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Soil as the landscape balance indicator

Abstract
The subordinated position of soil in the geosystem allows it to be used as an indicator of the landscape balance. Examples where soil plays such an indicative role are presented in this paper. The theory of the "geochemical landscape" has been used as the theoretical-methodological basis. Soil properties indicating direction, intensity and quality of matter migration in the landscape have been discussed (profile environment, pH, redox, quantitative and qualitative humus properties). The indicative role of soil in the monitoring of "sustainable landscape" has also been characterized. According to the authors, three models of this landscape can be created: natural, rural and urban sustainable landscapes.

Keywords
landscape balance • soil in the landscape • landscape monitoring • soil monitoring

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Introduction

In physical geography, "landscape" means a system composed of abiotic (relief, atmosphere, water) and biotic (plants and animals) elements as well as soil, which is a bridge between the two (Przewoźniak 1987, Ostaszewska 2002).

Soil is included in the subordinated (dependent) components, which strongly react to changes in other components (Armand 1980, Richling 1992, Finke 1994). In the practice of landscape studies, soil subordination is often used to specify its features based on the properties of other landscape components. Possibilities of reverse conclusions, leading from the analysis of soil features to defining the properties of the whole landscape, are presented in this paper. The concept of the geochemical landscape elaborated by Połynow (1956) and developed in later papers (e.g. Głazowska 1964, Perelman 1971, Perelman & Kasimow 1999) was used as the theoretical and methodological foundation. Considerations were directed to practical issues important for the organization of landscape balance monitoring. Therefore, attention was focused on the interpretation of contemporary landscape dynamics based on soil properties.

Soils and direction of matter migration in the landscape

The analysis of soil profile enables preliminary identification of: 1) the routes by which the landscape is supplied with matter, and 2) the main directions of matter migration. In the temperate (forest) zone, the soil profiles largely retain the direction of water migration. On water divisions or the upper parts of slopes, soil develops irrespective of ascending groundwater. Examples of such soil profiles can be found in Rendzics, Leptosols, Chernozems, Cambisols, Luvisols, Podzols, Brunic Arenosols and Stagnosols in the key to WRB 2006/2007 (IUSS Working Group WRB 2007). In these soil profiles, the stream of migrating water and the substances carried (dissolved, colloidal or suspended) is directed vertically downwards.

In landscape geochemistry, a location that is independent of ground water inflow is termed eluvial or subaeral and is treated as autonomous. In autonomous landscapes, matter is delivered exclusively from the atmosphere (Perelman 1971). Landscape processes (e.g. weathering) gradually proceed deep into the rocks. Products of weathering, especially easily soluble products, are washed out to the ground water table. Various geochemical barriers may appear across the route of migration stream, the most important of which are biological barriers, i.e. the uptake of substances by biota. The efficiency of such a barrier depends on the type of plant cover. Other types of barriers are associated with the presence of colloidal substances in the soil, with changes of redox conditions or pH. However, irrespective of the presence of migration barriers, the general trend in the development of eluvial landscapes is impoverishment due to the loss of matter that migrates with ground water to lower areas.

The main direction of migration changes in terrain depressions. Soil profiles are formed under waterlogged conditions caused by ascending groundwater. In landscape geochemistry, such locations are termed subordinated, accumulative, superaqueous, (semi)hydrogenic etc. Typical soils are Gleysols, Gleyic Podzols, Histosols, Mollic Gleysols and Drainic Histosols and Fluvisols. The properties of the soil profiles and the quality of sites are most affected by the chemistry of infiltrating waters (including

Vol. 17 • No. 2 • 2013 • pp. 38-41 • ISSN: 2084-6118 • DOI: 10.2478/v10288-012-0036-z

Table 1. Buffer ranges of mineral soil, its chemistry and habitat conditions (after Bartels & Knabe 1990, simplified)

pH $_{H_2O}$ Type of buffer	**above 6.2 Carbonate $CaCO_3$**	**6.2-5.0 Silicate**	**5.0-4.2 Clay**	**4.2-3.8 Residues of mineral lattice**	**below 3.8 Aluminium and iron hydroxides**
An example of buffering reaction	$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^-$	$CaAl_2Si_2O_8 +$ anorthite $2H_2CO_3 + H_2O \rightarrow Ca^{2+} + 2HCO_3^- + Al_2Si_2O_5(OH)_4$ kaolinite	$n[AlOOH$ clay $+ 0{,}5H^+ + H_2O \rightarrow [Al(OH)_{2,5}{}^{0,5+}] + 0{,}5nH_2O$	$AlOOH + 3H^+ \rightarrow Al^{3+} + 2H_2O$	$FeOOH + 3H^+ \rightarrow Fe^{3+} + 2H_2O$
Limitation of plant growth	Slight restriction at high Ca^{2+}/K^+ ratio	No chemical limitation	Restricted growth of Al sensitive species; decreased number of calciphilous species	Destruction of mainly plants by toxic Al; limitation to growth of many plants including beech, spruce and pine	Destruction of all plants by Al-Fe toxicity; species shallowly rooted in litter survive

ionic composition, pH and redox) formed in close relation to the chemistry of eluvial landscapes.

The connection between eluvial and superaqueous landscapes, i.e. their geochemical coupling, is an extremely important element of the characteristics of the whole landscape system. Without the knowledge of eluvial landscapes, it is impossible to understand the properties of subordinated units. Errors resulting from ignoring this relationship are often encountered in practical land management. The siting of an illegal landfill within a highly permeable catchment area is an example of such ignorance and it leads to water pollution in wells and soil pollution in the river valley.

Another example is the excessive fertilisation of soils in eluvial landscapes, which may lead to water eutrophication and excessive concentration of nitrates, phosphates and other nutrients in drinking water. So land management without consideration of the existing geochemical couplings can hardly be considered "sustainable development", let alone "saving resources". For these reasons, identifying eluvial areas and subordinated superaqueous units should be considered a preliminary but indispensable stage in the assessment of the sustainability of the whole landscape (Ostaszewska et al. 2011). Soil maps may help to identify both types of landscapes (Ostaszewska & Harasimiuk 1990).

Soil and the intensity of migration and the quality of migrating substances

Knowledge of physical and chemical soil properties enables the specification of: 1) the intensity of water migration and 2) the type of substances migrating with water in the landscape. Coarse-textured soils that are poor in humus (e.g. sand) have a low capacity to retain water and dissolved substances. On the other hand, fine-textured soils that are rich in humus (e.g. clays) have a well-developed sorption complex composed of mineral, mineral-organic and organic colloids. Soil particles and organic matter have negative charges on their surfaces and adsorb mainly cations, e.g. calcium, potassium, magnesium, aluminium and hydrogen. Migration of substances depends also on soil pH, so in acid soils, the low pH causes migration of iron, zinc, nickel, copper, lead, cadmium, mercury and silver, while in alkaline soils – of vanadium, molybdenum and uranium. Migration also depends on redox conditions, e.g. iron and manganese are mobile in reducing conditions and immobile in oxidizing conditions. Zinc, copper and lead behave in the opposite way and form insoluble sulphides under reducing conditions. The knowledge of soil texture, organic matter content, pH and redox conditions is therefore helpful in estimating the migration capacity of elements that are typical for a given landscape, as well as those introduced by human activity.

The soil's ability to conduct or retain substances plays a special role in the diagnosis of landscape pollution. An example of this is the assessment of degradation caused by acid rain (Ulrich 1981, 1991, Prusinkiewicz et al. 1988, Ostaszewska 2002, pp. 94-98). As is known, this phenomenon is caused by the emission of sulphur (and, to a lesser degree, of nitrogen) compounds to the atmosphere that, after a series of chemical reactions, are transformed into water-soluble acids. The concentration of hydrogen ions increases in atmospheric precipitation. The mineral part of the soil is the main buffer counteracting acidification of the landscape system. Depending on pH, the buffering of acidifying substances proceeds at the cost of destroying primary minerals, secondary clay minerals, residues of their crystal lattice and other colloid substances (tab. 1). By measuring soil pH, the mechanism of buffering of acidifying substances can be estimated. Knowing this, predictions can be made of the rate of degradation of the forest habitat conditions and forecast changes that will appear in subordinated landscape units (e.g. the appearance of mobile forms of toxic metals in surface and ground water, increase of sulphate and aluminium concentrations, worsening conditions for freshwater fish etc.) (Brechtel 1989, Benecke 1990, Urlich, Büttner 1985, Urlich 1986).

Soil and biogeochemical equilibrium of the landscape system

In view of the landscape geochemistry, soil is a part of the lithosphere, which was included in the biological cycling (Perelman 1971). The existence of humus horizon is the result of the co-operation of the soil in the processes of appearance, transformation and decomposition of live matter. This horizon may be considered the most important "product" of the whole landscape system (compare Finke 1994). Humus properties of the world's soils differ depending on thermal, water, biotic, lithologic and other conditions.

Humus is the most important element of the soil. It has large cation exchange capacity and provides the main store of plant nutrients. It is also the largest carbon reservoir and actively participates in CO_2 accumulation. The accumulation of carbon in the global humus layers is estimated at 30-50 x 10^{14} kg C, which

Vol. 17 • No. 2 • 2013 • pp. 38-41 • ISSN: 2084-6118 • DOI: 10.2478/v10288-012-0036-z

is many times greater than that in the atmosphere, biomass or waters (Bednarek, Dziadowiec et al. 2004).

The quantitative and qualitative assessment of humus allows conclusions to be drawn regarding the equilibrium of biogeochemical cycles in the landscape.

At equilibrium, the threshold humus store remains virtually unchanged and the humus quality is connected to the quality of the sites. For example, humus rich in grey and brown humic acids develops under a thin litter layer on loamy substratum that is rich in alkaline cations (deciduous sites). On sandy, infertile substratum (coniferous sites), a thin humus horizon that is rich in fulvic acids develops under a thick litter layer.

The incompatibility between humus properties and primary habitat properties often appears in the practice of landscape studies. For example, this happens when coniferous monocultures (pines on lowlands or spruce in the mountains) are planted on eutrophic deciduous sites. Another example is humus that is in a state of permanent, dynamic disequilibrium, which leads to a decrease of substance storage in the landscape. Disequilibrium may be caused by harvesting plant biomass every year (humus of soils under crops) or by other human activities (e.g. land contamination which decreases the activity of microorganisms cooperating in humus production). Those landscapes whose store and quality of humus are incompatible with natural conditions are in a state of biogeochemical disequilibrium. Analyses of humus properties are helpful in finding the reasons for this disequilibrium and specifying its nature.

Soil as an object of monitoring and protection

Due to their critical importance for agricultural and forest production, soils have long been the subject of monitoring activities. For example, over 200 sites of arable soils and several dozen sites of grassland and forest soils are studied within the State Environmental Monitoring Programme (compare Bednarek, Dziadowiec et al. 2004). Measurements include pH, conductivity of aqueous extract, concentration of sulphates and selected metals. Monitoring of pH and nutrients in soils is carried out in other countries such as England and Wales as well as France (Brittany) – compare Sinner, Todd 1998, Baxter et al. 2006, Lemercier et al. 2008. Soil studies also constitute part of the monitoring programmes of entire landscape systems. For example, integrated monitoring has been conducted at seven basic stations since 1994 under the State Environmental Monitoring Programme in order to study various issues including the properties of soils affected by acid rains (Kostrzewski 1995, Degórski 2007). Landscape monitoring in the Little Spree River catchment includes measurement of humus content, sorption capacity and soil pH (Syrbe et al. 2007). International actions are also undertaken to protect soils, the most recent example of which is the proposal of a thematic strategy on the protection of soils in Europe prepared by the European Commission (*Proposal for a Directive of the European*...). According to the Commission, soil should be treated as non-renewable resource that needs protection due to the slowness of the processes of its formation. In the landscape, soils play the role of a biomass producer (including crop production), they determine biodiversity, they accumulate, filter and transform solid substances and water, they are important source of raw materials, they act as carbon reservoirs, provide physical and cultural human habitat and form an archive of geological and archaeological heritage. All these functions are threatened by processes that destroy the soil cover of the continent, i.e. water and aeolian erosion, mass movements, constant decrease of humus content, increase of soil density and tightening of its surface and salinity and contamination. The Directive, being part of the strategy of European soil protection, lays down an obligation to identify areas threatened by soil degradation, as well as to catalogue them, carry out measurement and develop and implement recovery strategies.

Summary – soil as an object of sustainable landscape monitoring

In the studies of landscape sustainability, understanding soil properties carries a double meaning. Firstly, the subordinated position of the soil in the geosystem makes it a good indicator of the status of the entire landscape. The analysis of soil cover helps to determine the main directions of matter migration, both vertically as well as between particular fragments of the terrain. It allows landscape types that are variously fed with matter and thus affected by potential change of the natural equilibrium to differing degrees to be distinguished. The detailed analysis of physical and chemical soil properties allows a biogeochemical landscape equilibrium to be defined and enables the prediction of landscape changes determined by the soil buffering capacity. It also offers the possibility of assessing the present landscape status and estimating the distance between the present and primary (forest) status. For these reasons, studies of soil cover should be seen as an indispensable stage of landscape analysis, diagnosis and prognosis.

Secondly, soil studies may appear useful in the assessment of landscape “sustainability” and thus help in its proper management. Unfortunately, the term “sustainable landscape” has not yet been clearly defined. In the authors’ opinion, such landscape patterns should be constructed separately for forest, agricultural and urban landscapes.

In forest landscapes one should strive to attain the closest similarity between the present and the natural status. Soil monitoring may help in estimating the existing differences and indicating methods to eliminate these.

In rural landscapes, soil also plays a special role. As the basis for agricultural production, soil is subjected to many human activities that change its properties, the results of which are not always deliberate. Apart from the above mentioned decrease of humus content, these changes affect physical properties (compaction by machines), as well as chemical properties (improper fertilisation and biocides), disrupt biological equilibrium, degrade water relations (defective reclamation) and partly or totally destroy soil profiles via water and aeolian erosion etc. (Ostaszewska et al. 2011). Protection and restoration of soil resources should therefore become an important qualitative target of a sustainable agricultural landscape. This objective should be included in the monitoring of the entire landscape as well as of its components.

In urban landscapes, soils play mainly ecological functions such as absorption and transformation of pollutants, supporting ground water recharge, outflow regulation and providing a base for plant cover development (Szumacher 2005). Sustainable urban landscapes should fulfil these functions most efficiently, while the soil status and possibilities of its improvement should be the object of further study.

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