War and 1969 and thirdly between 1970 and the realization of the research project in 2007. For some parameters such as Pb and Zn the contaminant concentration was related to the age of the building construction phase (Fig. 2.1). Some elements did not react or only to a very small extent (e.g. Cr, Ni). Organic pollutants like the Polycyclic Aromatic Hydrocarbons (PAH_{EPA}) tended to reveal a slight dependence on the period of construction.

2.3 Present Urbanization Process

The population living in an urban environment (cities, agglomerations) shows a tendency to grow and simultaneously the degree of urbanisation is becoming higher. In general, the degree of urbanization exhibits extreme differences. In the developed countries such as France, Germany, United Kingdom and USA it is higher than 70%, in less developed and developing countries such as Kenya and India the values