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# Application of the catena concept in studies of landscape system dynamics

**Abstract**
The concept of catena in landscape surveys is used to demonstrate the surroundings of landscape units, their vertical structure and inter-unit processes, as well as the mosaic nature of the landscape. Furthermore, it reflects the structural and functional heterogeneity of the surveyed area, at the same time indicating types of links between landscape units, depending on a variety of geological, habitat-related and biotic conditions, including land use and its transformation arising from anthropopressure.

The catena survey performed included four key morphological and lithological units with varied landscape structure and functioning: glacial upland, vast outwash plains, the Wisła River valley and deepened channel valleys, as well as dune hills and hillocks. The results prove that the functioning of landscape systems depends on the forms of land use and their durability. Characteristics of leading components in catenas are diverse despite a similar genesis of landforms and relief shaping processes.

**Keywords**
Catena • landscape • system • functioning • dynamics



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## Introduction

The functioning of a landscape system is influenced by both the supply and transformation of solar energy and migration between elements and components of the natural environment (Richling, Solon 2011). Changes in landscape systems that extend standard functioning but do not result in modification of structure reflect the dynamics of these systems (Demek 1995). An analysis of the functioning of landscape units should include various forms of chemical substance migration (water, air, biological migrations, etc.), which depend among other things on topographic position, relief of the land surface, geological characteristics, soil cover, groundwater level and type of land use.

The nature and power of functional links between environmental components determine the structure of matter migration (Przewoźniak 1987 based on Richling, Solon 2011; Malinowska 2005). Matter flow processes are particularly clear on slopes where landscape changes depend mainly on the relief dynamics and topographical situation (Ostaszewska 2002). The fact that these processes are so clear makes it easy to identify them with a variety of survey methodologies. However, poor dynamics are typical for plain landscapes characterized by weak denudation and soil washout due to water circulation (Malinowska 2005; Richling, Lechnio 2005; Malinowska, Deglińska 2011).

## Assumptions and survey methodology

The catena concept originates from soil science and was first used by Milne in 1936 (Milne 1936) to describe the typical soil succession that occurs on homogenous (in terms of climate conditions and geological structure) slopes. Similar concepts can be found in more recent soil science literature (Polynow 1956; Opp 1983; 1985).

The specific variability of landscape structure and functioning within a catena depends on eluvial, illuvial and coluvial processes; their intensity is in turn determined by drainage conditions (Komisarek 2000; Sołtyk 1995):

- energy inflow and outflow in the ground level air;
- water inflow and outflow on the surface of the terrain and within the soil;
- inflow and outflow of clastic matter.

The above factors determine the intensity of weathering processes, as well as elevation, transport and accumulation of the products of weathering along slopes. The processes determined by their impact disappear on flat uplands, flattening slopes and valley bottoms. Therefore, autonomous upland units are characterized by matter outflow, transitional slopes by matter transportation, with local accumulation or denudation, while spots located under slopes, on the valley bottom and in subordinate depressions, are characterized by accumulation.

It should be noted that catenal processes are not limited to soil transformation along a slope, but concern all aspects of geosystem functioning and a number of interlinks between landscape units (Ostaszewska 2002). Depending on the survey nature and subject, aspects such as soil catenas (e.g. Gennadiev, Zhidkin 2012; Albaa et al. 2004; Kozłowski, Komisarek, Wiatrowska 2011), soil and geochemical (Meijer, Buurman, 2003), geochemical

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(Perelman 1971), ecological (Bird 1957), and landscape may be included (Ostaszewska 2002). Polish landscape ecology studies use the term "geoecological catena" exceeding the pedosphere and understood as the correct sequence of ecotopes (facies) along the topographical cross-section (Richling 1992), where unit positions within a catena correspond to its functioning.

Assuming that catenal processes depend on the land inclination, theoretically a catena may be limited to a slope (transitional area). According to Ostaszewska (2002), however, such a definition of a catena may overly restrict the landscape survey scope and thus limit its practical use. Furthermore, Ostaszewska (2002) proves that excluding watershed areas and valleys disqualifies the "slope" catena in landscape planning and evaluation. Accepting the above arguments, the authors treat a catena as a sequence of landscape units including autonomous, transitional and subordinate areas. A catena indicates proximity of the units, their vertical structure and processes that occur between them, as well as the mosaic-like nature of the landscape. Furthermore, it reflects structural and functional heterogeneity of the surveyed area, at the same time indicating types of links between landscape units related to a variety of geological, habitat and biotic conditions, including land use and transformation as effects of anthropopressure.

The objective of the survey was to determine the effects of the above processes on landscape functioning in different lithological, soil, hydrologic and land use conditions. For this purpose, the authors have used selected soil, geochemical and geodynamic indicators: soil profile morphology, granulometric composition, the content of organic carbon and selected macro- and micro-elements.

In the Geoecological Laboratory of the Faculty of Geography and Regional Studies at the University of Warsaw and in the Laboratory of the Mazovian Geographical Centre in Murzynowo near Płock, the following parameters were determined based on collected samples:

1) Physical and chemical parameters regarding the mineral substrate and organic matter of the soil: grain size (with a sieve and Casagrande's aerometric method modified by Prószyński), bulk density, carbonates (percentage content of $CaCO_3$) with the Scheibler volumetric method, exchangeable acidity measured with the potentiometric method in 1M KCl suspension and in $H_20$, exchangeable acidity (Hw - cmol(+)·$kg^{-1}$ of soil) with the Daikuhara method, hydrolytic acidity (Hh - cmol(+)·$kg^{-1}$ of soil) with the Kappen method, base exchangeable cations ($Ca^{+2}$, $Mg^{+2}$, $K^+$, $Na^+$ - cmol(+)·$kg^{-1}$ of soil) with the Kappen method, organic carbon (%Corg) with the Tiurin method, cation exchange capacity (CEC - cmol(+)·$kg^{-1}$ of soil).

2) Chemical parameters: macro- and micro-elements Al, Fe, Mg, Mn, Cd, Cr, Ni, Pb, Zn, (mg·$kg^{-1}$ of soil) with the mass spectrometry method (checking mineral contents of samples using Anton Paar's Multiwave Digestion System, ICP MS Perkin Elmer Elan 6100 DRC).

Statistics v. 7.1. software was used to perform statistical analyses.

## Characteristics of the surveyed area

The survey was carried out within ten large-scale catenas determined within the examined transect (Figure 1). Their upper section, in an autonomous location, is characterized by a slight slope of up to 2 meters. In the transitional section, with a reduced elevation over sea level, slope inclination decreases. In the upper and middle sections of the slope, the slope inclination exceeds ten percent, while lower sections demonstrate a smaller inclination (below five percent). At the bottom of the slope,

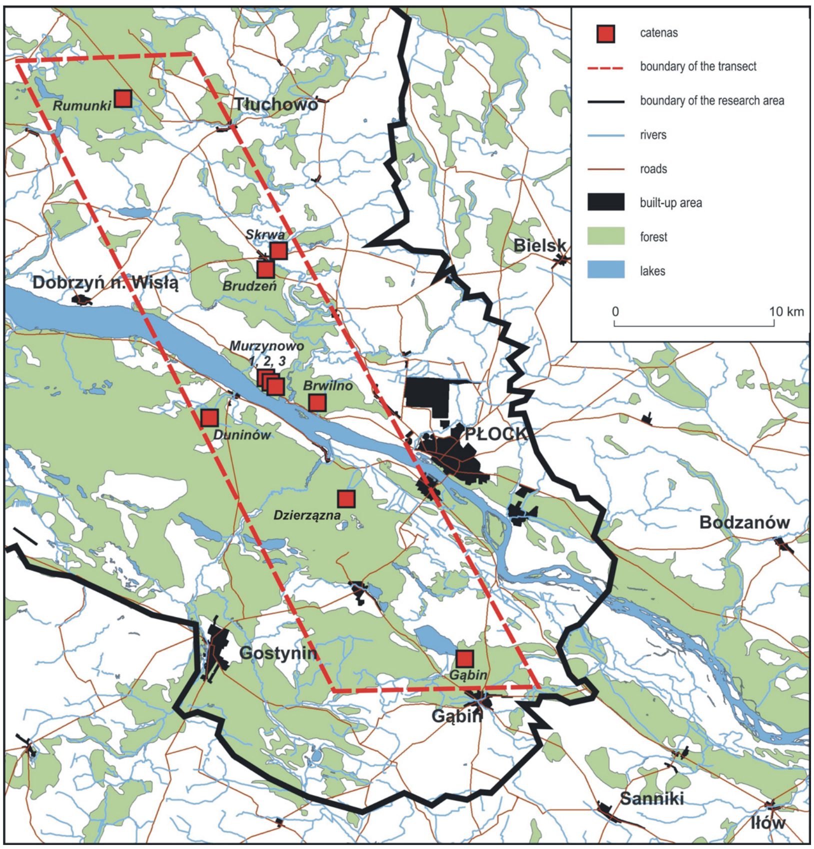


*Figure 1. Location of the surveyed catenas*

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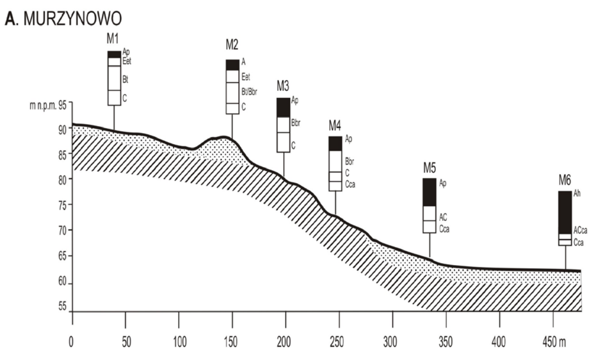
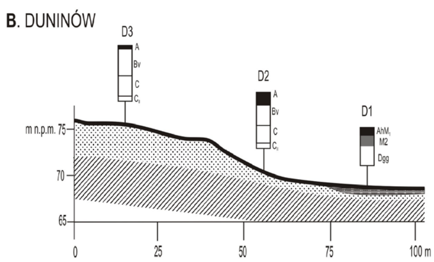
*Table 1. Landscape structure of the surveyed catenas*

| Field location | Autonomous | Transitional | Subordinate |
|---|---|---|---|
| Land lie | Undulating plain, deleveled up to 2-3 meters | Slopes with 5-12% inclination, steeper in the upper part | Plain with deleveling below 2 meters |
| Surface forms | Fluvioglacial and Aeolic sands on clay, clay eluvia | Fluvioglacial and Aeolic sand on clay, clay eluvia, till (bare substratum) | Sandy and silty, humus deluvia, organic forms: peat and muck |
| Aquifer | Water table at 2-5 meters below ground level, no effect on soil characteristics | Water table at 2-5 meters below ground level, no effect on soil characteristics, no water sources | Water table at 0-1 meters below ground level, locally at 1-2 meters below ground level |
| Soil cover | Luvisol, Brunic Arenosol, Endoeutric Cambisols | Luvisol, Brunic Arenosol, Endoeutric Cambisols and Cambisols with erosion of the humus level | Phaeozems, Umbrisols |
| Land use | Forests and agriculture (arable land) | Forests and agriculture (arable land) | Forests and agriculture (meadow) |




| Land lie | plain | hillock | steep slope | easy slope | plain | |
|---|---|---|---|---|---|---|
| Field location | autonomous | | transitional | | subordinate | |
| Surface forms | sand | loamy sand | sandy loam | sandy clay loam | loamy sand | loamy sand |
| Soil cover | luvisol | leached cambisols | cambisols | phaeozems, umbrisols | | |
| Aquifer | unconfined | | | | | |
| Habitat | fresh coniferous forest | mixed, coniferous forest | mixed forest, fresh | fresh forest | | |
| Use | arable land | wasteland | orchard | | arable land | meadow |




| Land lie | undulating plain | slope | plain |
|---|---|---|---|
| Location | autonomous | transitional | subordinate |
| Surface forms | sand | | peat |
| Soil over | brunic arenosol | | gleyic histosols |
| Aquifer | unconfined | | |
| Habitat | dry coniferous forest | fresh forest | alder carr |
| Use | coniferous forest | leafy forest | |

*Figure 2. Exemplary catenas: A-lithogenic, B- litho-hydrogenic*

the section of catenas occupying the subordinate location, there are plains again. Therefore, the examined catenas include the full sequence of autonomous (top of uplands), transitional (slope) and subordinate (slope bottom) areas allowing evaluation of various types of landscape functioning. They constitute an open landscape system, formed by internal and external impacts (both natural and anthropogenic). The landscape structure of the examined catenas is presented in Table 1.

The determined catenas (Figure 1) may be divided into two types distinguishing the area adjacent to Płock:

1. Lithogenic catenas (Murzynowo 1, 2, 3, Brwilno, Skrwa) with a uniform landscape structure, where the leading landscape components (surface geology, morphometric relief types and land use) determine diversity of landscape processes (Figure 2A Murzynowo).

2. Lithogenic-hydrogenic catenas (Rumunki, Brudzeń, Duninów, Dzierzązna, Gąbin), which have a bipartite landscape structure, so it has been assumed that in the upper and middle section the same factors determine landscape processes as in the lithogenic case, while in the lower part hydrogenic processes dominate (Figure 2B Duninów).

## Results and discussion

As mentioned above, increasing inclination within a catena determines the pace of matter migration along the slope and the related fraction sorting. Many authors consider the process to be an immanent part of catenal processes. Surface flow, downhill creep and other slope processes are the key transport triggers. The examined lithogenic (Murzynowo 1, 2, 3, Brwilno, Skrwa) and litho-hydrogenic (Rumunki, Brudzeń, Duninów, Dzierzązna, Gąbin) catenas demonstrate an absence of material differentiation in grain size (Figure 3), in particular in relation to the clay fraction, which is particularly exposed to leaching. Only rarely do fractions of fine sand and silt increase in the lower part of a slope. According to the authors, this phenomenon does not prove that slope processes have stopped, but rather suggests a limited scope of fraction sorting during transport, hindered by dense vegetation that poses a barrier for mineral matter migration along the slope and reduces the pace of processes determining landscape changes.

A change in the thickness of humus layers, characterized by a clear thickness increase in the lower part of the lithogenic

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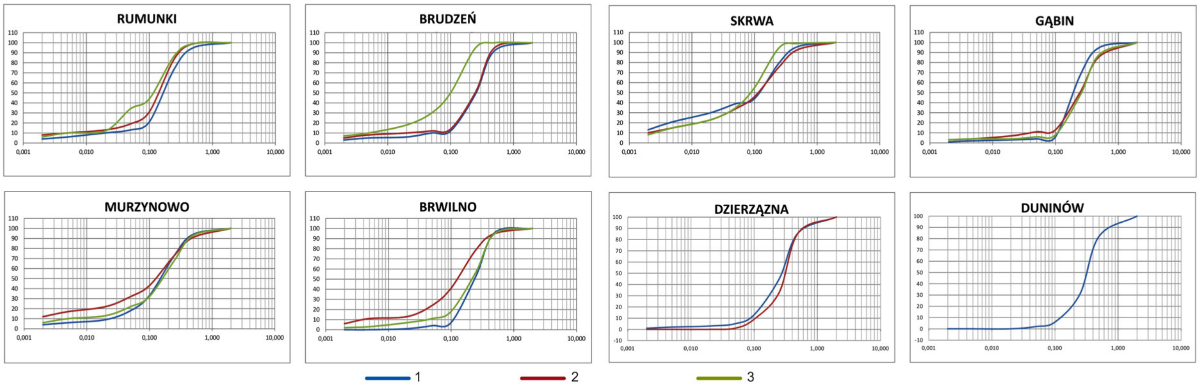


*Figure 3. Grain-size distribution curve of the outer layer of soil in the examined catenas. 1. The upper part of the slope; 2. The middle part of the slope; 3. The lower part of the slope (for Murzynowo – mean value for catenas: Murzynowo 1, 2, 3)*

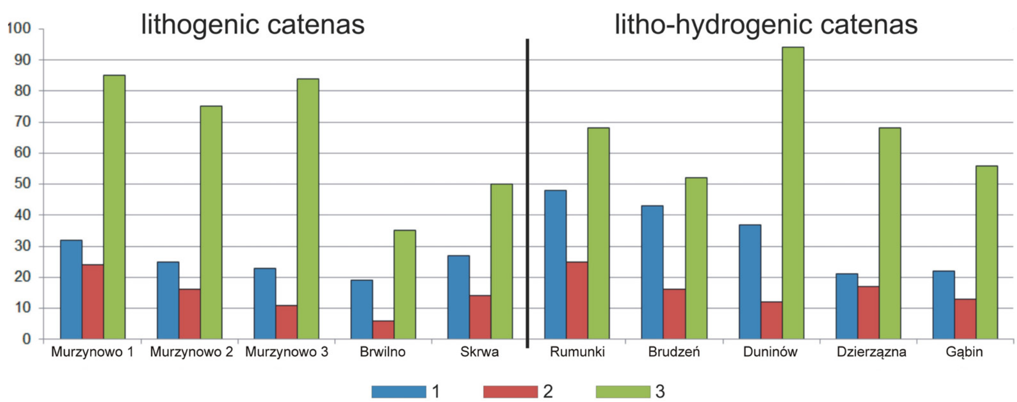


*Figure 4. Thickness (in cm) of humus layer in the soil of the examined catenas. 1. The upper part of the slope; 2. The middle part of the slope; 3. The lower part of the slope*

catenas, is proof that slope processes have not stopped (Figure 2, 4). In this zone, the nature of pedogenesis and the related reaction (acidic and slightly acidic) does not support intense humification; therefore, the layer, reaching up to 80 cm, has been produced by an inflow of humus deluvia from upper parts of the slope. The regularity is visible for all catenas regardless of slope length and inclination, being especially clear in those under agricultural use, involving periodic bearing of soil surface and intensified erosion. This is further confirmed by a lack of increase in Corg content (Figure 5), remaining at the level characteristic for high elevation soil, accompanying the growing thickness of the humus layer. Therefore, it may be stated that the operation of and changes in lithogenic catena landscapes, as well as the upper and middle sections of lithogenic-hydrogenic landscapes, are more dependent on land cover and land use than on slope inclination.

The significant increase in the thickness of humus layers and increasing Corg content at the bottom of the slope in lithogenic-hydrogenic catenas is mainly the result of local conditions that support accumulation and humification of organic matter in high-humidity substrata. The observed regularities result in the Corg pool (t/ha) being an indirect measure of biological activity in the soil and at the same time indicating its degradation (Siuta 1995). This depends mostly on processes occurring in the subordinate zone, in particular on hydrogenic factors, since these spots are the main source of organic carbon within the catenas. For lithogenic-hydrogenic catenas, it reaches up to 500 t/ha, of which 45-80% in subordinated locations. In lithogenic catenas, it is much lower, its total not exceeding 100 t/ha in the soil profile, but as in the above case, the highest values occur in subordinate locations. For both catena types, the lowest Corg pool characterizes transitional locations (Figure 6).

Thickness analysis of deeper genetic soil levels (Table 2) provides material conclusions regarding landscape functioning within the examined catenas. Among other things, it indicates that eluvial soil levels (Eet, Ees), their presence in the profile corresponding to the level of chemicals being leached to deeper soil layers, are the best developed and thickest in the autonomous parts of both catena types. Additionally, acidification of these levels and a reduction of macro- and micro-elements accumulated in deeper sections of the soil profiles are observed. Well-developed eluvial levels in autonomous-location soil are accompanied by an increased thickness of illuvial levels and their relocation deeper in the profile. Their lower profile lies at about 90 cm under the ground level. Most macro- and micro-elements in these layers usually reach top concentration levels (Figure 7), and relatively low acidity (Figure 8). Furthermore, the total thickness of eluvial and illuvial levels of autonomous locations is the highest in the entire catena, averaging 60 cm. This illustrates the significant domination of vertical substance transport in the substratum and its leaching with underground outflow. Physical and chemical soil and sub-soil characteristics (high permeability, acid soil reaction, little CEC) do not pose substantial barriers to the process and allow a broad distribution of substances in the water and ground.

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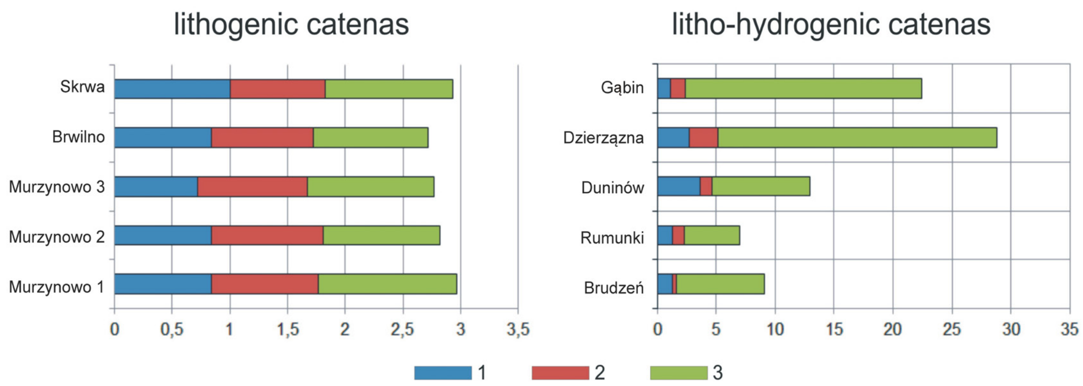


*Figure 5. Corg contents (in %) in the outer layers of soil in the examined catenas. 1. The upper part of the slope; 2. The middle part of the slope; 3. The lower part of the slope*

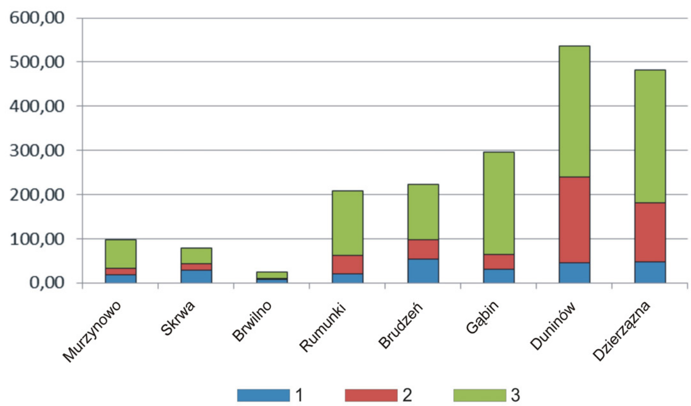


*Figure 6. Corg pool size (t/ha) in the soil of the examined catenas. 1. The upper part of the slope; 2. The middle part of the slope; 3. The lower part of the slope*

*Table 2. Thickness (in cm) of genetic levels of soil in the examined catenas*

| Level | Upland | Slope | Bottom |
|---|---|---|---|
| Lithogenic catenas: Murzynowo 1, 2, 3, Brwilno, Skrwa | | | |
| A | 19-32 | 6-24 | 35-85 |
| E (Eet, Ees) | 8-24 | 7-15 | - |
| B (Bt, Bfe, Bbr, Bv) | 20-62 | 14-43 | 22-68 |
| Lithogenic-hydrogenic catenas: Gąbin, Dzierzązna, Duninów, Rumunki, Brudzeń | | | |
| A | 21-48 | 12-25 | 36-94 |
| E (Eet, Ees) | 10-22 | 10-16 | - |
| B (Bt, Bfe, Bbr, Bv) | 24-65 | 12-38 | 26-58 |

The observed regularities allow an assumption that links between autonomous, transitional and subordinate parts of the catenas have been weakened and most frequently take the form of interflow of substances, not of surface flow.

In slope soil of certain catenas, a reduced thickness of all soil levels is observed compared to the top part. The total thickness of eluvial and illuvial layers reaches an average of 35 cm. This proves a change (compared to the top portion) in proportions between the processes determining matter flow: the slope processes listed above are intensified due to land lie, and result in damage to the topsoil and downhill transport of matter, at the same time reducing the leaching of soil profiles. Therefore, the processes determining changes and functioning of the landscape in this location are different from those in the autonomous parts of the catenas. In light of the research, slopes are the zones where matter is released and transported to subordinate areas, both by surface flow and, to a lesser extent, by interflow. Therefore, close functional relationships exist

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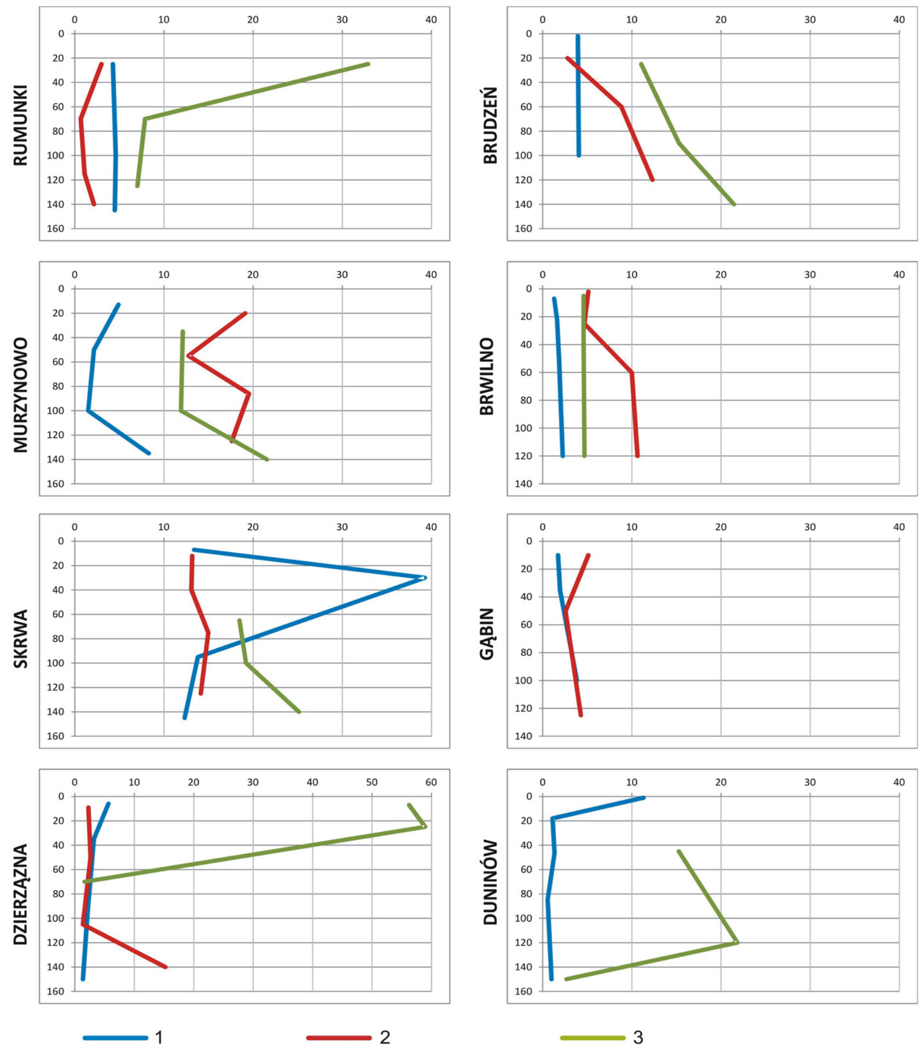


*Figure 7. Base exchangeable cations [cmol (+)·kg$^{-1}$] in the examined soil profiles. 1. The upper part of the slope; 2. The middle part of the slope; 3. The lower part of the slope*

between the transitional and subordinated areas, in particular in lithogenic catenas, visible for examplein the above processes of accumulating humus deluvia at the bottom of the slope. This relationship may also occur in lithogenic-hydrogenic catenas, but in this case, deluvia accumulation is affected by the intense accumulation and humification of organic matter, which are hard to separate with the use of the methods applied in our research.

Changes in concentration of examined macro- and micro-elements in the soil profile in a variety of locations within a catena and their accumulation series may indirectly indicate relations involving matter transport and accumulation. They are presented in Table 3.

Despite differences between individual catenas, changes in the concentration of most analyzed elements are regular. In general, two change patterns occur. The first characterizes lithogenic-hydrogenic catenas, where the element concentration is the lowest in autonomous locations, growing steadily downhill all the way to the bottom. In the second pattern, concentration fluctuations occur involving a clear reduction of content from the top to the middle slope sections, with a relatively fast increase in concentration in the lower section of the slope and at the bottom. The lithogenic catenas were characterized by this pattern. Regardless of the element content change pattern along the slope, however, the average concentration was highest in the bottom part. Regularities observed in the distribution of concentration of the examined macro- and micro-elements correspond to relations detected in analyses of organic carbon and the soil profile morphology.

In both catena types, despite diverse conditions of landscape functioning and changes, the accumulation series of the examined elements are similar. Full recurrence of these series in each location occurs for macroelements, mostly sourced from rock weathering. Accumulation of the microelements examined, however, is more diverse, which may be a result of their external, local supply from anthropogenic, agricultural and industrial sources. In order to provide a detailed interpretation of the observed variability, further research is required, to include geochemical conditions of heavy metal migration.

## Conclusions

The observed diversity of characteristics in the examined catenas allows a conclusion based on the following regularities in the functioning of the landscape system in the discussed area:

1. In the examined area, two catena types occur, differing

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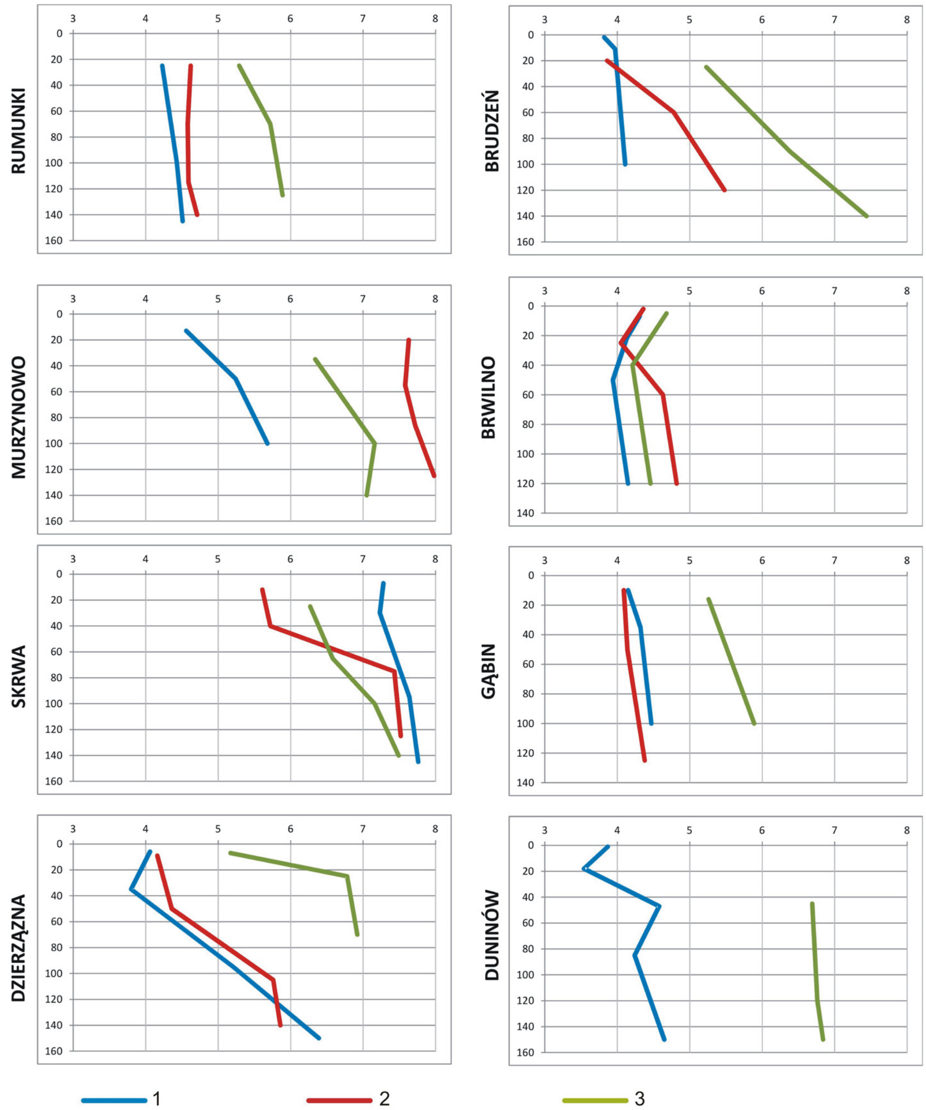


*Figure 8. pH in KCl in the examined soil profiles. 1. The upper part of the slope; 2. The middle part of the slope; 3. The lower part of the slope*

*Table 3. Changes in concentration of macro- and micro-elements in the soil of the examined catenas*

| Catena type | Changes in concentration of macro- and micro-elements | Accumulation series | | |
|---|---|---|---|---|
| Lithogenic | Fluctuating concentration, no clear dependence on topographic situation | Autonomous location | Fe=Al>Mg>Mn | Zn=Pb>Ni>Cr>Cd |
| | | Transitional location | Fe>Al>Mg>Mn | Zn>Ni=Pb>Cr>Cd |
| | | Subordinate location | Fe>Al>Mg>Mn | Zn=Pb>Ni>Cr>Cd |
| Lithogenic-hydrogenic | Significant concentration increase in subordinate locations | Autonomous location | Fe>Al>Mg=Mn | Pb=Zn>Ni>Cr=Cd |
| | | Transitional location | Fe>Al>Mg=Mn | Zn=Pb>Cr>Ni>Cd |
| | | Subordinate location | Fe>Al>Mg=Mn | Zn>Pb>Ni>Cr=Cd |

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in terms of functioning: lithogenic and lithogenic-hydrogenic catenas, with diverse matter flow conditions.

2. Despite differences in the landscape structure in individual catenas, eluvial and deluvial processes and differences in water flow may be considered of key importance for landscape functioning diversity.

3. In each autonomous, transitional and subordinate section of a catena the matter flow follows a different course; vertical substance flow and its underground runoff are characteristic of autonomous areas; release, surface transport and interflow are characteristic of slopes, while subordinate areas see increased accumulation, therefore acting as the main source of mineral and organic matter.

4. The strongest functional relationships occur between transitional and subordinate areas, while autonomous areas are more independent.

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## *References*

Albaa, SD, Lindstrom, M, Schumacher, TE & Malo, DD 2004, ‘Soil landscape evolution due to soil redistribution by tillage: a new conceptual model of soil catena evolution in agricultural landscapes’, *Catena*, vol. 58, pp. 77–100.

Bird, ECF 1957, ‘The Use of the Soil Catena Concept in the Study of the Ecology of the Wormley Woods,Hertfordshire’, *Journal of Ecology*, vol. 45, no. 2, pp. 465–469.

Demek, J 1995, ‘Problems of landscape behaviour’, *Ekologia* (Bratislava), Supplement 1, vol. 14, pp. 23–28.

Gennadiev, AN & Zhidkin, AP 2012, ‘Typification of Soil Catenas on Slopes from the Quantitative Manifestations of the Accumulation and Loss of Soil Material’, *Eurasian Soil Scien*ce, vol. 45, no. 1, pp. 12–21.

Komisarek, J 2000, *Kształtowanie się właściwości gleb płowych i czarnych ziem oraz chemizmu wód gruntowych w katenie falistej moreny dennej*, Wydawnictwo Akademii Rolniczej im. Augusta Cieszkowskiego, Poznań.

Kozłowski, M, Komisarek, J & Wiatrowska, K 2011, ‘Bilans wodny gleb układów katenalnych Pojezierza Poznańskiego w sezonie wegetacyjnym’, *Nauka Przyr. Technol*., vol. 5, no. 5.

Malinowska, E 2005, ‘Zastosowanie parametrów pokrywy glebowej do opisu procesów funkcjonowania krajobrazu’ in *Z Problematyki Funkcjonowania Krajobrazów Nizinnych* eds A Richling & J Lechnio, WGSR UW, Warszawa, pp. 147–188.

Malinowska, E & Beglińska, K 2011, ‘Przestrzenna zmienność właściwości gleb w układach katenalnych w rejonie Murzynowa’ [Spatial variability of soil properties in the slope catenas in the vicinity of Murzynowo (central Poland], *Prace i Studia Geograficzne*, vol. 46, pp. 77–92.

Milne, G 1936, ‘A provisional soil map of East Africa’, *Geograf Review*, vol. 26, pp. 522–523.

Meijer, EL & Buurman, P 2003, ‘Chemical trends in a perhumid soil catena on the Turrialba volcano (Costa Rica)’, *Geoderma*, vol. 117, pp. 185–201.

Opp, Ch 1983, ‘Eine Diskussion zum Catena-Begriff’, *Hall. Jb. F. Geowiss*., vol. 8, pp. 75–82.

Opp, Ch 1985, ‘Bemerkungen zur Catena-Konzeption unter besonderer Berücksichtigung der eine Catena ausbildenden Prozesse’, *Petermanns Geographische Mitteilungen*, vol. 129, no. 1, 25–32.

Ostaszewska, K 2002, *Geografia krajobrazu. Wybrane zagadnienia metodologiczne* [The Geography of Landscape. Selected Methodological Issues], Wydawnictwo Naukowe PWN, pp. 165–177.

Perelman, AI 1971, *Geochemia krajobrazu* [Geochemistry of Landscape], Wydawnictwo Naukowe PWN, Warszawa.

Połynow, BB 1956, *Izbrannyje trudy*, Izd. Akademii Nauk SSSR, Moskwa.

Przewoźniak, M 1987, *Podstawy geografii fizycznej kompleksowej* [The Basis of Complex Physical Geography], Uniwersytet Gdański.

Richling, A 1992, *Kompleksowa geografia fizyczna* [Complex Physical Geography], Wydawnictwo Naukowe PWN, Warszawa.

Richling, A & Lechnio, J 2005, Koncepcja krajobrazu – operatory i indykatory ewolucji systemów przyrodniczych [Conception of the landscape – drivers and indicators of systems evolution], in *Z problematyki funkcjonowania krajobrazów nizinnych* [On the problems of functioning of the lowland landscapes] eds A Richling & J Lechnio, WGSR UW, Warszawa.

Richling, A & Solon, J 1996, *Ekologia krajobrazu* [Landscape Ecology], Wyd. Naukowe PWN, Warszawa.

Richling, A & Solon, J 2011, *Ekologia krajobrazu* [Landscape Ecology], Wyd. Naukowe PWN, Warszawa.

Siuta, J 1995, *Gleba – diagnozowanie stanu i zagrożenia*, IOŚ, Warszawa.

Sołtyk, K 1995, *Typy katen krajobrazowych okolic Sandomierza*, master thesis, WGiSR UW, Warszawa.