World Reference Base for Soil Resources (Subject Editor: Stefan Norra)

Classification of Urban and Industrial Soils in the World Reference Base for Soil Resources

David G. Rossiter

International Institute for Geo-information Science & Earth Observation (ITC), P.O. Box 6, 7500AA Enschede, The Netherlands (rossiter@itc.nl)

DOI: http://dx.doi.org/10.1065/jss2007.02.208

Please cite this paper as: Rossiter DG (2007): Classification of Urban and Industrial Soils in the World Reference Base for Soil Resources. J Soils Sediments, DOI: http://dx.doi.org/10.1065/jss2007.02.208

Abstract

Background, Aims, and Scope. Historically, built areas were ignored in soil mapping and in studies of soil formation and behaviour. It is now recognized that these areas, and therefore their soils, are of prime importance to human populations. Another trend is the large increase in reclaimed lands and new uses for old industrial areas. In several countries there are active projects to map such areas, either with locally-developed classification systems or ad-hoc names. Soil classification gives unique and reproducible names to soil individuals, thereby facilitating correlation of soil studies; this should be possible also for urban soils. The World Reference Base for Soil Resources (WRB) is the soil classification system endorsed by the International Union of Soil Science (IUSS). The 2006 edition has important enhancements which allow urban and industrial soils to be described and mapped, most notably a new reference group, the Technosols.

Main Features. Urban soils are first defined, followed by the philosophical basis of soil classification in general and the WRB in particular. WRB 2006 added a new Technosols reference soil group for soils whose properties and function are dominated by technical human activity as evidenced by either a substantial presence of artefacts, or an impermeable constructed geomembrane, or technic hard rock. Technosols are one of Ekranic, Linic, Urbic, Spolic or Garbic; further qualifiers are added to show intergrades to other groups as well as specific soil properties. Soils from fill are recognized as Transportic Regosols or Arenosols. Toxic soils are specifically recognized by a qualifier.

Discussion. The limit between Technosols and other groups may be difficult to determine, because of the requirement that the technic nature dominate any subsequent pedogenesis.

Recommendations and Perspectives. The WRB should certainly be used in all urban soil studies to facilitate communication and correlation of results. In the period leading up to the next revision in 2010, the quantitative results from urban soil studies should be used to refine class definitions.

Keywords: Soil classification; Technosols; urban soils; World Reference Base for Soil Resources (WRB)

1 Urban soils

The term 'urban soils' is here used as a shorthand for all soils occurring in urban and industrial areas [1]; it is thus a discussion term rather than a classification. All soils in urban areas affect the life of the city. In turn all soils in the city are more-or-less affected by human intervention. At one extreme are anthropogenic soils [2], where the main soil-forming factor is human influence; at the other extreme are natural soils that have not been used by humans but have nevertheless received inputs of contaminated dust or precipitation. Most soils in the city are intensively used and therefore heavily influenced by humans. Processes in these soils often differ greatly from those in rural soils. Contaminant loads are often much higher, parent materials are diverse and often of extreme chemical composition. Soils from technical materials such as industrial wastes often experience rapid weathering unlike that in natural soils [3,4].

Urban and industrial soils have been much studied in recent years [5–7], as has their management [8]. Their importance was recognized by the establishment of an International Union of Soil Science (IUSS) working group Soils of Urban, Industrial, Traffic and Mining Areas (SUITMA) at the 16th IUSS World Congress in Montpellier in 1998. SUITMA has held well-attended international conferences in 2001 (Essen), 2003 (Nancy) and 2005 (Cairo) and sponsored sessions at major soil science congresses.

2 Soil Classification

Soil classification is the process of grouping soil individuals into more or less homogeneous groups with respect to defined objectives [9], thereby highlighting the essential differences in soil properties and functions between classes. Soil classification may be used to correlate soil studies, thereby facilitating technology transfer. Another objective of a soil classification is to provide a ready-made map legend for soil surveyors; if the classification is useful, the resulting soil map is a stratification of the mapped area into groups about which specific soil management statements can be made. In a technical classification, such as engineering soil classification for construction [e.g. 10,11], there is only a single objective. However, it has long been recognized that soils are natural bodies with interrelated properties resulting from their often-complex pedogenesis [12], and that groupings based on natural bodies can be more efficient in dividing the vast universe of soils into classes with similar behaviour, problems and potentials for multiple uses [13]. These classifications are called 'pedologic' or 'natural' systems. Although the logic of hierarchical soil classification systems such as WRB has been questioned [14], they have proved to be useful tools for correlation and mapping. Since the 1930's many classification systems have been proposed, and countries with active soil mapping programs have adopted systems which best match their soils and soil survey programmes [15]; the best-known is the USDA Soil Taxonomy [16].

2.1 The World Reference Base for Soil Resources (WRB)

Since the earliest days of soil science, attempts had been made to develop a universal pedological soil classification system. These efforts were thwarted by the priority each country gave to solving its own mapping problems, and by philosophical differences about the basis of such a system. Finally with the FAO's Soil Map of the World project of the 1960's [17] it became necessary to establish a common map legend suitable for this generalized (1:5M) map. This legend was refined in the 1980's [18], aiming also at somewhat larger scale maps (1:1M) and finally developed into a comprehensive classification system, which was adopted by the International Union of Soil Science (IUSS) as the recommended terminology to name and classify soils at its 16th Congress in 1998 [19–21]. It was intensively tested for the eight years leading up to the 2006 Congress, at which time a revised version was adopted [22]. The WRB is ideally suited to discussing soil properties, function, use potential and genesis at world or regional scale [23]. The wide acceptance of the WRB is due to three factors: (1) it is not intended to replace any existing system, but rather to facilitate communication and correlation between national and local systems; (2) it does not attempt to provide names for large-scale maps and so does not interfere with local initiative; (3) it is based on extensive field experience and thus forms a useful stratification of the soil universe at high to medium categorical levels.

WRB 2006 is fully described in FAO World Soil Resources Report 103 [22], available from the FAO and ISRIC websites. Classification in the WRB is based on soil properties defined in terms of diagnostic horizons, properties and materials, which are as far as possible measurable and observable in the field. The selection of diagnostic characteristics takes into account their relationship with soil forming processes and their significance for soil management. The WRB is a two-level classification: (1) thirty-two (32) Reference Soil Groups (RSG) which have major differences in terms of pedogenesis, geography, and use potential; and (2) a list of prefix and suffix qualifiers for each Reference Group which are added to the RSG name to indicate detailed soil properties. Prefix qualifiers are of two types: typically associated with the RSG (thus effectively acting as subgroups) and integrades to other RSG. Suffix qualifiers provide additional detail on diagnostic horizons; chemical, physical and mineralogical soil properties; surface characteristics; general texture; colour; and miscellaneous properties. The RSG are arranged in a hierarchical key, whereas the qualifiers for each RSG are presented as a list, out of which all that apply to the soil being classified must be named. Names are intended to be as connotative as possible, using traditional soil names. For example, the name Umbric Gleyic Fluvisols (Humic) clearly implies a regularly-flooded soil with subsoil saturation from groundwater, a thick dark acid surface horizon, and a high organic matter content. Of course, these statements are all quantified.

2.2 The concept of soil in the WRB

In the WRB prior to 2006, as in almost all national soil classification systems, the soil to be classified was conceived as earth surface material that had been organized into genetic horizons by pedogenesis. Clearly, this is difficult to relate to many soils in urban areas, including pavements, and especially to fresh industrial wastes. For WRB 2006, Nachtergaele [24] suggested the eminently practical approach of naming all identifiable bodies on the Earth's epidermis; the major advantage is that one classification can be used to discuss environmental functions anywhere within the first two metres from the Earth's surface (a practical rather than philosophical limitation) except where it is covered by continuous ice or water bodies deeper than two metres at their shallowest.

3 Urban Soil Classification

Soil mapping has historically been associated primarily with agriculture and rural land resources assessment, and in studies of soil formation and behaviour. This has changed in recent years with the growing recognition that urban areas are of prime importance to human populations, and that soil function is vital to the life of the city. In some industrialized countries, in particular Britain [25], Germany [26], Russia [27], and the USA [28], there are active projects to map these areas, and parallel efforts to adapt national classification systems accordingly [29]. A related trend is the large increase in reclaimed lands (e.g. mine spoils) and new uses for old industrial areas (e.g. rail yards, steel mills) and the corresponding increase in soil studies in these areas. Efforts to map and describe these soils have suffered from a lack of connotative and well-defined names.

The WRB, as a comprehensive international system, is intended to be used to correlate soil studies of any type and in any area. However, the original WRB (1998) and its predecessor FAO map legends (1974, 1990) were developed with concepts from national classifications and pedogenetic studies that were skewed in favour of rural soils, so that some of the names that were assigned to urban soils were not very connotative. Similar issues with anthropogenic soils of intensively-farmed rural areas led the appointment of two WRB working groups, one for urban soils and one for anthropogenic soils. A wide consultation and several papers [30–32] lead to a majority proposal, with some minority opinions, presented to the WRB Commission in December 2005; these were taken into account in the WRB 2006 adopted by the IUSS at its 2006 Congress. Parallel to this work, the Americans set up an International Committee on Anthropogenic Soils (ICOMANTH) under the auspices of USDA-NRCS, charged with defining appropriate classes in the USDA Soil Taxonomy for soils whose major properties are derived from human activities [33,34]; this has not yet resulted in major changes to that system.

3.1 Urban soils in WRB 2006

The most far-reaching change is the introduction of a new RSG: the Technosols, whose central concept is dominance of soil properties and function by technical human activity as evidenced by one of: (1) substantial presence of 'artefacts', defined as material created or substantially modified by humans as part of an industrial or artisanal manufacturing process and with more or less their original properties; or (2) a nearly continuous impermeable, constructed geomembrane, commonly called a liner; or (3) technic hard rock, for example, pavement. Artefacts also include material excavated from a depth where they were not influenced by surface processes, with properties substantially different from the environment where they are placed. Examples of artefacts are bricks, pottery, glass, crushed or dressed stone, industrial waste, garbage, processed oil products, mine spoil and crude oil.

The first five prefix qualifiers for the Technosols effectively form subgroups; by design, all Technosols will qualify as either Ekranic (sealed), Linic (lined), Urbic (rubbly), Spolic (industrial wastes), or Garbic (organic wastes); these clearly are useful categories for soil management. The remaining prefix qualifiers are intergrades to other RSG, e.g. Histic, Stagnic, and Gleyic. Suffix qualifiers refer to detailed soil properties, e.g. Calcaric and Skeletic, and generalized texture: Arenic, Siltic and Clayic.

Technosols are keyed out as the third RSG, after the Histosols (soils dominated by organic matter) and Anthrosols (cultivated soils profoundly influenced by long-term human activity). Thus organic soils with high artefact content (e.g. sewage sludges) are identified as Technic Histosols; this preserves the traditional split between organic and mineral soils at the highest level, while still recognizing the technical origin of such soils. Similarly, Technic Anthrosols are recognized, although these are likely to be scarce, except perhaps in urban garden allotments on rubbly sites (Technic Hortic Anthrosols).

Classification of soils formed on recently-transported material caused considerable controversy. The principle finally adopted was that material that would not be present in the soil environment if it had not been for human intervention is defined as an artefact, and thus qualifies the soil as a Technosol, whereas material that has already been exposed to soil-forming processes (i.e. from the upper epidermis) is not an artefact, even though transported by humans. Thus fresh mine spoil is a Technosol, because the mine spoil does not occur naturally at the surface; by contrast, freshly-dumped overburden is a Regosol or Arenosol, depending on its texture. Transport is recognized by the Transportic suffix qualifier in these groups, e.g. Arenosols (Transportic) for sandy fill, which is quite common in the Netherlands. Non-sandy fill with jumbled remanants of diagnostic horizons is recognized as Aric Regosols.

An important process in urban areas is transport of fill or disposal of technical material on top of an existing soil. If both together qualify as a Technosol or Arenosol, they are classified as one soil, since the material is similar and the stratification may be difficult to establish. If the new material is 50 cm or more thick, it is the named soil, with the buried soil being classified separately and recognized with the Thapto ('buried') prefix ; e.g. Spolic Technosol (Thapto-Luvisolic) for a rubbly fill over an unaltered Luvisol developed in loess. If the new material is thinner, the original soil is classified and the new material is indicated with the Novic qualifier, e.g. Technic Haplic Luvisol (Siltic, Novic).

Urban areas contain many soils from the other 29 RSG, especially in parks and unbuilt areas; many of these show significant effects from their urban environment. Qualifiers have been introduced to indicate some of these, e.g. Densic for strong compaction. The most connotative is the Toxic qualifier, which we now discuss.

3.2 Toxic soils

One of the motivations for establishing the Technosols, and keying them out almost at the beginning, was to clearly show areas where technical material had been deposited. This material is likely to have toxic constituents or be highly-reactive. It was also realized that any soil in urban areas can become contaminated by spills, toxic dust, or atmospheric deposition (e.g. from leaded petrol), even if the proportion of such artefacts is too low to qualify the soil as a Technosol; this contamination need not be in city centres [35]. There have been some studies on these soils [36–39] but their extent is largely unknown. Still, it was thought important to define a Toxic suffix qualifer as "having in some layer within 50 cm of the soil surface toxic concentrations of organic or inorganic substances other than ions of Al, Fe, Na, Ca and Mg". The named ions can reach toxic levels in natural soils and so were already covered by various RSG and qualifiers. The Toxic qualifier is at present restricted to the Histosols, Technosols, and Gleysols, until it can be documented in other RSG. The phrase 'toxic concentrations' is deliberately vague and must be quantified by further studies. The Toxic qualifier can further be specialized as Anthrotoxic, Ecotoxic, Phytotoxic, or Zootoxic; these also are defined in qualitative terms only, and must be quantified.

It is recognized that there are difficulties with this definition, which should be refined prior to the next revision of the WRB. First, it is not semantically correct to refer to the 'toxicity' of the soil, since toxicity by definition depends on the receptor and the manner of exposure as well as the source. For phytotoxicity this is already a complex issue [40], let alone the more complex case of zootoxicity or anthrotoxicity. This definition could perhaps be made operational by defining a standard receptor and exposure pathway for each of the qualifiers. Or, the most common receptors and pathways could all be evaluated, with the qualifier 'toxic' understood to mean "potentially toxic to a defined receptor under defined conditions". Second, it may be quite hard to separate the specialized qualifiers: for example, a soil with sufficient heavy metals to be toxic to plants will almost certainly be toxic to humans. One solution is to define 'toxicity' as specific levels of defined soil constituents; at these levels the soil is considered potentially toxic in general. This is the approach taken by regulations such as the German Federal Soil Protection and Contaminated Sites Ordinance [41]. In any case, the WRB classification is not intended to replace site-specific risk assessment, in the same way it is not intended to replace site-specific management recommendations for agriculture.

3.3 Difficulties

A difficulty with identifying Technosols in the field is the requirement that the technic nature dominate any subsequent pedogenesis. At one extreme is fresh pavement, at the other a Roman road which over the years has developed a strong mollic horizon and whose continuous dressed-stone pavement has been disrupted by frost, animals, or tree roots; the first is a Technosol, the latter not. The phrase "substantially the same properties as when first manufactured, modified or excavated" must be documented by the classifier.

4 Mapping urban and industrial soils

The WRB is a soil classification system, not a map legend. It assigns names to soil individuals (pedons), whereas a map legend refers to spatial entities (e.g. polypedons) aggregated into map units. WRB names may be assigned to the constituent soil individuals within a map unit; in addition the map unit is characterized by the proportional composition and spatial pattern of the constituents. Map units are also commonly defined and named on the basis of site, morphology, substrate, or land use.

In the context of urban soil mapping, an important site property is its (anthro)geomorphology. For example, Rosenbaum et al. [42] describe a classification of what they term "artificial ground", emphasizing the anthropogenic processes which formed the ground, including void formation (excavation). This classification has been adopted by the British Geological Survey [43]. It is an anthropogenetic approach, using in the first instance morphology (a diagnostic landform) and then material composition and arrangement (physical, sedimentological and lithological). This is meant for mapping at any scale including detailed site investigations. There is no information on soil properties as such. This classification could be used, in conjunction with WRB, to name map units.

Another important property of urban soils is the substrate, also called parent material. Since the WRB emphasizes the results of soil genesis rather than the soil material, the same WRB soil type may develop in contrasting substrates. In the USDA Soil Taxonomy this is addressed at the family level (not present in WRB), where both the general particle-size profile and mineralogy are named. Jahn and colleagues [44] have proposed a simplified substrate classification to supplement WRB; this could be used define Reference Soil Series (RSS) in the framework of WRB [45]. An RSS would specify the soil form (i.e. WRB class), the general texture as in Soil Taxonomy families, with substitutes for particle-size class for technical soils suggested by ICOMANTH, and the substrate from detailed lists [e.g. 6]. In the USA, detailed mapping has proceeded by defining soil series, as the most detailed level of Soil Taxonomy, as necessary [46]; these then require changes to categorical higher levels.

Finally, the actual and historical land use may influence the properties and use potential of the map unit; for rural areas this is not usually known but for urban areas it is well-documented.

5 Perspective

Urban soil management can only increase in importance as the World's population becomes increasingly urbanized; the expansion of industry and the reuse of abandoned industrial lands also show no sign of abating. The WRB has successfully expanded its role as the reference soil classification system for correlation of soil studies and for small-scale mapping to cover these areas. By the time of the next WRB revision in 2010 the usefulness of the Technosols reference groups, its qualifiers, and the new qualifiers in other groups should be clear, so that definitions can be revised to produce an even more useful system. Another challenge is the use of WRB in urban soils mapping: coupling the somewhat general categorical level of the WRB with other information to usefully describe map units at the level of detail needed for urban soil management.

References

[1] Burghardt W (1994): Soil in urban and industrial environments. Zeitschrift für Pflanzenernährung und Bodenkunde 157 (3) 205–214

[2] Sobocka J (2003): Urban soils vs anthropogenic soils, their differentiation and classification. Paper presented at SUITMA 2003, Nancy, France

[3] Zevenbergen C, Bradley JP, Van Reeuwijk LP, Shyam AK, Hjelmar O, Comans RNJ (1999): Clay formation and metal fixation during weathering of coal fly ash. Environmental Science & Technology 33 (19) 3405–3409

[4] Zikeli S, Kastler M, Jahn R (2004): Cation exchange properties of soils derived from lignite ashes. Journal of Plant Nutrition and Soil Science-Zeitschrift Fur Pflanzenernahrung Und Bodenkunde 167 (4) 439–448

[5] Bullock P, Gregory PJ (eds) (1991): Soils in the urban environment. Blackwell Scientific Publications, Oxford, Boston

[6] Hiller DA, Meuser H (1998): Urbane Böden. Springer, Berlin

[7] Norra S, Stüben D (2003): Urban soils. J Soils Sediments 3 (4) 230–233

[8] Brown RB, Huddleston JH, Anderson JL (eds) (2000): Managing soils in an urban environment. ASA-CSSA-SSSA, Madison, WI

[9] Cline MG (1949): Basic principles of soil classification. Soil Science 67 (2) 81–91

[10] United States Corps of Engineers (1953): The unified soil classification system (Technical Memorandum). Waterways Experiment Station, USCE, Vicksburg, MS

[11] Dumbleton MJ (1981): The British soil classification system for engineering purposes: Its development and relation to other comparable systems. Transport and Road Research Laboratory, Crowthorne

[12] Jenny H (1980): The soil resource: Origin and behavior. Ecological Studies 37, Springer Verlag, New York

[13] Buol SW (2003): Soil genesis and classification (5th ed). Iowa State University Press, Ames

[14] Webster R (1968): Fundamental objections to the 7th approximation. Journal of Soil Science 19, 354–366

[15] Eswaran H, Rice T, Ahrens R, Stewart BA (eds) (2002): Soil classification : A global desk reference. CRC Press, Boca Raton, FL

[16] Soil Survey Staff (1999): Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys (2nd ed). Agricultural Handbook 436. US Department of Agriculture Soil Conservation Service, Washington, DC

[17] FAO (1974): Soil map of the world (Vol. 1: Legend). Food and Agriculture Organization of the United Nations, Rome

[18] FAO (1990): Soil map of the world: Revised legend. World Soil Resources Report 60, Food and Agriculture Organization of the United Nations, Rome

[19] FAO (1998): World Reference Base for Soil Resources. World Soil Resources Report 84, Food and Agriculture Organization of the United Nations, Rome

[20] Deckers JA, Nachtergaele FO, Spaargaren OC (eds) (1998): World Reference Base for soil resources: Introduction. ACCO, Leuven

[21] Bridges EM, Batjes NH, Nachtergaele FO (eds) (1998): World Reference Base for Soil Resources: Atlas. ACCO, Leuven

[22] IUSS Working Group WRB (2006): World reference base for soil resources 2006 (2nd ed). World Soil Resources Report 103. FAO, Rome

[23] Driessen P, Deckers J, Spaargaren O, Nachtergaele F (eds) (2001): Lecture notes on the major soils of the world. FAO, Rome

[24] Nachtergaele F (2004): The soils to be classified in the World Reference Base for Soil Resources. Paper presented at Soil Classification 2004, Petrozavodsk, Russia

[25] Hollis JM (1991): The classification of soils in urban areas. In: Bullock P, Gregory PJ (eds), Soils in the urban environment. Blackwell Scientific Publications, Oxford, Boston, pp 5–27

[26] Arbeitskreis Stadtböden (1997): Empfehlungen des Arbeitskreises Stadtböden der Deutschen Bodenkundlichen Gesellschaft für die bodenkundliche Kartierung urban, gewerblich, industriell und montan überformter Flächen (Stadtböden) (2. Auflage ed. Vol. Teil 1: Feldführer). Sekretariat Büro für Bodenbewertung, Kiel, Germany
[27] Stroganova M, Prokofieva T (2002): Urban soils classification for Russian cities of the taiga zone. In: Micheli E, Nachtergaele FO, Jones RJA, Montanarella L (eds), Soil Classification 2001 (European Soil Bureau Research Report No. 7, EUR 2-398 EN). Office for Official Publications of the European Community, Luxembourg, pp 153–156
[28] New York City Soil Survey Staff (2005): New York City reconnaissance soil survey. USDA-NRCS, Staten Island, New York, USA
[29] Bryant RB, Galbraith JM (2003): Incorporating anthropogenic processes in soil classification. In: Eswaran H, Rice T, Ahrens R, Stewart BA (eds), Soil classification: A global desk reference. CRC Press, Boca Raton, FL, USA
[30] Blume HP, Giani L (2004, August 2004): Classification of soils in urban/industrial agglomerations in Germany and recommendations for WRB. Paper presented at Soil Classification 2004, Petrozavodsk, Russia
[31] Lehmann A (2004): Proposals for the Consideration of Urban Soils within the WRB (World Reference Base for Soil Resources). Paper presented at Soil Classification 2004, Petrozavodsk, Russia
[32] Rossiter DG (2004): Classification of urban and industrial soils in the World Reference Base for Soil Resources. Paper presented at EUROSOIL 2004, 2nd European Soil Science Conference, 04–12 September 2004, Freiburg im Bresgau, Germany
[33] Galbraith JM, Mount HR, Scheyer JM (2002): Anthropogenic Soils: ICOMANTH Report No. 1, [CD-ROM]. USDA-NRCS. Lincoln, NE
[34] Galbraith JM (2004): International Committee for the Classification of Anthropogenic Soils (ICOMANTH) Circular Letter No. 5 (Circular Letter). USDA-NRCS, Lincoln, NE
[35] Pouyat RV, McDonnell MJ (1991): Heavy metal accumulations in forest soils along an urban-rural gradient in southeastern New York, USA. Water, Air, & Soil Pollution 57–58, 797–807
[36] Norra S, Weber A, Kramar U, Stüben D (2001): Mapping of Trace Metals in Urban Soils: The Example of Mühlburg/Karlsruhe, Germany. J Soils Sediments 1 (2) 77–93
[37] Lu Y, Gong Z, Zhang G, Burghardt W (2003): Concentrations and chemical speciations of Cu, Zn, Pb and Cr of urban soils in Nanjing, China. Geoderma 115 (1–2) 101–111
[38] Krauss M, Wilcke W (2003): Polychlorinated naphthalenes in urban soils: analysis, concentrations, and relation to other persistent organic pollutants. Environmental Pollution 122 (1) 75–89
[39] Jartun M, Ottesen RT, Steinnes E (2003): Urban soil pollution and the playfields of small children. Journal De Physique IV, 107, 671–674
[40] Kirkham MB (2006): Cadmium in plants on polluted soils: Effects of soil factors, hyperaccumulation, and amendments. Geoderma 137 (1–2) 19–32
[41] Schwartz R, Gerth J, Neumann-Hensel H, Förstner U (2006): Assessment of highly polluted Fluvisol in the Spittelwasser floodplain based on national guideline values and MNA-criteria. J Soils Sediments 6 (3) 145–155
[42] Rosenbaum MS, McMillan AA, Powell JH, Cooper AH, Culshaw MG, Northmore KJ (2003): Classification of artificial (man-made) ground. Engineering Geology 69 (3–4) 399–409
[43] McMillan AA, Powell JH (1999): BGS rock classification scheme, Volume 4: Classification of artificial (man-made) ground and natural superficial deposits – Applications to geological map and datasets in the UK. British Geological Survey Research Report, RR 99-04. British Geological Survey, Nottingham
[44] Jahn R, Joisten H, Kabala C (2003): Vorschlag einer einfachen Substratsystematik für die World Reference Base of Soil Resources (WRB) – Erzielbare Auswertungen demonstriert für die nFK der Leitbodenformen am Beispiel der internationalen BK 50, Blatt Zittau. Mitteilungen der Deutschen bodenkundlichen Gesellschaft 102, 499–500
[45] Zikeli S, Kastler M, Jahn R (2005): Classification of anthrosols with vitric/andic properties derived from lignite ash. Geoderma 124, 253–265
[46] Hernandez LA, Galbraith JM (1997): Soil survey of South Latourette Park, Staten Island, New York City, NY. USDA Natural Resources Conservation Service, Syracuse, NY

Received: October 20th, 2006
Accepted: February 16th, 2007
OnlineFirst: February 17th, 2007

J Soils Sediments 1 (2) 77–93 (2001)

Mapping of Trace Metals in Urban Soils

The Example of Mühlburg/Karlsruhe, Germany

Stefan Norra*, Andreas Weber, Utz Kramar and Doris Stüben

Institut für Petrographie und Geochemie, Universität Karlsruhe (TH), Kaiserstr. 12, 76128 Karlsruhe, Germany (stefan.norra@bio-geo.uni-karlsruhe.de; http://www.uni-karlsruhe.de/~ipg)

DOI: http://dx.doi.org/10.1065/jss2000.12.005

Abstract. Spatial distribution maps depicting the concentrations of antimony, lead, tin, copper and zinc, and the presence of land-use units were generated for Mühlburg, a district of the City of Karlsruhe, Germany. The influence of the spatial land-use structure on the distributions of the element concentrations is statistically evaluated and discussed. The variography for Mühlburg shows an average range of 200-400 m for the spatial correlations of Sb, Pb, Sn and Zn. The variograms of Pb and Zn are characterised by hole effects at 300 m distances, i.e. the result of repeated stronger spatial correlations for certain distances between the sample sites. Most probably, this is an effect of the typical urban structure of streets, buildings, green spaces, and industry. Kriging method was used for the interpolation of Sb, Pb, Sn and Zn concentrations. Only Cu does not show a spatial correlation. In this case, the interpolation was carried out with a smoothed triangulation routine. Pollution plumes of point sources such as lead works, a bell foundry and a coal-fired thermal power station superimpose the more diffuse pollution from traffic, household heating processes, waste material disposal, etc. The trace element concentrations in soils of housing areas increase with the age of the developed area. Industrial areas show the highest level of pollution, followed by housing areas developed before 1920, traffic areas, allotments, housing areas developed between 1920 and 1980, parks and sports areas, cemetery and housing areas developed after 1980.
It is demonstrated that spatial distribution maps of element concentrations indicate potential emission sources of harmful substances, even if the emission itself or the direct surrounding soil have not been analysed. The analytical tools presented enable town planners to discern areas of higher soil pollution. Detailed investigations can be focussed on these areas to evaluate the possibilities of soil usage and transfer. These methods enable one to manage urban soil in an adequate manner. For these reasons, the methods demonstrated support an urban environmental impact assessment and are a part of a sustainable urban soil management.

Keywords: Environmental chemistry; environmental impact assessment; geographic information system (GIS); Germany; geostatistics; GIS; Karlsruhe; mapping; research articles; soils; spatial variability; sustainable development; trace elements; urban development; urban land-use; urban soil management