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LANDFORM EVOLUTION IN MOUNTAIN AREAS

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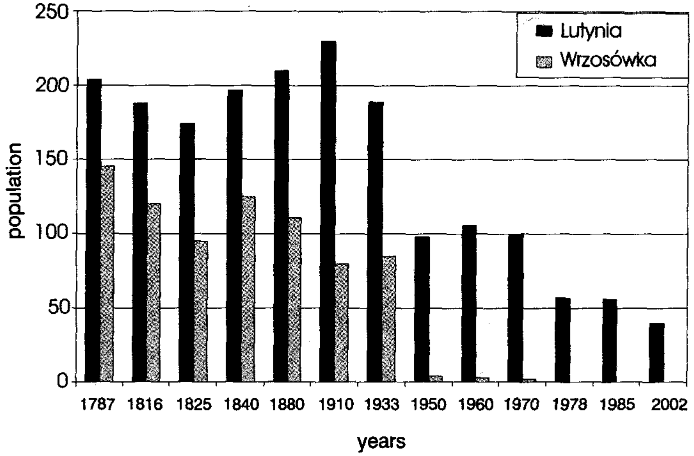
GEOMORPHIC EVOLUTION OF MID-MOUNTAIN DRAINAGE BASINS UNDER CHANGING HUMAN IMPACTS, EAST SUDETES, SW POLAND

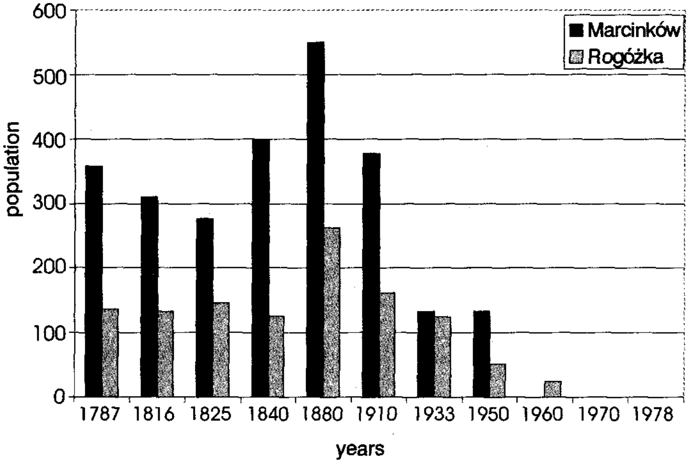
Abstract. Changing intensity of human impacts in the East Sudetes, from an initial increase of mountain population and economic activities to subsequent population decline and land abandonment, has been reflected in geomorphic evolution of three representative mid-mountain drainage basins. Human impact has influenced the environmental system mainly by strengthening or weakening slope-channel linkages, resulting in turn in changes in surface denudation rate, sediment supply and river channel patterns. Several phases of slope-channel system development have been proposed, in relation to altering historical factors and resulting changes in type and intensity of morphogenetic processes. The present state of slope-channel systems in the study area is a response to recent withdrawal of intensive human activity from mountain regions and shows only weak slope-channel coupling, with geomorphologically relatively stable slope domains and more dynamic channel domains.

Key words: Sudetes Mountains, human impact, surface denudation, erosion, land use change, secondary vegetation succession

INTRODUCTION

The present-day state of a geomorphic system is an outcome of both present and past morphodynamic processes occurring on slopes and in river channels. The strength of linkages between these two subsystems seems to be the crucial factor influencing sediment supply, transfer and storage within slopes or valley floors or its removal out of the drainage basins. The relationships between slope and channel subsystems are influenced to a great extent by natural environmental factors, such as bedrock, vegetation type and pattern, slope angle and aspect, and climate. Climate changes have the greatest impact on the geomorphic systems under natural environmental conditions, that is, when they are undisturbed by human impact. These changes refer both to major changes, such as at the turn of Pleistocene and Holocene period (Starkel 1977; Roberts 1998; Mannion





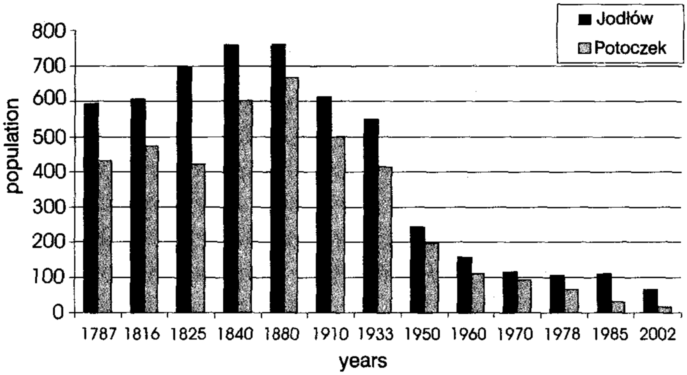


Fig. 1. Population changes in the study areas (based on: Staffa 1993a, b; Blaschke 2001; statistical data of the District Council of Lądek Zdrój and Międzylesie 2001)

2001) and to smaller scale minor climatic alternations as during the Little Ice Age (Kotarba 1987). However, within the last several thousand years in Europe, human activity has become an important factor altering natural environmental conditions and changing the functioning of many geomorphic processes. Therefore climate change influences have been obscured by human impact in the recent period of the Holocene (Starkel 1988, 1989; Bork at al. 1998; Bell and Walker 1992; Beniston 2000; Klimek 2000, 2002). Mountain environments are especially prone to even slight disturbances which in turn can often have a cascade effect on the entire environmental system (Bell and Boardman 1992).

The Sudetes Mountains, like many other medium-high ranges in Europe, were subject to human penetration since early mediaeval times (Walczak 1968). The main phase of colonisation of the higher parts of the mountains took place in the 14th and 15th centuries (Bartkiewicz 1977) and the population continued to increase up to the second part of 19th century (Fig. 1), bringing agriculture, forestry, mining, textile and glass manufacturing to upper parts of the mountain valleys and causing substantial changes in natural vegetation patterns (primeval forest clearances), leaving the land bare and prone to intense soil erosion (Inglot 1979). However, within the last one hundred years major socio-economic changes have caused an immense population decline in these mountain areas.

The aim of the paper is to show how changing intensity of human impacts, from an initial increase of mountain population and economic activities to subsequent population decline and land abandonment, has been reflected in geomorphic evolution of three representative mid-mountain drainage basins in the East Sudetes. To do so, the contemporary state of surface denudation system is analysed first and on this background past situations are presented and assessed. In particular, several phases of slope-channel system development have been proposed, in relation to changing historical factors and resulting changes in type and intensity of morphogenetic processes, and thus also in strength of slope-channel linkages.

STUDY AREA

Three drainage basins which are considered to be representative for the Eastern Sudetes region were selected for detailed investigation (Fig. 2). The elevations within the Luty Potok basin, an area of 5.7 km^2, range from 460 to 900 m a.s.l. and most slopes are inclined 10–25° (Fig. 3a). One village still exists in the area — Lutynia, which was founded in 1346 and there is one abandoned village — Wrzosówka, founded in 1571 and depopulated in the 1970's (Fig. 1a). The area of the Konradowski Potok basin is 6.6 km^2 with slopes from 15 to 30° and altitudes between 530 and 890 m a.s.l. (Fig. 3b) There were two villages — Rogóżka, founded in 1346, and Czatków, founded in 1631, of which only one farmstead remains. In the upper Nysa Kłodzka basin (9.9 km^2) altitudes vary

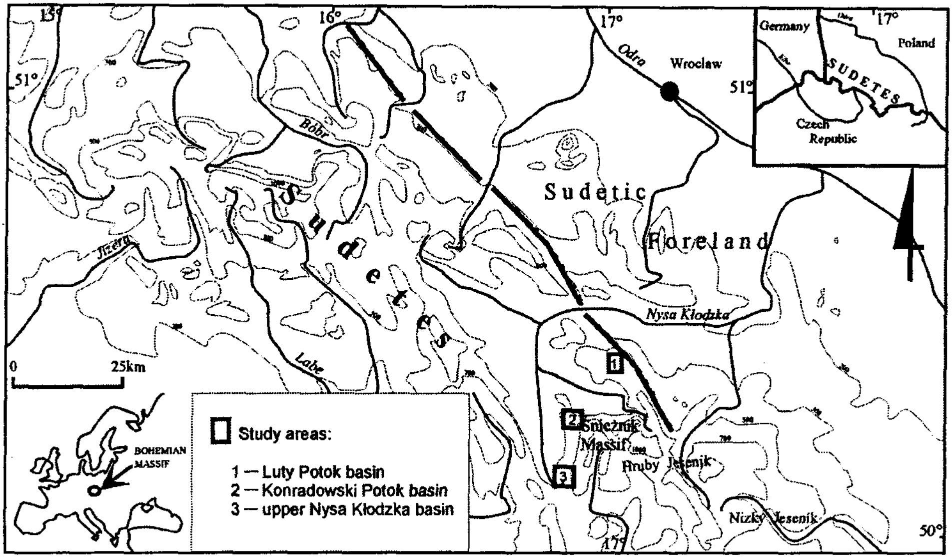
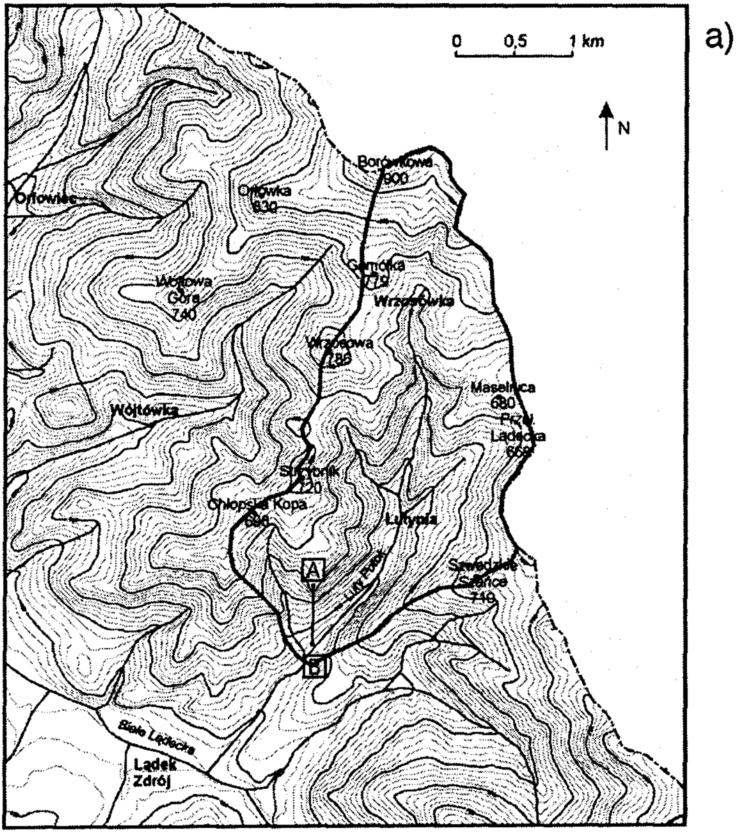


Fig. 2. Study area



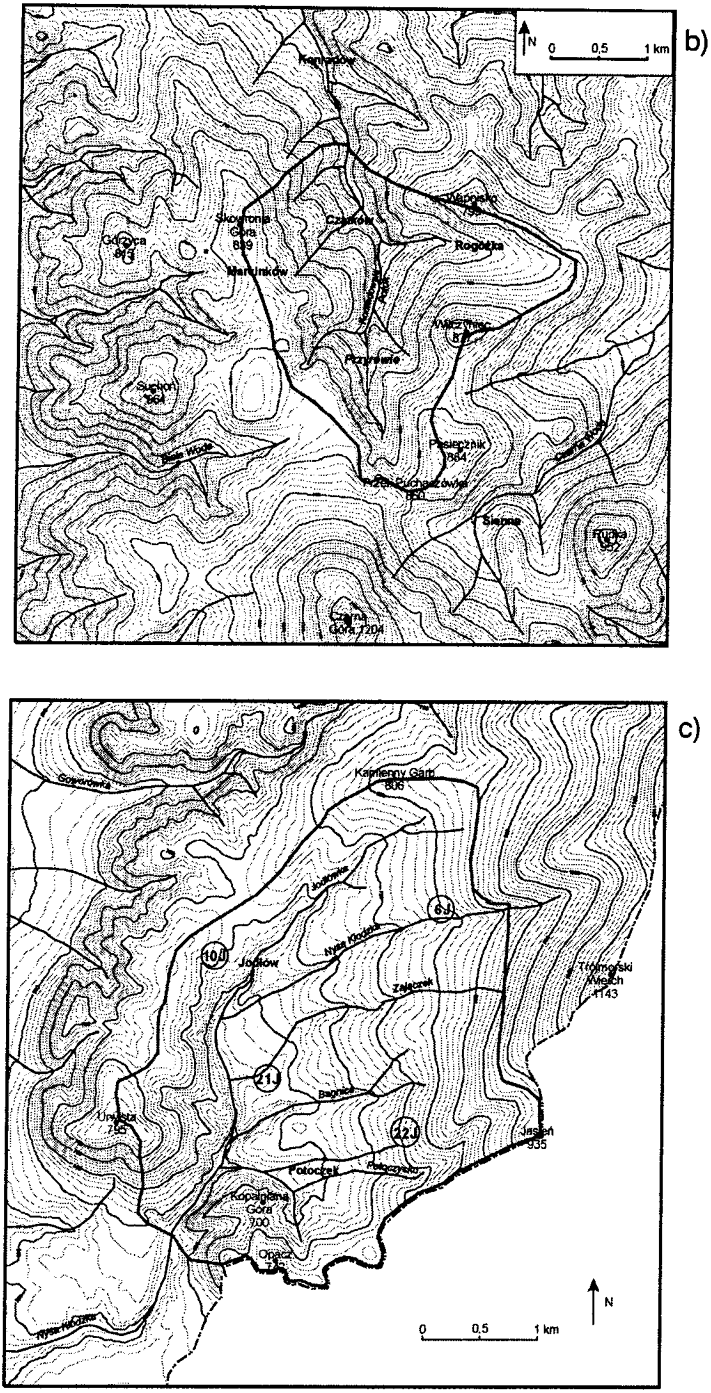


Fig. 3. Hypsometry and extent of the study areas. a — the Luty Potok basin, A–B — slope profile presented in Fig. 10; b — the Konradowski Potok basin; c — the upper Nysa Kłodzka basin, numbers in circles indicate sites of C14 dated sediments, presented in Fig 8

from 560 to 935 m a.s.l. and slope inclination is also very diverse, ranging from 5 to 20° (Fig. 3c). There are two villages, Potoczek and Jodłów, founded in 1564 and 1572 respectively (Fig. 1). All villages have a similar socio-economic history, with an initial increase in population density peaking in the second part of the 19th century (Fig. 1). All selected areas have been consequently subject to constant decrease in population and economic, mainly agricultural, decline, which were most intense after the second world war (especially in the 1950s and 1960s). Some of the villages (Wrzosówka, Rogóżka, Czatków) have been totally deserted and are no longer in existence. The selected areas also have a similar geological background, with Palaeozoic metamorphic rocks dominating, mainly gneiss and mica schist (Gierwielaniec 1971). Annual rainfall at 800 m a.s.l. is 800–1000 mm with occasional storm events with rainfall intensity of the order of 20–50 mm per hour (Piasecki 1996).

CONTEMPORARY STATE OF GEOMORPHIC SYSTEMS

SURFACE DENUDATION OF SLOPES UNDER VARYING VEGETATION COVER

The extent of arable land in the study area is currently negligible in both the Luty Potok and Konradowski Potok valleys, and is of importance only around Jodłów in the upper Nysa Kłodzka basin (Fig. 4). Agricultural land use survived only on slopes with an inclination of less than 15°, while steeper slopes (up to 25°) have been abandoned. Former fields are used either as pastures where they become covered with dense grassy surface or they have been abandoned and the process of secondary vegetation succession follows. It results in a constant increase in the vegetation cover density on the slopes.

The process of natural succession occurs widely in the whole study area and has mainly spontaneous character, though in places it is also steered and maintained by forestry economy (Zimny 1996; Latocha 2003a). Most slopes are overgrown with grasses and shrubs with pioneer trees, such as rowan, birch and spruce, encroaching on former agricultural lands. As a result, a substantial lowering of the forest-arable land boundary can be observed within the last 100 years and has led to an immense spread of forest stands at the expense of agricultural lands (Fig. 5). For example in the Konradowski Potok basin the area covered with forest is now around 280% of its extent in the second part of the 19th century. Former agricultural terraces can be found within the forest at present. The forest-arable land boundary has descended within last century by a few metres (e.g. in upper Nysa Kłodzka basin), to a few hundred metres in the Konradowski Potok basin. In the latter area forest stands spread not only downslope but also expand upslope, towards summits. This bi-directional forest expansion is the result of the variety of slope inclinations — agricultural lands occupied lower and upper parts of slopes where angles are up to 25°, while an inclination of 25–35°, which occurs in the middle part of the slope, allowed forest stands to survive and not be re-

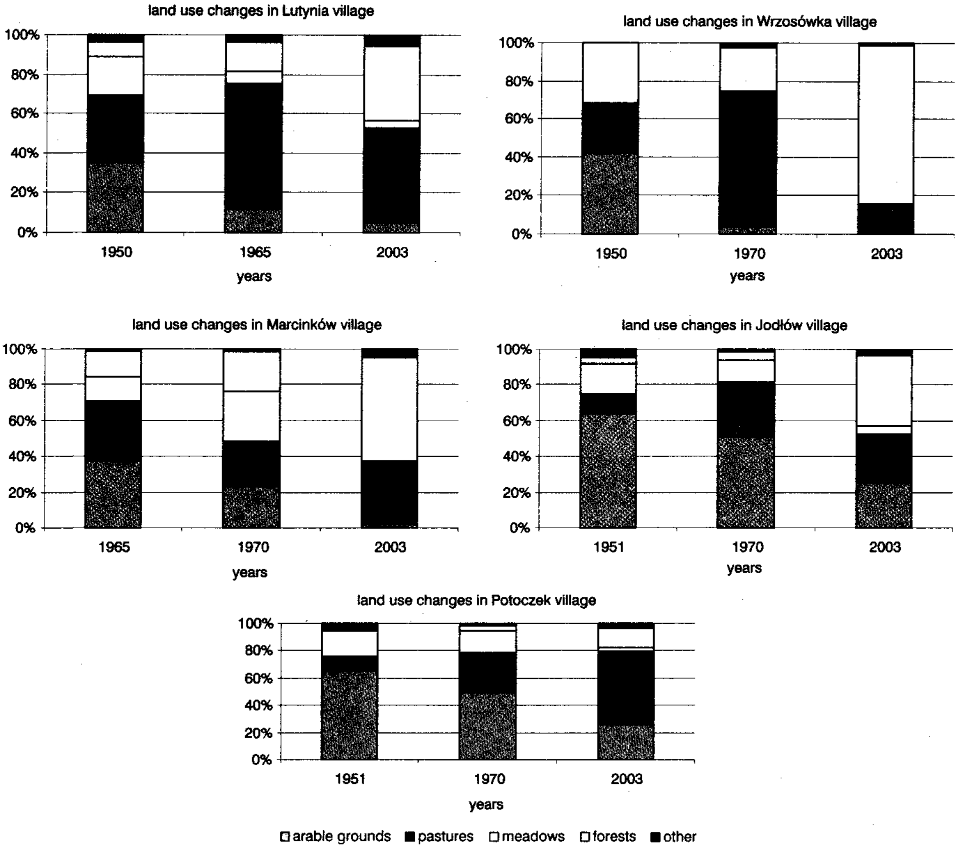


Fig. 4. Land-use changes in the study area within the last 50 years

moved for agriculture extension. The summit surfaces on the Konradowski potok watersheds are broad and flat, and so were used as arable fields in spite of their high elevation (800–840 m a.s.l.).

The spread of trees occurs not only at the forest edges but also from patches of trees and shrubs overgrowing agricultural terraces or former field tracks. As a result,

Table 1

Surface wash on slopes with various land-use

surface wash				author
forest	grassland	crops	potatoes	
0.2–0.8 $g \cdot m^{-2} \cdot yr^{-1}$	0.6–0.9 $[g \cdot m^{-2} \cdot yr^{-1}]$	58–230 $[g \cdot m^{-2} \cdot yr^{-1}]$	7,000–10,000 $[g \cdot m^{-2} \cdot yr^{-1}]$	J. Klementowski 1996
–	1.2 $[m^3 \cdot ha^{-1}]$	8–11 $[m^3 \cdot ha^{-1}]$	33 $[m^3 \cdot ha^{-1}]$	J. Fatyga 1998

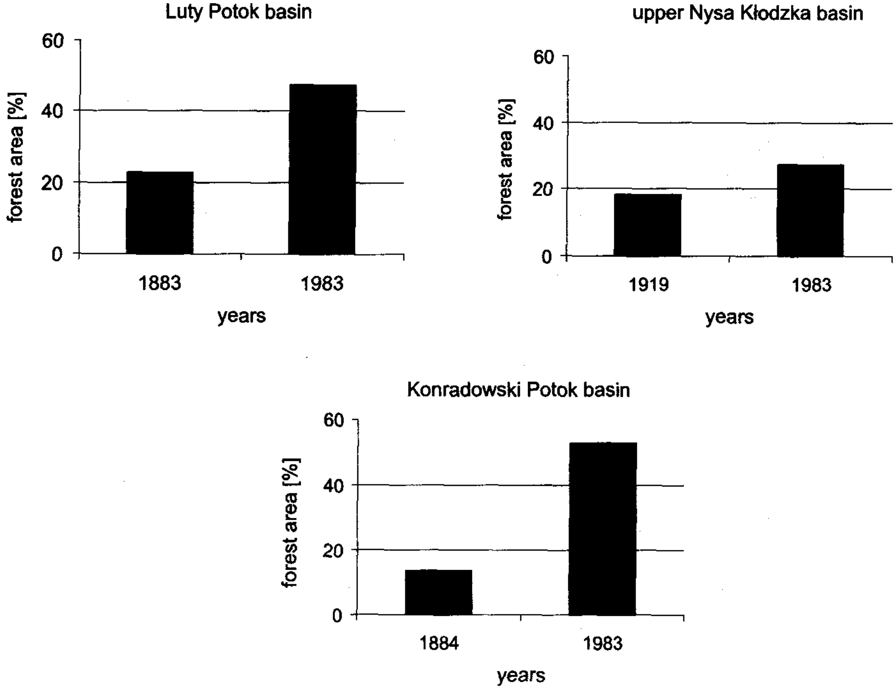


Fig. 5. Increase in forest areas within the last century

the pattern of secondary succession is very irregular, forming lines, clusters or patches of trees, shrubs and grasses on abandoned lands (Klimczak 1996).

As a result of the grassy cover on most slopes in the study area and great expansion of forest areas surface wash from the slopes is of minor importance. In fact, no fresh signs of contemporary erosion from slope surfaces can be observed (Latocha 2004). This is also true of other Sudetic areas, where forest or grass covers on slopes reduced the geomorphic effectiveness of extreme climatic events, hindering erosion (Czerwiński and Żurawek 1999). The role of vegetation cover in favouring or hindering surface runoff has been widely discussed elsewhere (Gerlach 1966; Gil 1976; Słupik 1981; Lach at al. 1990). Detailed studies on surface wash and sediment yields from the Sudetes region (Oświecimski 1950; Bieroński et al. 1992; Klementowski 1996; Fatyga 1998) also indicate that surface wash and surface denudation rates on slopes with dense forest or grass cover are several orders of magnitude smaller than those operating on slopes with arable fields, especially those sewn with potatoes which favours the most intensive soil erosion (Table 1). Therefore it may be concluded that morphogenetic processes on slopes, where agricultural activity was abandoned, and which are subject to intense and fast secondary vegetation succession, are of minor intensity and effectiveness.

The stability of slopes and preservation of slope covers under forest and grass also suggests that sediment supply directly from the slopes is of little importance in the present-day geomorphic system in the Sudetes (Table 1). In addition, other factors indicate that the contemporary slope-channel coupling is weak such as the disappearance of natural connections between slopes and channels, i.e. field tracks.

Unpaved field roads are the main lines of sediment transfer from slopes to their footslopes and on to the channels. According to research in the Carpathians, up to 90% of the suspended load in rivers is supplied by such field roads (Froehlich 1982; Froehlich and Słupik 1986). Their linear shape and frequent elongation downslope favour concentration of energy, and thus of erosional forces, during rainfall events.

In the study area most former field access tracks have vanished and in many cases they are no longer discernible in the landscape, with the exception of places where tree-lines indicate the former existence of roads. A comparison of field road networks in the 1970s (as presented on the topographic maps) with the present-day state of the roads based on field investigations revealed that the entire length of unpaved roads is currently on average only 50% of their length 30 years ago (Fig. 6). In places, especially on steeper slopes (over 25°) as in the

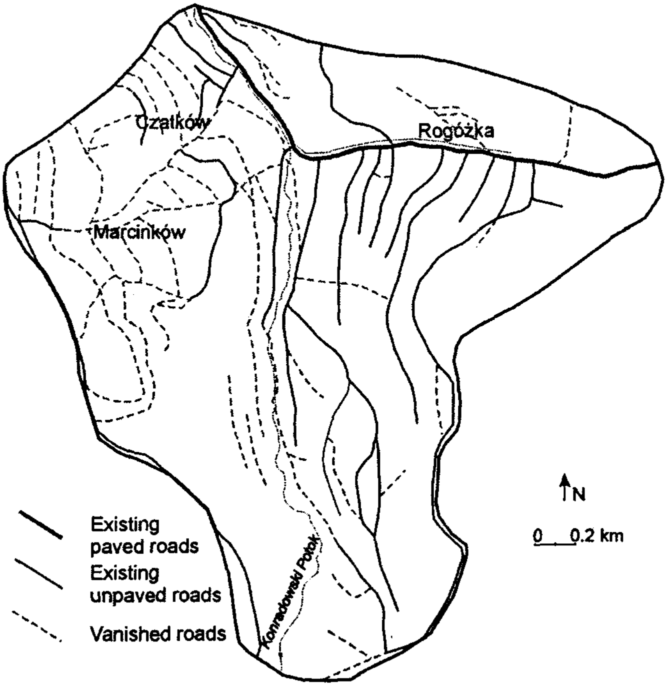


Fig. 6. Disappearance of unpaved field and forest road within the last 30 years in the Konradowski Potok valley

Konradowski Potok valley, on higher slopes (over 700 m a.s.l.) as in the upper Nysa Kłodzka basin or on slopes with an aspect less favourable for agriculture (N, NW, NE) as in the Luty Potok basin, the percentage of vanished roads can be as much as 70–80% of the total length present in the 1970s.

Field access road disappearance is mainly caused by two factors. In some cases roads have become overgrown with grasses, shrubs and even trees, and in others they are filled with fine sediments derived from denudation of adjacent road scarps of road cuttings. The latter process is best seen in former road gullies which, when no longer in use, become filled with both organic and mineral matter consequently raising the floors and smoothing the scarps. Eventually the entire form degrades and becomes obscure in the landscape (Latocha 2004).

However, some places in the study area (e.g. on the slopes of Borówkowa in the Luty Potok basin and Wilczyniec in the Konradowski Potok basin) are subject to intensive forestry activity, including timber felling and its transportation down to the valley floors resulting in many new roads, originating from logging tracks. Examples of their morphometric characteristics are given in Table 2. They dissect the slope surface to a depth of over 0.5 m and thus form new sources of sediment erosion and supply. Colluvial fans are a common feature at the mouth of logging tracks, with the most extended one at the footslope of Wilczyniec in the Konradowski Potok basin — its surface covers almost 60 m^2. Nevertheless, linear erosion and sediment transfer and accumulation related to logging tracks is of importance only locally and covers only a very small percentage of the entire study area.

Table 2

Morphometric characteristics of logging tracks in the Konradowski Potok basin

No.	Road width [m]	Logging track width [m]	Logging track incision [m]
I	2.3	1.7	0.4-0.45
II	3.0	0.4–0.7	0.5–0.55
III	2.0	1.6	0.35–0.4

The disappearance of field roads presents two indications that contemporary slope and channel linkages are of minor importance and negligible intensity. Firstly, roads overgrown by dense vegetation cover can no longer act as the main corridors for sediment transfer down the slope. Secondly, the filling of road cutings with fine material derived from road scarps indicates that denudational processes, even if they do occur, act only at a local scale. Sediment eroded from scarps accumulates close to its origin, right below the scarp footslope and is not transferred to lower parts of slope (Latocha 2004).

In general then, the role of unpaved roads in sediment transfer and in slope-channel coupling has substantially diminished within the last few decades.

The processes of incision and lateral erosion are common along most streams in the study area. The incision ranges from 0.2 to 2.5 m, with an average depth of 1–1.5 m. Dendrochronological analyses of trees overgrowing stream banks, especially in places where lateral erosion has left their roots exposed up to 0.5 m over the present water level, allowed the time when erosional processes started to operate to be estimated at between 50 and 80 years ago (Latocha 2003b). It coincides with the period of population decline of mountain villages which started at the end of 19th century and intensified after the second world war (Fig. 1). Consequently, the onset of bed and lateral erosion can be linked with abandonment of agricultural activity on those slopes. As was shown above, secondary vegetation succession on former arable grounds, along with the decrease in field road densities, have hindered sediment supply to the footslopes and on to the channels. As a result, fine-grained suspended load in rivers diminished, which in turn has induced erosional processes in their channels.

The present-day channels are of sinuous or meandering type with gravel beds. During heavy precipitation events, deposition occurs both in the channel zone and, locally, in the overbank zone; however, it is largely confined to places with favourable morphological conditions (valley widening or flattening, decrease in slope). Deposition takes the form of boulder and gravel mounds, bars and berms, deposited along river banks (Zieliński 2003). These depositional features are much more common in channels where boulders of up to 1 m in diameter, eroded from river banks, are deposited within them. Detailed geomorphic mapping revealed the existence of several recent generations of overbank depositional forms suggesting intensification of overbank deposition of gravel and blocks within the last century (Latocha 2004). In addition, no signs of contemporary overbank deposition of fine-grained sediments have been found in the valleys investigated. Bed incision and coarse-grained accumulation are not the only characteristic features of high discharge events. During episodes of intense or prolonged precipitation most streams show a tendency towards braiding (Zieliński 2001, 2003; Migoń et al. 2002; Hrádek and Lacina 2003; Klimek at al. 2003). Abandoned dry channels on floodplains can be found in all valley floors investigated in the study area. As with the overbank depositional gravel forms, they are relatively young features, eroded within the last few decades. Both erosional and depositional landforms developed during extreme flooding events are common features in other Sudetic floodplains, (Czerwiński and Żurawek 1999; Żurawek 1999; Łach 2001).

In conclusion, the subsystems of river channels have become more dynamic within last century or so which is evidenced by widespread incisions and lateral erosion as well as by gravel beds in the channels, coarse-grained overbank deposition and braiding tendency during extreme events.

SLOPE-CHANNEL COUPLING IN HISTORICAL TIMES

The present state of the geomorphic system in upper parts of mid-mountain valleys with decreasing human impact seems to be one of relative stability with geomorphic processes operating mainly at a local scale, which refers mainly to slope domain. In addition, the linkages between slope and channel subsystems are weak. However, the question arises as to whether this was always the case and what the relationships between slopes and channels were during the period of intensive human activity.

Detailed sediment analyses of slope covers and alluvial sediments within the valley floors have indicated much more intense morphological processes in the past. Slope covers display a distinct division into two layers (Latocha 2003b, 2004). The upper unit consists of unstructured, fine material, mainly sand and silt

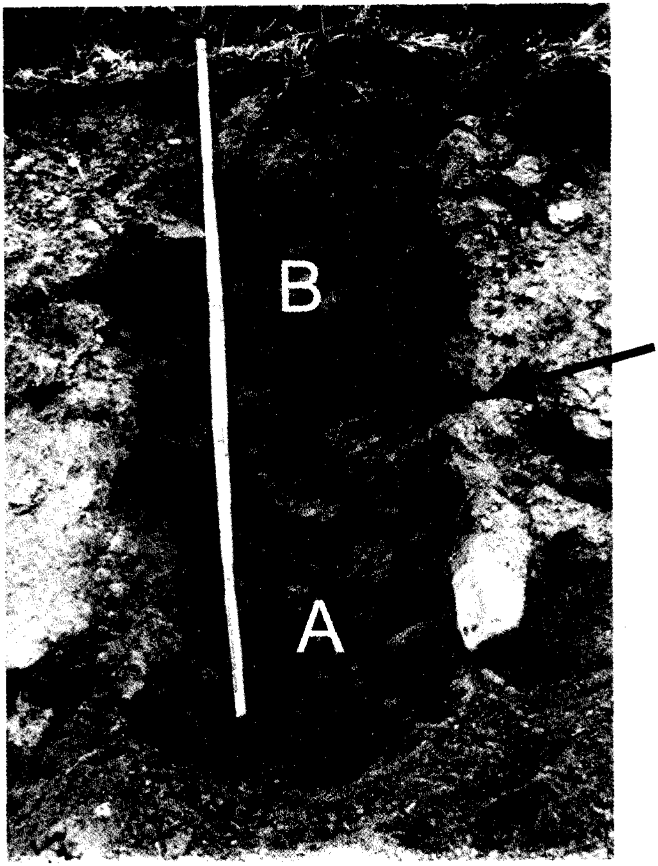


Photo 1. A section through slope sediments in the upper Nysa Kłodzka valley; two distinct layers are discernible, representing periglacial cover with solifluidal elongation of long axis of clasts (A) and anthropogenic colluvium with charcoal (B). A layer of charcoal (indicated by arrow) separates the two layers

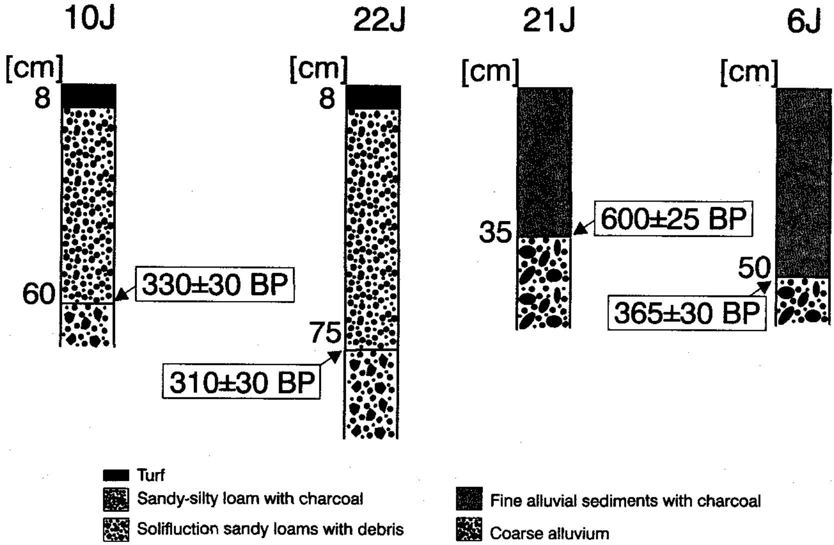


Fig. 7. Sediment logs of ^{14}C dated slope and alluvial deposits (upper Nysa Kłodzka basin); location in Fig. 3c

with an abundance of charcoal particles. In contrast, the lower layer consists mainly of coarse-grained material with angular and semi-angular clasts up to 20 cm which in places show clearly visible solifluction structures, elongated in a downslope direction (Photo 1). The boundary between these two layers is very clear, often delineated by a layer of charcoal a few centimetres thick. Radiocarbon dates for charcoal particles from a section in the upper Nysa Kłodzka basin coincide well with the foundation of nearby villages (Jodłów and Potoczek) (Fig. 7). Both radiocarbon datings and grain size, and structural characteristics of the upper layer allow its interpretation as an anthropogenic colluvium (agricultural diamicton) which was washed down from bare slopes under cultivation. Soil erosion from arable lands can be significant as has been shown in historical sources; for example, S. Bac (1948) describes an 8–12 cm thick soil layer that was washed down during one extreme precipitation event in the Kłodzko region in the 1920s. In contrast, the lower layer is interpreted as an inherited Pleistocene deposit caused by solifluction.

Analyses of alluvial sediments within the valley floors suggest that some of the slope material was stored within the basins, deposited on the valley floors during extreme events, resulting in floodplain build-up. This conclusion is based on the two-facies characteristics of alluvial sediments which occur commonly in the study areas and in other Sudetic drainage basins (Teisseyre 1985). The lower layers of the alluvial sediments are coarse-grained, while the upper layers are very fine grained, with a substantial amount of charcoal particles. The former can be interpreted as channel facies, related to gravel-bed, possibly braided rivers which dominated in the Sudetes before the onset of human settlements and agricultural activity on slopes (Teisseyre 1985; Hrádek 1999). In contrast, the upper layer can be correlated with the clearance of forest and increase in fine sediment supply from slopes under cultivation. This unit consists mainly of sand and silt and ranges in thickness from 8 to 80 cm in the study area, while in other places in the Sudetes and their foreland layers of fine overbank deposits vary from 0.5 m to 4 m (Teisseyre 1985; Szczepankiewicz 1989; Klimek 2002). The increase in suspended load carried by rivers was followed by changes in channel patterns and establishment of a sinuous or meandering single channel pattern which still dominates, even though braiding occurs temporarily and locally (Photo 2).

Photo 2. Single channel sinuous rivers are typical for the study area, although episodic braiding and coarse material deposition occurs during flooding events. Braiding is hypothesized to be the reaction of channel systems to reduction of fine sediment supply from the slopes

To estimate the general rate of surface denudation detailed studies were conducted on slopes with agriculture terraces. Terraces, introduced to agricultural practices in the second part of the 19th century in order to reduce soil erosion (Walczak 1968), acted as sediment traps. Calculation of slope material stored within terraces allows the surface denudation rate from upper parts of slopes to be estimated (Latocha 2004). It shows that the process of surface washing was much more intense when slopes were under cultivation and that soil erosion was a crucial problem for mountain communities (Table 3). Terraces turned out to be a successful method of limiting material losses from slopes as proved by distinct

Table 3

Slope sediment storage and surface denudation on slopes in the study area

Location	Terrace	Volume of material stored behind the riser [m^3]	Total denudation [mm]	Denudation within last 150 years [mm/year]
Luty Potok basin	I	1,872	260	1.73
	II	2,297	174	1.16
	III	6,349	214	1.43
	IV	4,092	341	2.27
Konradowski Potok basin	I	1,080	56.2	0.37
	II	1,260	37.5	0.25
	III	765	56.2	0.37
	IV	2,080	400	2.67
	V	3,912	326	2.17
	VI	5,292	196	1.31
	VII	7,540	306	2.04
	VIII	5,549	199	1.33
	IX	3,580	358	2.39
Upper Nysa Kłodzka basin	I	573	71.6	0.48
	II	582	91	0.6
	III	582	91	0.6
	IV	490	122.4	0.82
	V	381	95.2	0.63
	VI	310	22.8	0.15

differences in thickness of anthropogenic colluvium within slope segments. Within the terraces colluvium thickness is between 50–100 cm on average, increasing in places up to 160 cm, while in the upper parts of the terraces its thickness is only 10–40 cm (Fig. 8). However, as terraces are quite recent features it is hypothesized that before terracing a much larger amount of sediment was washed downslope and transported on to stream channels, and away from the drainage basin. It is not possible though to estimate the probable amount of sediments removed from the basins within historical times.

EVOLUTION OF LOCAL GEOMORPHIC SYSTEMS IN THE HOLOCENE

Analyses of slope covers and alluvial sediments in the study areas, together with available historical data allows us to distinguish five phases in the Holocene, strongly correlated with changes in human activity in these mountain environ-

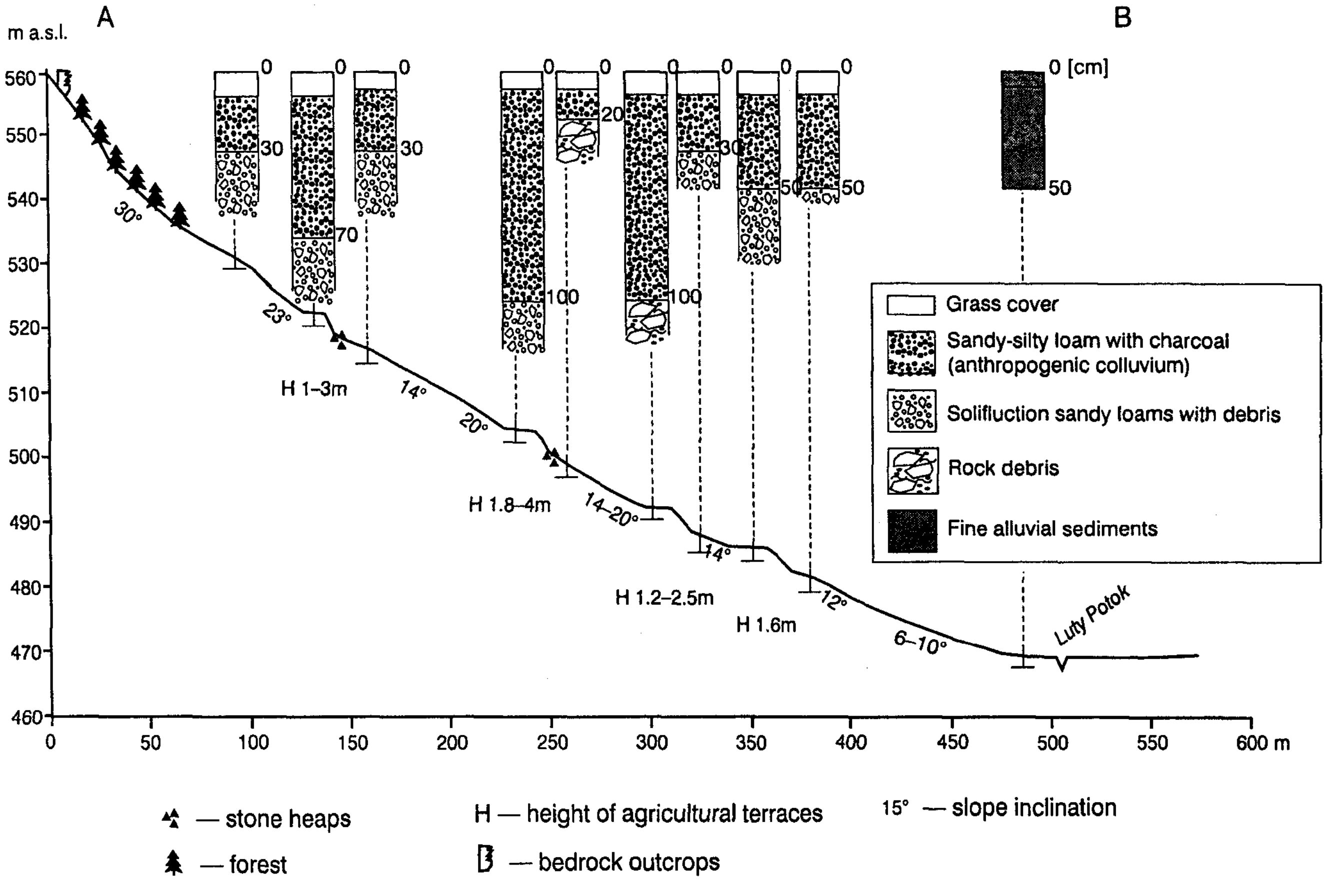


Fig. 8. Slope profile to show the role of terracing in sediment storage within the slopes. Profile location in Fig. 3a

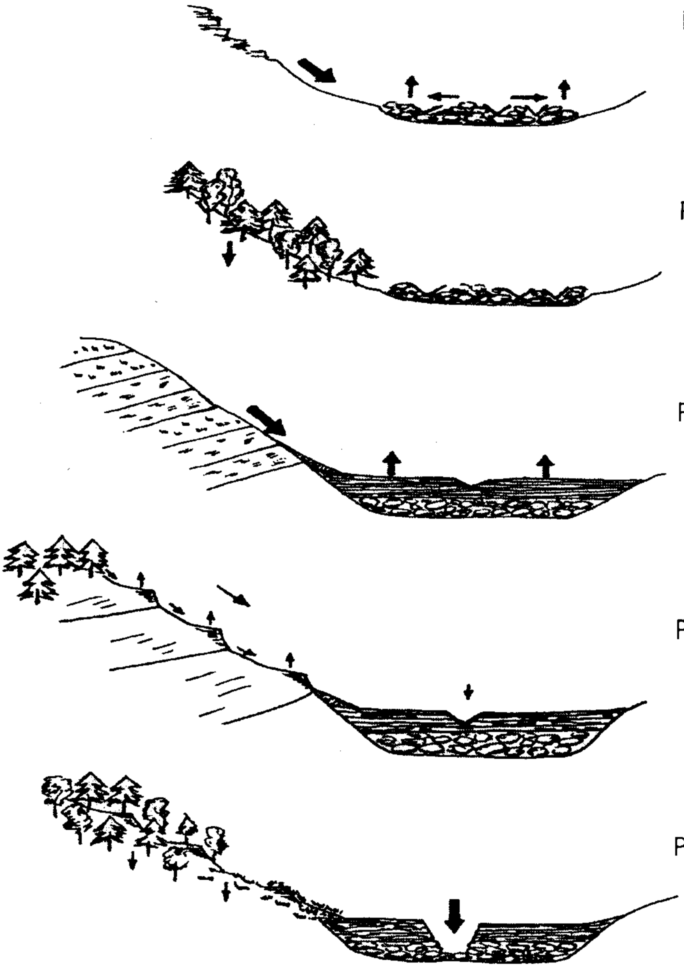


Fig. 9. Phases of geomorphic evolution of the study areas in the Holocene. See explanation in the text; arrows indicate direction and intensity of geomorphic processes

ments. They were characterised by diverse morphological processes, alternating in intensity and thus changes in strength of slope-channel system linkages (Fig. 9):

PHASE I — INTENSE SLOPE-CHANNEL COUPLING UNDER NATURAL ENVIRONMENTAL CONDITIONS

The first stage of contemporary landscape development can be placed at the end of the Pleistocene. The cold climate favoured intensive weathering and solifluction on bare slope surfaces before vegetation cover developed in a later stage. There were no obstructions to transferring a huge amount of coarse material downslope to the valley floors and stream channels which braided across broad gravel beds.

PHASE II — STABILISATION OF GEOMORPHIC SYSTEM UNDER PRIMEVAL FOREST COVER

Development of dense vegetation cover, mainly forests, stabilised slope covers and both surface run-off and soil erosion were substantially reduced. Weathering of local bedrock and formation of soil cover dominated in that period. As a result, supply of coarse material to channels ceased and delivery of new sediments from the slopes was of minor importance. Morphological processes on the slopes and in channels were least intense during the whole Holocene with very weak connections between slopes and channels. It can be assumed that during this phase the environmental system was most stable. This lasted until late mediaeval times when human settlements and economic activity developed in upper parts of the mountain valleys. The low morphodynamics of the geomorphic system is confirmed by slope cover characteristics with anthropogenic colluvium deposited directly over periglacial sediments.

PHASE III — INTENSIFICATION OF MORPHOLOGICAL PROCESSES UNDER HUMAN IMPACT

Forest clearances and agricultural use of terrain up to 850 m a.s.l. and with a slope greater than 20° induced more intensive morphological processes. Bare slopes, devoid of protective tree cover, were easily eroded and soil was washed down. Soil erosion was especially intense on slopes where cereals and potatoes were cultivated as well as along the dense network of field roads — road gullies up to 2. 5 m deep developed at that stage. Fine-grained material, which was selectively removed in the first stage, was subsequently either deposited at footslopes and at road outlets as colluvial fans or delivered directly to channels and transported onward as a suspended load in rivers. A characteristic feature of the anthropogenic colluvium is an abundance of charcoal related to forest clearances. Some of the fine sediments were entirely removed from the basin and may have accumulated at the mountain foreland (Wroński 1974; Teisseyre 1985; Szczepankiewicz 1989; Klimek 2002) while the remainder was deposited within the valley floors as overbank sediments during flooding events. Fine material was deposited above older, coarse channel facies sediments. Consequently, the channel was transformed from a braided pattern to a single sinuous or meandering channel. Moreover, the removal of a substantial amount of slope sediment (Table 3) was reflected in the vertical accretion of floodplains and a build-up with layers of sand-silt layers. In the study area the thickness of fine overbank sediments connected with agricultural activity on slopes ranges from a few centimetres to 0.8 m, depending on local relief, and is to be found at altitudes up to 700 m a.s.l.

This phase reflects the most efficient slope-channel coupling. Slopes and channels formed one strongly interlinked geomorphic system with a dense network of field roads acting as the main pathways of sediment transfer from the slopes to valley floors and channels.

PHASE IV — WEAKENING OF SLOPE-CHANNEL LINKAGES UNDER PLANNED MANAGEMENT OF THE ENVIRONMENTAL SYSTEM

In the second part of the 19th century, even though economic activity in mountain regions was still significant and the population reached its peak, some changes in land-use, aimed mainly at limiting soil erosion, triggered changes in the geomorphic system as well. Coniferous plantations on steeper slopes (Bugajski and Nowiński 1983; Zimny 1996) reduced surface run-off and terracing of cultivated slopes (Walczak 1968) resulted in decrease in surface wash downslope. Most sediments were then trapped within terraces and were not transferred to the footslopes or channels. Terraces changed not only the longitudinal profiles of slopes, which became step-like, but also divided slopes into smaller, partially closed units with erosional processes dominant in the upper sections, while accumulation dominated in lower parts. Such sequences of sections with diverse morphological processes could repeat many times along the slope profile and are reflected in alternating colluvial thicknesses, varying from 10 up to 160 cm. Storage of slope material within terraces (Table 3), along with new forest plantation on the slopes, reduced sediment supply to the river channels. Incision into fine alluvial sediments, deposited in the previous phase, presumably started at this stage as is supported by dendrochronological studies.

Human activity in this phase (terracing, afforestation) resulted in weakening of slope-channel linkages. However, a dense network of field roads was still active in sediment delivery downslope and thus this period can be described as a transitional phase from very intense to moderate morphodynamics of the slope-channel system.

PHASE V — SLOPE-CHANNEL SYSTEM DECOUPLING AS A RESULT OF POPULATION DECLINE AND LAND ABANDONMENT

The last phase of environmental change is related to population decline in the mountain regions and abandonment of intensive agriculture on slopes, followed in turn by a rapid process of secondary vegetation succession, including a substantial increase in forest area and a descending forest-arable land boundary (Fig. 5). Grass, shrubs and trees have spread not only onto former fields or pastures but also onto field roads which are no longer in use. Consequently, around 50% of former field roads in the study area have disappeared from the landscape which further weakens the linkage between slopes and channels. No signs of contemporary erosion from overgrown slopes are discernible, with the exception of areas with intensive forestry industry, where erosion occurs locally, along logging tracks. Surface denudation, where it occurs on slopes, is limited to former road scarps and is of importance only at a local scale as the eroded sediments are deposited in the vicinity of the source area. Thus slope subsystems may be evaluated as quite stable, with intense morphological processes acting only locally and temporarily, in very limited areas.

A substantial decrease in sediment delivery from the slopes is reflected in changes in the fluvial systems. The lack of fine sediment supply results in a tendency to incision and lateral erosion — most streams in the study areas have already dissected their older fine alluvial floodplains and are cut into older coarse sediments of Pleistocene/early Holocene age. The depth of incision is up to 2.5 m (1–1.5 m on average) in the study area. Therefore contemporary rivers are of gravel-bed types and show a tendency to braiding during flooding events (Teisseyre 1985; Zieliński 2001; Klimek at al. 2003). Most recent overbank deposits, where they occur, consist mainly of coarse sediments, in contrast to the previous phase when fine material was more common.

The fact that erosion and deposition processes are limited indicates that slopes and channels do not act as one interconnected system but that they form two separate subsystems with weak linkages. Contemporary fluvial processes are a response to diminished sediment supply from slopes.

CONCLUSIONS

The functioning of slope-channel systems in the Eastern Sudetes has been controlled by many internal and external factors which have triggered substantial changes in the intensity and type of prevailing morphological processes over time. These changes can be easily correlated with altering socio-economic factors, related to mountain communities. In this respect, human activity has influenced the environmental system mainly by strengthening or weakening slope-channel linkages, resulting in turn in changes in surface denudation rate, sediment supply and river channel patterns. The present state of slope-channel systems in the study area is a response to recent withdrawal of intensive human activity from mountain regions and shows only weak slope-channel coupling, with geomorphologically relatively stable slope domains and more dynamic channel domains.

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STRESZCZENIE

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EWOLUCJA GEOMORFOLOGICZNA ZLEWNI ŚRÓDGÓRSKICH W WARUNKACH ZMIENNEJ ANTROPOPRESJI, SUDETY WSCHODNIE, SW POLSKA

W pracy przedstawiono wyniki badań nad zmiennym wpływem działalności człowieka na przebieg procesów rzeźbotwórczych, wyróżniając kilka faz rozwoju geomorfologicznego rzeźby w nawiązaniu do aktywności człowieka w Sudetach Wschodnich. Do analizy wybrano trzy doliny śródgórskie, w których od średniowiecza obserwowano intensyfikację osadnictwa i działalności gospodarczej, w tym w szczególności rolniczej, a które od drugiej połowy XIX w. ulegały stopniowemu wyludnianiu, aż do całkowitego zaniku niektórych z położonych w ich obrębie wsi. Szczegółowe kartowanie geomorfologiczne naturalnych i antropogenicznych form terenu, analiza pokryw stokowych i osadów aluwialnych, a także analizy zmian w zbiorowiskach roślinnych pozwoliły na określenie wpływu zmian w użytkowaniu ziemi w obszarach górskich na intensywność i dynamikę procesów denudacyjnych i erozyjnych zachodzących w zlewniach. W pokrywach stokowych i aluwiach wyróżniono warstwy związane bezpośrednio z działalnością człowieka (deluwium antropogeniczne i mady rolnicze), co potwierdziły także wyniki datowań radiowęglowych węgli drzewnych, które dobrze korelują się z początkiem osadnictwa na analizowanym terenie.

Badania wykazały także istnienie silnych powiązań pomiędzy subsystemem stoków oraz dolin i koryt rzecznych w okresie intensywnej gospodarki człowieka oraz ich stopniowe osłabianie w wyniku wycofywania osadnictwa i rolnictwa z terenów górskich. Szczególną rolę odegrał tu około 50 procentowy (względem stanu sprzed 30 lat) zanik sieci dróg polnych, stanowiących naturalne drogi transportu materiału i łączniki pomiędzy stokiem a dnem doliny. W obecnych warunkach malejącej antropopresji subsystem stoków uznano za względnie stabilny pod względem procesów denudacyjnych, co jest wynikiem głównie procesów wtórnej sukcesji roślinnej na dawne grunty porolne, w tym w szczególności przyrostu powierzchni leśnych. Z kolei subsystem koryt jest obecnie aktywny, z wyraźną tendencją cieków do erodowania. Jest to efektem zmniejszenia dostawy drobnofrakcyjnego materiału ze stoków, który to proces dominował w okresie intensywnego rolniczego użytkowania i który doprowadził do nadbudowy den dolin piaszczysto-pylastymi aluwiami (mada rolnicza). Zmiany w dostawie materiału do cieków prowadzą z kolei do przekształcania koryt: intensyfikacja rolnictwa na stokach doprowadziła do przekształcenia odziedziczonego po warunkach peryglacjalnych wielokorytowego układu koryt w cieki jednokorytowe, aluwialne, kręte lub meandrujące. Obecnie, w wyniku erozji, większość cieków posiada koryta żwirodenne, które w trakcie większych wezbrań wykazują tendencję do roztokowania.

Podsumowując, można stwierdzić, że zmiany w charakterze oraz intensywności procesów geomorfologicznych na analizowanym obszarze można korelować ze zmianami społeczno-ekonomicznymi, a zapis tych zmian zachował się zarówno w istniejących formach rzeźby, jak i pokrywach stokowych oraz osadach aluwialnych. Rola oddziaływania człowieka na środowisko polega w tym kontekście przede wszystkim na intensyfikowaniu bądź osłabianiu powiązań pomiędzy systemem stoków i dolin/koryt, czego efektem są zmiany w tempie denudacji, ilości transportowanego materiału oraz w układzie koryt.