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APPLICATION OF SOIL SCIENCE RESEARCH TO THE DETERMINATION OF THE POLLUTION RESISTANCE POTENTIAL OF LANDSCAPE

Abstract: The environment resistance potential is defined as the ability of the landscape to limit the negative pollutant impact consisting a.o.in the limiting, by means of accumulation, of the amount of pollutants circulating in the environment system. In practice, their quantity is contigent on the proporties of the components, which are capable of a relatively long-lasting chemical substance accumulation (thus, above all, the properties of the soil cover). The forecast model of environment changes describes the mechanisms and distribution rate of pollution in the soil profile and the interaction with the functional landscape structure. The methodological assumptions, determining of the real, complex diagnosis of the environment condition and for forecasting of the effects of the persisting anthropopressure and for establishing the necessary measures limiting the progressing degradation. Knowing, even approximatively, the mechanism of the existing changes one can determine the optimal (under circumstances) level of pollutant input, and when its limitation is impossible, one can control the use of the environmental potential in such a way as to minimize its negative impact.

Key words: soil, environment resistance potential, migration of pollutants, modelling.

In the scientific literature one can found numerous examples of papers devoted to the research on the anthropogenically conditioned phenomena and processes occurring in the environmental system, including changes caused by pollution of various kinds. More and more often such research is subordinated to the needs of forecasting. The main cause of this are, above all, practical reasons, since one should, considering both actual and potential environmental hazards, conduct not only a registration (monitoring) of the biotic and abiotic landscape components, but also (based on its results) forecast the results of environment utilisation on various spatial and temporal scales. Such actions should become the basis of rational land use and of planning of the necessary precautionary measures. It is also important that such research is already advanced and therefore there is a lesser need to conduct research of basic character.

Change in the quality of landscape components, most often documented historically, or an identified change of concentration of the substance under investigation, related to the observed damage and to symptoms of the disturbance of natural conditions as well as to the defined norms is a commonly used method of forecasting the direction and rate of environment changes. Attempts to work out a forecast regarding landscape functioning and dynamics in the context of the development of intensity of natural and anthropogenically enforced changes of its equilibrium (including changes caused by a long-term effect of pollution accumulation) are, however, undertaken extremely rarely. Models connecting directions and rate of environment changes with the functional features of the particular components constitute a particular example of such forecasting study.

In this paper proposals of selected research methods of environment changes in anthropopressure conditions are presented. Among many aspects of the pollution influence on the natural environment, particular attention has been paid here to the natural predisposition of the environment to modifications (limitations) of the negative action of pollution and to the construction of a model of the changes caused by them. The material presented here is a result of the long-term research of the author, conducted independently or in teams (Malinowska, 1988, 1993, 1995, 1996, 1997, 1998; Malinowska et al., 2000, Lechnio, 2000, 2003; Nowicki, 1992, and others) on various scales (1:10000, 1:25 000, 1:50 000, 1:10 0000) and in varying detail since the late 1980s in the vicinity of a large urban and industrial centre (mostly petrochemical) in Płock near Warsaw in central Poland.

The region under investigation is advantageous for such research for several reasons:

— It is situated in the immediate vicinity of the pollution source and its area allows identifying the effect of the full range of the pollutant concentration, from maximal values to background ones.
— It underwent a long-term anthropopressure, which caused noticeable symptoms of the physicochemical environment degradation, which made possible the determination of the trends of changes and their temporal dynamics.
— It is differentiated as regards the natural landscape structure, which allows to determine the influence of the pollutants on various systems of landscape components and to define the their role in the natural neutralisation of the contamination and the degradability connected with it.
— It is identified in many aspects and in many details from the point of view of the physicogeographical environment conditions allowing for the determination of the pollutant migration paths and of the areas of higher and lower pollutants accumulation and their natural resistance.
— It underwent long-term detailed research of the chemical composition changes of its individual components under the conditions of persistent anthropopressure, allowing for gathering of a large set of archival measuring data, necessary for the proper interpretation of both temporal and spatial changes.

The concentrations of substances characteristic for this region, taken from among many pollutants emitted into atmosphere or deposited on the land surface, were analysed. These are:

1. Gas pollution: mostly compounds of sulphur and nitrogen, definitely predominant in the emission and immission of the Petrochemia works.

2. Heavy metals (Al, Fe, Cu, Pb, Ni, Cr, Zn, Cd, V, Mn), which are characteristic for dust emission and which migrate easily in the environment; in natural conditions they occur in trace amounts and therefore their higher concentration is a clear indicator of anthropogenic environment pollution.

3. Macro elements (Ca, Mg, Na, K, P, Cl) related to the natural abundance of nutrients in the soil; their concentration in soil and plant matter may be an indicator of the intensity of agricultural measures.

Despite of the local specific features of anthropopressure, the research results obtained here may be applied also to other urban-industrial agglomerations and to the surrounding areas of fixed spatial structure of land utilisation. This is confirmed by the results of research of authors using this method (a.o. Balcerzak, Malinowska, 1996; Chadryś, 2002; Kazimierczak, 2003).

Contrary to the common opinion, the transformations of the natural characteristics of the natural environment which occur under the influence of the emitted pollution do not depend solely on the quantity of the environment pollutant input and its duration as well as on the physico-chemical features of the chemical substances introduced into the circulation (on which their migration intensity and potential toxicity depend). The process of migration of chemical substances in the environment, depending on natural causes is just as important, and under some circumstances it is the dominant factor. This factor, together with the elements listed above, determines the range, intensity of impact and concentration level of pollutants in individual components of the environment, causing a disturbance of the natural geochemical equilibrium, which eventually leads to the chemical degradation of the environment. The type of the migration process of chemical substances depends on the character and strength of the functional connections among the individual components of the environment; these connections determine the structure of the matter and energy flow and therefore allow to indirectly establishing the possibilities and range of their degradation.

It follows from this that the research dealing with the influence of various pollutant types on the natural environment require taking into account the role of natural mechanisms modifying the hazard caused by the quantity of emission and immission. This ability is called in the literature by various terms, a. o. as resistance or permeability. In geoecology this property is called the resistance potential and describes the ability of the landscape to modify the negative influence of pollutants by limiting their quantity circulating in the environment system. This property is the result of simultaneous occurrence and mutual impact of specified properties of the components, which determine the intensity of the processes of assimilation, accumulation, transport and transformation of chemical substances. The environment resistance formulated this way is close to the notions of geocomplex stability and self-cleaning potential, distinguished by Hasse as one of the partial geocomplex potentials (Richling, 1992). An analysis of the environment resistance potential brings in this case satisfying results, since this potential can be regarded as a relatively permanent (compared with other potential types) property of the environment, although it too undergoes changes in time. The rate of such changes is close to the dynamics of the physicochemical properties of soils.

The resistance of the environment to pollution can be viewed from at least two points of view. In the first, it is the ability of the environment to accumulate the pollutants and to exclude them from the geochemical circulation; in the second, it is the ability to quickly neutralise the pollutants by chemical and biochemical means. The author assumes that as regards permanent pollutants (e.g., heavy metals, practically not underlying decomposition or microbiological pollutants, in which case the ability of bacteria to survive may last months or even years) the first approach should be used, according to which it is the ability to neutralise the negative effects of anthropopressure by their accumulation in various components that is the measure of environment resistance. In the case of organic pollutants, undergoing quick biochemical transformations, the environment resistance means their actual neutralisation, that is, quick mineralisation.

In most cases the environment resistance potential is determined by means of analysis of the natural components of the biogeochemical circulation in a representative network of research points situated in autonomous, transitional and subordinated localisations, reflecting the differentiation of the landscape structure. Natural parameters were so far analysed in two ways; they were divided into: (1) factors which determine the potential quantity of dry and wet input to the terrain surface and (2) factors which determine the transformation of the pollutant load in the substratum, with respect to various pollutants migrating in the substratum in form of cations or anions.

The potential quantity of the pollution input was determined according to the following parameters:

— Relief (inclinations, horizontal and vertical dimensions of the forms, exposition with respect to emitters), upon which the geodynamical functioning of the landscape is dependent.
— Meteorological conditions (frequency of air flow from above the emitter to the given point, precipitation amount, evaporation, radiation balance of the active surface) all of them together determining the potential dry and wet deposition and the aerosanitary conditions.
— Area cover, influencing on the one hand the amount of the input, through its capability to absorb air pollution and to modify the topoclimatic conditions, and on the other hand, determining, due to bioaccumulation, the exclusion from the circulation of a specific amount of pollutants.

The directions and rate of the pollution transformation in the substratum were determined on the basis:

— Physico-chemical properties of the soil influencing the intensity of pollution accumulation in the soil sorption complex and the mobility of the elements under investigation in soil solution; the most important in this respect are: mechanical composition, absorbing capacity, buffer capacity, active and potential acidity, oxidation and reduction potential, humus content, exchange cation content, and, among physical properties, actual volume density, capillary and non-capillary porosity, water capacity (defining the contents of unconfined water, quickly percolating gravitational water, field water capacity, capillary water – based on the pF curves), amount of capillary infiltration.

— Substratum permeability, which determines the time of water infiltration through the aeration zone to the level of unconfined groundwater (effective infiltration);

— Rate of groundwater runoff outside the landscape unit, determined from the hydrodynamic parameters of the aquifer.

The above-mentioned general criteria of the estimate of the environment pollution resistance are not of universal character. Their detailed selection has to be strictly adapted to the specific properties of pollutants characteristic for the given area, including their geochemical features and the type of migration in the environment. Table 1 shows examples of criteria of the estimation of environment pollution resistance to pollutants migrating in cation form (e.g., heavy metals), applied in the zone of influence of the Płock Urban-Industrial Complex (scale 1: 25 000).

The above parameters have been determined on the basis of reproducible measurements and analyses of physicochemical and functional landscape characteristics, corresponding to various structure types of the selected landscape components, their states and evolution phases. Its joint analysis allows determining the summary potential of the environment resistance, presented as a dynamical model built on principles described below. Sometimes, for planning purposes and for overview plans, an estimate of the environment resistance potential by the quality classes method, using only approximate criteria, is sufficient. In this case the potential value is determined, depending on the accepted assumptions, by the sum, product or the difference of points. Table 1 shows examples of quality classes of the pollution environment resistance estimate in the case of pollutants migrating as cations.

Environment resistance potential depends above all on those components which have the capability to accumulate chemical substances to a relative large extent or which facilitate intensification of chemical and biological neutralisation. Soil cover and soil are two main such components. Vegetation is in this respect less useful for research, because on farmlands, which dominate in zones of heightened antropopressure, biomass is annually exported outside the landscape unit area; this makes balancing difficult or even impossible. The remaining components (atmosphere, water) fulfill, it seems, mostly the role of transporting media, which may be attested by their variable chemical composition, depending on the current hydrometeorological condition and on the amount of anthropogenic input.

Table 1.

Selected criteria of estimation of the environment pollution resistance in the case of pollutants migration as cations

Process of pollutant spreading	Estimate criterion	Example of division into quality classes
General, natural conditions of the substance migration process, including the possibility of the pollution input from other areas, migration rate and direction a. o.	Area location (basic landscapes)	1. subordinate 2. autonomous 3. transit
Conditions of pollutant exportation and of deformation of the urban heat mass	Wind speed	1. below than 1 m/sec 2. to 5 m/sec 3. above 5 m/sec
Conditions of pollutant dispersion (dilution) in the vicinity of the emitter	State of atmospheric equilibrium	1. stable and very stable 2. neutral 3. unstable
Absorption of air pollutants by the area cover	Coefficient of dust and gas pollutant absorption from the air (Vd)	1. small (Vd < 1): dunes, open [uncovered] soils, meadows, pastures 2. medium (Vd 1–2): corn crops, bog meadows 3. large (Vd > 2): coniferous, leafy, mixed forests, scrub, brush, thicket, moss areas
Conditions of pollinates dispersion in near-ground zone: terrain barriers of pollutant propagation in the near-ground zone, zones of good aeration and of pockets of polluted air	Radiation balance of the substratum	1. areas of limited radiation exchange 2. areas of average radiation exchange 3. areas of intensive radiation exchange
	Forms of relief	1. V-shaped valleys, isolated depressions without drainage 2. Hilly plain, hills, wide valleys 3. Flat and hilly plain
	Exposure with respect to the emitter	1. Perpendicularly to the direction of propagation of the pollutant plume 2. Intermediate exposure 3. Parallel to the direction of propagation of the pollutant plume
	Type of land cover	1. Wide, compact forest areas or developments forming barriers for air movement

Continued:

		2. Various types of utilisation: forests, meadows, fields 3. Wide areas with low vegetation not forming barriers for air movement: fields, meadows, pastures
Pollutant accumulation in the soil sorption complex	Absorption capacity of organic and mineral colloids	1. Below 5 cmol(+) $\cdot$ kg^{-1} 2. 5 – 15 cmol(+)$\cdot$kg^{-1} 3. Above 15 cmol(+)$\cdot$kg^{-1}
	Degree of saturation of the sorption complex by alkaline cations	1. Below 40% (undersaturated soil) 2. 40% – 70% (medium saturated soil) 3. Above 70% (saturated soil)
	Humus content	1. Below 1% 2. 1% – 3% 3. Above 3%
	Humus type	1. Mor (acidic, weakly decomposed, undersaturated, with predominance of fulvic acids) 2. Moder (weakly acidic, with varying degree of saturation and a varied structure of humic acids) 3. Mull (sweet, well decomposed, saturated, with predominance of humic acids)
"Mobility" of cations in soil solution	pH	1. Below 4.5 2. 4.5 – 6.5 3. Above 6.5
	Oxidation and reduction potential	1. Reduction conditions (rH below 25) 2. Transitional conditions (rH between 25 and 30) 3. Oxygen conditions (rH above 30)
Accumulation of pollutants in plant tissues	Bioaccumulation capacity	1. Coniferous and leafy trees 2. Grass, fruit 3. Field crops – vegetables (leafy, root), grains
Isolation of groundwater level from the pollutants deposited on the surface; rate of infiltration of precipitation water	Substratum permeability (effective infiltration coefficient)	1. Above 30%: loose sand, gravel, organic deposits 2. 10% – 30%: loamy sand, dust 3. Below 10%: heavy loam, clay
	Thickness of the aeration zone	1. 0 – 2 m 2. 2 – 5 m 3. Above 5 m

Continued:

Rate of ion transport through the soil profile; availability for the plants	Succion force of the soil pF	1. Quickly infiltrating gravitational water, hygroscopic water, pellicular water (pF 0 – 0.2; above 4.2) 2. Slowly infiltrating gravitational water, hard-to-access capillary water (pF 2.0 – 2.2; 3.0 – 4.2) 3. Easily accessible capillary water (pF 2.2 – 3.0)
Rate of groundwater runoff outside the unit boundaries	Inclination of the grounwater table	1. Below 2% 2. 2% – 5% 3. Above 5%
Rate of groundwater runoff outside the unit boundaries	Aquifer permeability (filtration coefficient)	1. Small: loam, alluvium, clay (filtration coefficient above 10-6 mps) 2. Medium: dust, loamy sand (filtration coefficient above 10-4-10-6 mps) 3. Large: sand and gravel (filtration coefficient below 10-4 mps)

The arguments for the utilisation of the soil for the identification of the quantity of the resistance potential are:

— Specific properties of the soil cover (e. g. absorption capability, buffering) due to which it is the main centre of element accumulation in the environmental system. This is because the soil cover functions like a "membrane" on the way of the moving pollutant flow (for that reason, a. o., parameterised soil characteristics, expressed for instance in form of the so-called critical loads are commonly used to estimate the hazard in numerous European and EPA programmes, see Barkman et al., 1995; Manual for Integrated Monitoring…, 1998);

— Specific function of the soil cover in the environment structure, due to which the elements concentrations observed in the soil are the determinant of long-term changes in the qualitative and quantitative structure of their circulation and not a reflection of momentary input.

— The strict connection between the soil cover and the remaining environment components (soils are commonly regarded as a subordinate element), allowing determination of not only the immediate influence of the pollutant input, but also forecasting its intermediate effects for other environment components.

Analysis of the potential amount and of all estimates connected with it should be conducted within natural landscape units (geocomplexes of indefinite rank), delimited on the basis of these characteristics which influence the development of the process of chemical substance migration supplied to the substratum. As opposed to similar studies conducted for the drainage basin for instance within the Integrated Environment Monitoring System (Sverdrup et al., 1995), where forecasting possibilities with respect to another terrain are limited by the necessity of hydrological comparability of the area, this method of resistance potential analysis can be, it seems, applied more widely, because it uses individual reference fields (landscape units) and not a complex drainage basin system.

In the conditions of the fixed spatial structure of land use, all changes observed within the specified landscapes with varied physico-chemical properties depend on the course of natural processes and on the transformations caused by the use and circulation of substance originating from pollutants. A definite state of dynamic equilibrium of the soil features, and therefore of the environment, is the direct result of this process; it is manifested in form of transformations of their physico-chemical features and of destabilisation of the state of the remaining components, functionally connected with the soils.

The spatial image of the interconnections discussed here is the resultant of many factors acting simultaneously; due to that, research aiming at determining the degree of the environmental hazard can't be reduced to a simple interpretation of the empirical data in form of an algorithm "connecting" the data. The result of such research consists only of an integrated, conceptual forecast model of the dynamics of the physico-chemical properties of the soil cover. The applied method must include also a verification of the mathematical principles describing specific processes and events under investigation, utilised during the estimation of the form of the model; or else it should take into account the simultaneous verification of the parameters and structure of the model. As a result of this procedure a forecast model of the dynamics of the potential of the natural environment resistance will be created. In this model, changes of the physico-chemical properties of the soil cover are considered from the point of view of the arrangement of the functional landscape properties. The following assumptions should be taken into account when constructing the model:

1. The model should define the dynamics of the physicochemical properties of the soils, which determine the value of the resistance potential. Functional relations of the soils with the remaining environmental components should be treated at this stage as the main characteristics determining the interrelations of the model operators. This first level of verification allows for parameterisation of the functional model.

2. The model should have two layers: the first layer should include the functioning of the individual soil types with respect to their biotic and abiotic properties, which determine the natural physico-chemical and functional characteristics in the environmental system, as well as anthropogenic interactions (e. g., type and intensity of use, quantity of immission). The second layer should include a complex system, in which the specific

functional types of the soil cover are related to the landscape units, separated because of the features mentioned above, whose boundaries will be determined by functional types of landscape units.

3. In the first system (layer) the basic structure should be explained by the internal variables (that is, originating from this system), both functional and formal and structural. All modifications of the system, on the other hand, will be described by means of variables common for both layers. These variables are treated as "driving variables" (Manual on Methodologies…, 1998). They will be chosen after the analysis of feedbacks and correlations and by means of other statistical analyses (PCA, DCA, etc.).

4. During the analysis of the complex system the quantity of immission, its structure, carbon reserve, pool of available elements, quantity of atmospheric precipitation, relationship with groundwater, permeability and effective infiltration, use, habitat, substratum type, localisation in relief forms and others will be taken into account.

This model refers in its elements to the dynamic model of the soil chemistry PROFILE and its later version SAFE (Sverdrup, Alveteg et al., 1999; Sverdrup, Warfinge et al., 1998), which takes into account the profile structure.

The change of the physicochemical properties of the soils, considered from the point of view of their susceptibility or resistance to the disturbance of the dynamic equilibrium constitutes a determinant of the long-term dynamics of the resistance potential in the regional setting. Analysis of interrelations viewed this way allows for establishing of the influence of the soil cover on the rate of environmental change stemming from a definite process of pollutants transformations within the soil and their interactions with the functional landscape type. Therefore, an estimate of the degree of the landscape resistance potential is possible.

A forecast of the dynamic changes of the soil cover (and therefore and the landscape resistance potential) is an effect of the simulation of the soil properties changes and of the functional environmental components related to them. The forecast deals with mechanism and rate of the distribution of the selected heavy metals, macroelements and carbon in the soil profile and with the interaction with the functional structure of the landscape. Pollutants in the form of dry and wet heavy metal deposition, acidifying substances as well as other macroelements are treated as a factor influencing physicochemical properties of soils; from the point of view of changes observed in them, they are treated also as influencing the functional properties of landscape components, directly related to the soil cover. One should note also certain humus in soil, since this parameter is directly related to the biogeochemical functions of the soil and determines a. o. the course of the process of pollutants bioabsorption. The analysis must include data related to the chemical contents of the vegetation cover.

The procedure presented here indicates therefore the need of the control over a large number of parameters, which may eventually be useful at the stage of the model estimation. Independently of the theoretical knowledge of the processes considered here and the knowledge of their dominant factors, it is difficult to accept a specific scheme of their mappings by means of the identified empirical properties. One should remember that the selected set of parameters should make possible the description and the choice of the leading factors, determining the interrelations between the soil cover properties and the remaining environment components in the aspect of functional entropy, considered within the specific spatial units. For this reason the research goal may be achieved only thanks to long-term, reproducible, stationary measurements and analyses of physicochemical and functional properties of various soil types and selected landscape components (their seasonal states and stages of evolution); such measurements should be conducted within representative and appropriately equipped research fields, reflecting the variability of the soil cover and the environment structure.

To summarize, one can state that the scope and direction of the research presented here brings a number of important results, such as:

— Identification of the natural capabilities of the environment to neutralise pollutants in the system of biogeochemical circulation (potential of landscape resistance).
— Identification, on the regional scale, of the factors influencing the pollutant displacement in the landscape system.
— Identification of the factors influencing the bioavailability of pollutants.
— Working out a methodology of landscape feature measurement allowing for concluding about its functioning and dynamics.
— Measurement and modelling of long-term changes of potential quantity, depending on the type of functional connections in the landscape system.
— Determining which media accumulate and conduct pollutants.

Such research may have also an important practical application consisting in:

— Detailed determination of procedures raising the effectiveness of landscape protection, and thus of the quality of the particular components.
— Optimisation of land use aiming at protection soils, waters and landscape structure.
— Adjustment of the localisation of investments in regional scale to the natural resistance properties of the landscape and environment.
— Preparation of a database of environment data, which can be utilised in spatial planning, in particular in verification of the existing network of regional monitoring.

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