S T U D I A G E O M O R P H O L O G I C A C A R P A T H O - B A L C A N I C A
vol. LV, 2021: 71–88 PL ISSN 0081-6434

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INFLUENCE OF LAND USE CHANGES ON ROAD NETWORK AND CHANNEL LEVEL IN USZWICA CATCHMENT IN 1975–2015 (POLISH WESTERN CARPATHIANS)

Abstract: The impact of land use changes (LULC) on road network and channel level on the period 1975–2015 were studied in the Uszwica catchment (22.7 km^2) in the Polish Western Carpathians. This period covers the transformation of the Polish economy from a communist system to a free-market economy after 1989. The analysis of aerial photos using GIS technics indicates that during the investigated period the forest area increased by 25% and the cultivated land area decreased by 88% in the Uszwica catchment. The population density increased from 90 to 116 people·km^{-2}, while employment in agriculture decreased from 51.6% to 4.2%. As a result of forest succession and cultivated land abandonment the density of used roads and the roads that have connection with stream decreased by 27% and 8%, respectively in the Uszwica catchment. The fluvial system of Uszwica channel was strongly influenced by LULC changes. This has led to initiated channel incision by about 1 cm·year^{-1} after 1989.

Key words: LULC, socio-economic transformation, road network changes, river downcutting, GIS, Polish Carpathians

INTRODUCTION

LULC changes have been observed in many mountain regions of Europe at different periods of time, had to significant environmental consequences and is are often associated with social and economic problems in rural areas (Macdonald et al. 2000; Bender et al. 2005; Rudel et al. 2005; Meyfroidt, Lambin 2011). Relatively low agricultural profitability (Gellrich et al. 2007; Müller et al. 2013; Pazúr et al. 2014) with high cultivation cost due to individual small farms and agricultural land fragmentation (Pointereau et al. 2008; Soja 2008; Keenleyside, Tucker 2010; Kolecka et al. 2017) as well as availability of employment outside agriculture, especially in the vicinity larger urban centres are indicated as the main reason for this phenomenon (Bucała-Hrabia 2017a, b). Low soil quality and unfavourable climatic conditions are another important factor for abandoning cultivation on the steeper slopes and higher elevations (Gellrich et al. 2007; Pointereau et al. 2008; Baumann et al. 2011).

Each region presents a specific agricultural situation that is a consequence of diverse factors (historic, geographic and socio-economic) (Pointereau et al. 2008). After the collapse of the communist economy, in Central and Eastern European countries carried out land reforms to restructure the farming sector, individualise land use and privatise farmland (Kuemmerle et al. 2009; Baumann et al. 2011; Griffiths et al. 2013). In effect, cultivated land was mostly replaced by pastures and forests in Czechia (Bičík et al. 2001; Kupková, Bičík 2016), Slovakia (Šebo, Nováček 2014), Romania (Munteanu et al. 2014) and East Germany (Baessler, Klotz 2006). The transition from the communist system to the free-market economy in 1989 caused the lack of agricultural subsidies (Kozak 2010; Munteanu et al. 2014; Bucała-Hrabia 2017b) that led to the bankruptcy of most of the agricultural enterprises (Müller et al. 2013).

LULC changes have powerfully influenced in every aspect of the environment (Dale et al. 1998). The rising population has caused the transformation of the natural environment, which for a long time was conditioned by natural factors such as climate, relief and soil properties (Goudie 2006). Regardless of the type and duration of agricultural expansion in the natural environment, the effects of this activity typically first appear in the form of changes in vegetation (Geist, Lambin 2002; Benjamin et al. 2005; Baur et al. 2006; Bucała et al. 2015). LULC changes also have a variety of geomorphological consequences. Reduced soil erosion due to forest expansion at the expense of agricultural land (Asselman et al. 2003; Boardman, Poesen (eds.) 2006; Gil 2009; Kijowska-Strugała et al. 2018) and increased density of unused roads overgrown by grass and shrubs (Arnáez et al. 2004; Latocha 2014) have greatly limited the delivery of materials eroded from slopes to rivers and streams, which, in turn, has resulted in the conversion of braided rivers to incised, single-thread channels (Soja 1977; Klimek 1987; Wyżga 2001; Kondolf et al. 2002; Liébault, Piégay 2002; Wyżga et al. 2016).

The paper examines LULC changes and their effect on the natural environment, particularly on road network and channel level changes in Polish Western Carpathians. The main tendencies of environmental changes are analysed in the Uszwica catchment which represents the foothill part of Polish Western Carpathians, from the late phase of communism to the period of free market economy (1975–2015).

STUDY AREA

A detailed investigation was performed in the upper Uszwica catchment (22.7 km^2), located in the Rajbrot and Lipnica Górna villages (Wiśnickie Foothills – Polish Western Carpathians). The catchment is built by flysch sediments (alternate sandstone and shale layers) of the Silesia nappe in the foothills (Starkel 1972). The Uszwica catchment is characterized by wide hills rising mainly to 300–500 m a.s.l. and relatively wide valleys dissected up to 100–300 m (Fig. 1). Gentle relief with the domination of convex-concave slopes is reflected in only a 21% contribution of the steep slopes above 15°.

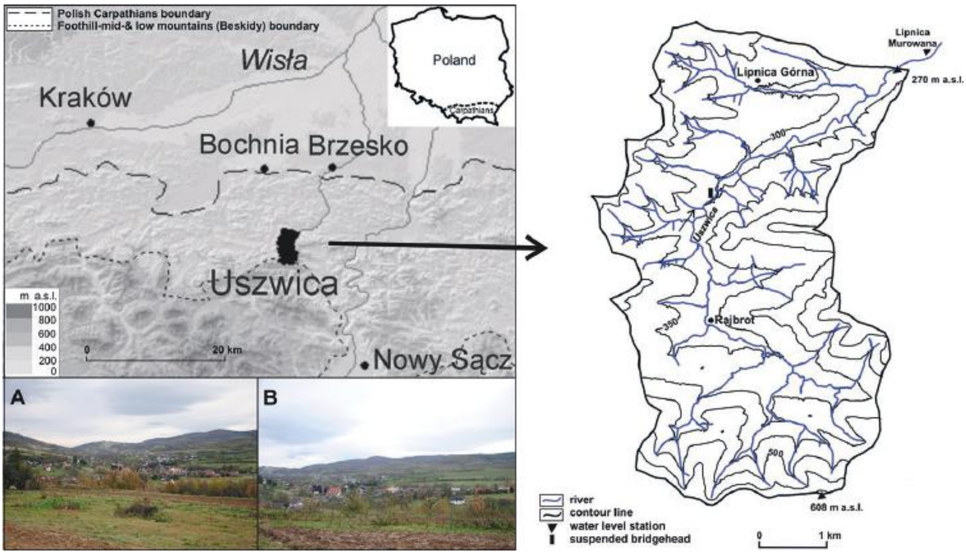

Fig. 1. Location of the Uszwica catchment: A, B - Rajbrot village

The entire Uszwica catchment is located in a temperate warm zone with a mean annual temperature from 8 to 6 °C up to 600–650 m a.s.l. (Hess 1965) and mean annual precipitation of 751 mm (Gnojnik IMGW Station at 310 m a.s.l. in 1996–2015). The silt loess-like formation supported the formation of the Luvisols in the Uszwica catchment. Soils are deep up to 280 cm and they consists mainly of silt loam (Skiba et al. 1998; IUSS Working Group WRB 2015; Szymański et al. 2017). The valley bottom of the catchment is covered by alluvial sandy clay soils. The foothill zone is occupied mainly with deciduous forests with hornbeams, oak, lime and beech (Staszkiewicz 1981; Grodzińska, Szarek-Łukaszewska 1997).

The powerful impact on the development of the local geomorphology of the Uszwica catchment was observed during the floods in 1997 which was the result of the series of 2–3 hour downpours after 2–4 days of moderate precipitation (Patkowski 2001). Heavy rainfalls connected with the downpour on 9 July 1997 with a daily precipitation of 120 mm (Rozdziele IMGW Station), caused the passing of thresholds values both of the slope and channel systems. The greatest geomorphological changes occurred in the upper part of the Uszwica river from Rajbrot to Lipnica Murowana, where the processes of erosion and transportation prevailed over the accumulation. Larger landslides and mudflows were developed on the slopes. As bank erosion dominated the entire length of the river, old bank undercuts were refreshed and new ones, developed. The flood also caused a considerable deepening of the Uszwica channel by over 2 m. As a result of rapid erosion in the main river, the outlets of tributary channels were undercut and suspended. A deposit of silts was observed on the upper part of the floodplain. Floodwaters triggered enormous losses to housing, agricultural land and damaged roads, bridges and other infrastructures (Photo 1) (Patkowski 2001).

Photo 1. The upper part of Uszwica catchment during the flood on July 1997 (Photo: S. Włodarczyk, source: www.lipnicamurowana.pl)

MATERIAL AND METHODS

The changes in LULC were derived from panchromatic aerial photographs at a scale of 1:8,000 for the year 1975, at a scale of 1:25,000 for the year 1987 and at a scale of 1:25,000 for the year 1997, as well as orthophotomaps at a scale of 1:13,000 for the year 2003 and natural colour orthophotomaps at a scale of 1:5,000 for the years 2009 and 2015 from the Main Centre of Geodetic and Cartographic Documentation in Poland. Six consistent LULC categories were defined: forests, grasslands, cultivated lands, groups of trees and shrubs, tree belts along roads and buildings. A Digital Elevation Model (DEM) at a 1 m spatial resolution, served to generate maps of a proportion of the LULC in relation to the slope inclination, as well as its changes in the 100 m classes of elevation across different time periods. Socio-economic information such as population data for 1978, 1988, 1997, 2003, 2009, 2015 and sources of inhabitants dependent only on agriculture for 1978, 1988, 2002 in the studied catchment was collected from Central Statistical Office of Poland. The information was supplemented by a questionnaire survey regarding inhabitants' income conducted in 2016. The survey covered 60% of the population in the Uszwica catchment.

The permanent river network and road network were digitized from aerial photographs for 1975 and supported with the topographic maps at a scale of 1:10,000 for 1980(81) as well as ortophotomaps for 2015 (Soja, Prokop 1996). Changes in the road network in terms of those that are used, unused (abandoned), connected to river (crossing river and/or ending close to the channel) as well as paved and unpaved were verified in the catchment during the field survey in 2015.

The impact of the LULC and road network changes on the channel bed position was assessed by an analysis of minimum water levels in the Uszwica river recorded at the Lipnica Murowana water level station in 2009–2017 (http://lsop.imgw.pl/brzesko/). In addition, measurements of the river bed's position were conducted in relation to the bridgehead with the known date of its construction collected from the Regional Water Management Authority.

RESULTS

LULC CHANGES IN THE COMMUNIST SYSTEM (1975–1987)

In 1975 over half of the Uszwica catchment was occupied by farmland (cultivated land (35.01%) and grassland (28.97%)), which dominated up to 500 m a.s.l. and on slopes inclined below 15°. The forest covered only

33.90% and dominated in the upper part of catchment between an elevation 500–600 m a.s.l., where it exceeded 75%. Groups of trees and bushes, as well as belts of trees and shrubs were concentrated along the roads (1.53%). Houses and farm storage buildings, located mainly in the lower part of the catchment occupied only 0.59% of the area. In 1978 the population density in the Uszwica catchment was 90 people·km^{-2}. Agriculture was the primary source of income for almost 52% of the population in the Uszwica catchment (Fig. 2, Tab. 1).

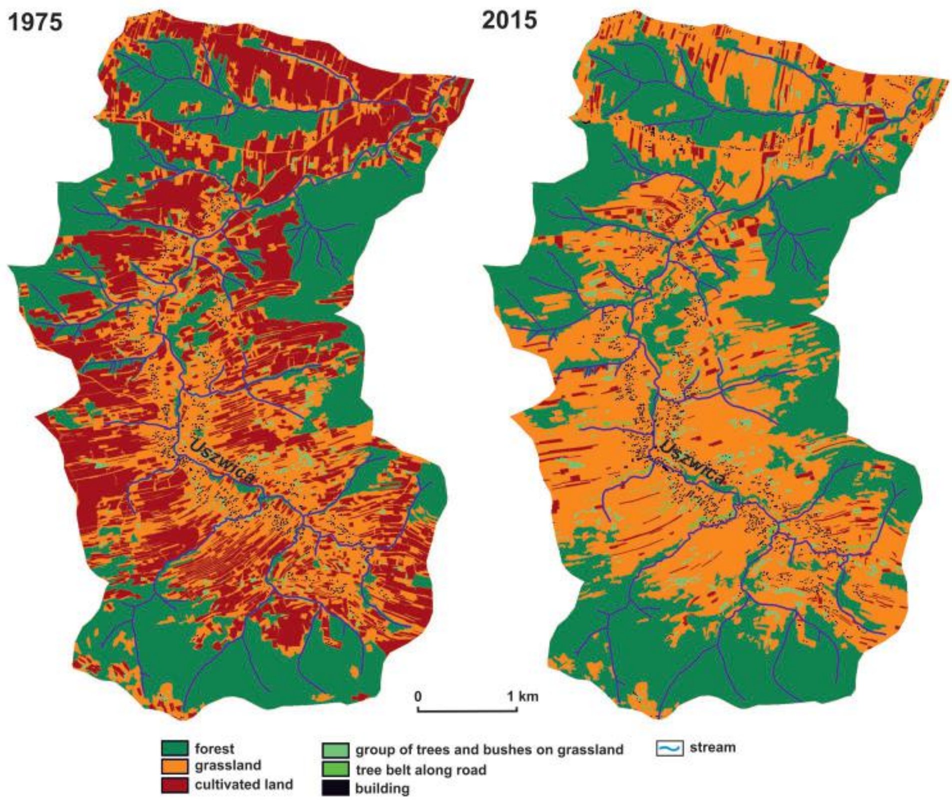

Fig. 2. LULC in the Uszwica catchment in the 1975–2015

Until 1987, just before the communist system collapsed, the LULC structure did not change substantially. However, trends of the gradual increase in forest area by 2.9% and a decrease in the cultivated land area by 10.6% in the Uszwica catchment became apparent. The upper boundary of the cultivated land in the Uszwica catchment was on the same elevation.

Table 1.

LULC changes (%), population density (people km^{-2}) and population dependent only on agriculture (%) in the Uszwica catchment for the 1975–2015 (author's elaboration based on Central Statistical Office and questionnaires survey 2016)

Uszwica catchment	1975	1987	1997	2003	2009	2015
Forest	33.90	34.88	38.22	40.08	41.27	42.52
Cultivated land	35.01	31.30	16.30	9.90	5.31	4.04
Grassland	28.97	31.76	42.97	47.16	50.42	50.07
Building	0.59	0.61	0.85	0.93	0.95	0.99
Group of trees and bushes	1.20	1.12	1.16	1.34	1.49	1.75
Tree belt along road	0.33	0.33	0.50	0.59	0.56	0.63
Population density *	90	101	113	115	115	116
Population dependent only on agriculture **	51.6	39.1	–	18.6	–	4.2

* - data for 1978, 1988, 1997, 2003, 2009, 2015 (Central Statistical Office)
** - data for 1978, 1988, 2002 (Central Statistical Office), 2016 (own questionnaires survey).

The grassland area in the Uszwica catchment increased by 9.6% to 31.76% and the areas of buildings by only 3.4%. The increase in population density (to 101 people·km^{-2}) was accompanied by significant changes in the income sources. The number of people dependent only on agriculture decreased by 24.2% to 39.1% in 1988.

LULC CHANGES FROM THE COMMUNIST SYSTEM TO A FREE-MARKET ECONOMY (1987–2003)

The highest dynamic of LULC change was observed in this period, especially up to 1997 (Tab. 1). A rapid decrease in cultivated land by 68.4% to 9.90% was observed in the Uszwica catchment with a tendency to abandonment on the steepest slopes >15^{o}. The forest cover increased by above 14.9% in the Uszwica catchment (to 40.08%) (Tab. 1). The forest exceeded an 83.5% contribution above 500 m a.s.l. in the Uszwica catchment. In the investigated catchment, a decreased large area of cultivated land had an influence on the increased grassland by above 48.5%. In this period population density increased rapidly, which caused a significant increase of building areas (about 52.4%) which was the largest in the entire period. Other land use types did not change their area significantly.

LAND USE CHANGES IN CURRENT PHASE OF A FREE MARKET ECONOMY (2003–2015)

This period is characterized by slower changes of the LULC with expansion of forests by 6.1% and a reduction of cultivated land by 59.2% (Fig. 2, Tab. 1). Only a single cultivated land remained above 450 m a.s.l. On slopes steeper than 15° the cultivated land did not exceed 1% to completely disappear on the slopes steeper than 30°. In this period the forest area also increased and covered 42.52% of the Uszwica catchment. Forest succession was mainly observed in the lower part of the catchment with abandoned cultivated land and grassland. The forest reached over 86.5% of the upper part of the catchment. On the slopes steeper than 20° the forest reached over 92.6% in the study area. The contribution of grassland in the Uszwica catchment still increased. The building area showed a continuous increase, though the surface did not exceed 1% in the catchment. The small contribution of trees and bushes as well as tree belts along roads was observed in the investigation area in each of the studied periods.

The increase in population density slowed down to 1% (116 people·km^{-2}). The contribution of population depending only on agriculture fell to less than 5% (questionnaires survey, 2016). The main sources of income for the inhabitants were off-farm activities e.g. construction, services, agritourism. About 29% of the Uszwica catchment's inhabitants were employed in the neighbouring towns of Bochnia and Brzesko (questionnaires survey, 2016).

LULC STABILITY IN 1975–2015

The study of LULC during the 1975–2015 period revealed that stable land use (the same land use category in each time period) dominates in the Uszwica catchment, covering 59.35% of its total area (Tab. 2). After 1987, there is a gradual increase in the percentage of stable areas in the investigation catchment. The increase of the stability of land use is also correlated with a decrease in the population dependent on agriculture. The period from 1987–1997 including the socio-economic transformation was the least stable period in the Uszwica catchment (73.17%) (Tab. 2). The stable land use area mainly consists of large parts of forests at the highest elevations and less accessible steep slopes, core areas of large grasslands and settlements located at the lower part of the catchment.

Cultivated lands were the least stable form of land use throughout the considered period, where 27.28% and 3.52% of their initial area was converted to grasslands and forests, respectively. 33.65% of the grassland area and 22.30% of the forest area were not subject to any changes in the Uszwica

Table 2.
Stable land with predominant types of LULC changes (%) in the Uszwica catchment for the 1975-2015

Uszwica catchment	1975 –1987	1987- –1997	1997– –2003	2003– –2009	2009– –2015	1975– –2015
Without changes	90.55	73.17	82.03	87.35	87.67	59.35
Forest to grassland	0.17	0.29	0.15	0.05	0.21	0.26
Grassland to forest	0.84	2.31	1.70	1.13	1.35	4.85
Cultivated land to forest	0.24	1.05	0.17	0.03	0.01	3.52
Cultivated land to grassland	4.68	16.94	9.55	6.43	4.21	27.28

catchment. In contrast, only 3.40% of the cultivated land from 1975 was still cultivated in 2015. About 4.85% of the grassland area became overgrown with forests due to natural succession. A small percentage of grassland areas was also designated for building.

EFFECTS OF HUMAN ACTIVITY IN THE NATURAL ENVIRONMENT

Over the last a few centuries in the Polish Carpathians, the rising population and hungry of land accelerated agricultural land partitioning and connection of small parcels with dense road network. In the Uszwica catchment the density of roads was 13.0 km·km^{-2} in 1975 and complemented lower permanent river network density (2.2 km·km^{-2}). Almost all of the roads were used and over 95% of them were unpaved at the end of the 1970s. Particularly the roads that have connection with river channel are an important source of material transported from slopes to rivers. These types of roads accounted for 30% of the total length of roads in the Uszwica catchment in the 1970s.

Between 1975 and 2015, LULC and population changes caused significant changes of the spatial pattern of the road network and its surface. The abandonment of the agricultural land started leaving the access roads to the fields, mainly on cultivated slopes but also in the forests (Fig. 3A). A simultaneous increase of the population and settlement development led to the construction of the new roads and their pavement, mainly in the valley bottom. The impermeable surfaces increased their contribution by about 100% (assuming a 5 m width of the main pavement road) in the study area. Such processes initiated changes of the LULC structure of the roads, and thus their role in the transfer of water and sediment within the catchment.

Fig. 3. A – Unpaved road between abandonment fields; B – suspended bridgehead and damage concrete structure in the Uszwica river

The density of roads slightly increased by 8% in the Uszwica catchment. However, the density of the used roads decreased by 27% and the decrease of the density of the roads that have connection with river by 8% in the Uszwica catchment was also significant.

The reduced slope wash from cultivated land and decrease of the used road density have greatly limited the amount of materials transported in the rivers. This has led to an interruption of aggradation in their channels. Now, channel incisions currently dominate in the Uszwica river, where the estimated river bed incision rate was at about 0.9 $cm \cdot year^{-1}$ in 1989–2016 near suspended bridgehead located 5 km above the water level station at Lipnica Murowana (Fig. 3B). This estimated result confirmed the decreasing of the absolute minimum water levels recorded at Lipnica Murowana water level station reveal about 1 $cm \cdot year^{-1}$ downcutting in 2009–2017.

In the study area, another human intervention such as construction works in the Uszwica channel intensified at the beginning of the 2000s. The first channelization work of the Uszwica river occurred in 1998/2000, as the consequence of flood damage in July 1997. These hydrotechnical structures are currently suspended or even damaged due to channel incision and more frequent floods (Fig. 3B).

In the Uszwica river the channelization and bank protection works were focused mainly in the zone around the river channel mainly in the Rajbrot village to protect the local roads and buildings at about a 6 km distance. Such measures were unnecessary in the upper, forested courses of the river. After another floods (2001, 2010) subsequent works were carried out in 2004/2005, and in 2011. The typical hydrotechnical structures that appeared in the Uszwica river channel reinforcing both river banks (mainly gabions) and the concrete correction steps which stabilized the river bed (Fig. 4). Furthermore, the construction of new bridges, strengthening bridge abutments and local road pavement were noted. The construction works were co-financed by European Union funds.

DISCUSSION

The conducted field survey and analysis of the cartographic materials and socio-economic statistical data permitted dynamic changes in the natural environment of the Uszwica catchment to occur, especially from 1975 to 2015. The cultivated land area was reduced by 88.46% to only 4.04% with a tendency to abandonment on the steepest slopes. The forest area increased by 25.42% during the entire analysed period (1975–2015). The forest dominated in the upper part of the Uszwica catchment, over 400 m a.s.l. An increase in

Fig. 4. A – Reinforcing right river bank (gabion); B – Concrete correction step with river bed stabilization

the forest area up to 86% above 550 m a.s.l. shows a similarity with processes in the other parts of the Polish Carpathians, where in the upper parts of these mountains, the forest area even exceeds 90% (Troll 1999; Kozak 2010; Bucała-Hrabia 2017a,b, 2018). The grasslands area underwent complex changes associated with increase in effect of cultivated land abandonment or decrease due to forest succession. The area of the buildings revealed a continuous increase from 0.59% to 0.99%. The population density increased from 90 people·km^{-2} in 1975 to 116 people·km^{-2} in 2015, while the population dependent on agriculture decreased from 51.6% to below 4.2% in the same period.

The general trend of LULC changes in the Uszwica catchment of the Polish Western Carpathians is similar to those occurring after 1989 in the neighbouring countries, which also belonged to the former communist system. After the collapse of the communist economy, cultivated land was mostly replaced with grassland and forests in most of the East European countries (Bičik et al. 2001; Baessler, Klotz 2006; Šebo, Novaček 2014; Kupková, Bičík 2016).

A direct expression of human activity in the natural environment are road networks, a remnant of the former agricultural activities (Soja, Prokop 1996). Increases in the population resulted in agricultural expansion, which, in turn, increased the extent of unpaved roads. In the Polish Carpathians the real road network density is 9 km·km^{-2} and is higher than the corresponding natural drainage density, which totals 3.5 km·km^{-2} (Soja 2002). For foothills the average natural drainage density is about 2.0 km·km^{-2} (Soja 2002) which corresponds with the Uszwica catchment. The contemporary road network density reached 7.4–14.0 km·km^{-2} in the foothills (Kroczak 2010; Bucała-Hrabia 2018); 4.9–11.9 km·km^{-2} in the mid-mountains (Froehlich, Słupik 1980; Soja 2002; Bucała 2014, Kijowska-Strugała 2015); 2.3–2.9 km·km^{-2} in high-mountain (Kroczak et al. 2016) catchments. These are one of the highest values reported in the mountain regions of the world, where usually is lower than 2 km·km^{-2} (Wemple et al. 2001; Takken et al. 2008). Road network density in the Uszwica catchment however, still remained much higher than the density of the permanent river network. In 2015 the unused roads accounted for 4.5 km·km^{-2} and were overgrown with dense vegetation.

Unpaved roads increase the natural drainage density by creating a network of seasonal drainage lines, which greatly accelerate runoff and erosion processes and provide the main source of material transported by the Carpathian rivers (Froehlich 1982; Reid, Dunne 1984; Froehlich, Walling 1997). According to W. Froehlich (1982) and W. Froehlich and J. Słupik (1986), unpaved roads in the Polish Carpathians contribute up to 90% of the suspended material transported by rivers. A similar result was by the research study conducted in the Bystrzanka catchment where during rainfall events in 2010 and 2011 M. Kijowska-Strugała (2015) indicated that suspended material transport on unpaved road was higher than in the channel stream. In the Uszwica catchment the roads that have connection with river accounted for 26% of total roads in the 2015, while in the Bystrzanka catchment roads crossing the stream were 16% of all roads in the same time (Kijowska-Strugała 2019).

After the Polish political changes of 1989, there was a rapid decline in the profitability of agricultural production as a result of depriving the farmers of special budgetary subsidies for farms in the mountains (Górz 2002, 2003). The traditional agriculture in mountains such as the Polish Carpathians became less profitable and this affected LULC changes (Kozak 2005). Cultivated land abandonment and unused roads limited the amount of material transported in the rivers and streams, which, in turn, resulted in the interruption of aggradation on floodplains (Wyżga 2001; Korpak 2007). The trend of intensified channel incision has been noted for most of the Carpathian rivers (Korpak 2007). In the Uszwica river downcutting was recorded at the Lipnica Murowana water level station and near suspended bridgehead in 2009–2017 and in 1989–2016, respectively i.e. about 1 cm·year^{-1}. The incision trend of the Uszwica river also corresponds with changes of the Ochotnica channel bed at the Tylmanowa water level station (Kijowska-Strugała, Bucała-Hrabia 2019). A similar observation was also conducted in the Homerka channel where downcutting was observed along suspended gabions i.e. 1.2 cm·year^{-1} in 1999–2016 (Bucała-Hrabia 2018). Based on measurements near the suspended bridgehead, the average bed erosion for the Jamne stream was estimated at 1 cm·year^{-1} in the past 40 years (Bucała 2014, Bucała et al. 2015).

CONCLUSION

The transition from centrally planned to a free-market economy changed the intensity of human activity that was reflected in the environment. The largest dynamic of LULC changes occurred just after the collapse of communism and during the early stages of the free-market economy. It was the period with the rapid decrease of the population dependent only on agriculture.

The withdrawal of agricultural activity has both positive and negative effects on the environment. Positive consequence of cultivated land and cart roads abandonment was forest succession resulted in lower efficiency of slope wash and sediment delivery to the river network in the Uszwica catchment.

This led however, to an interruption of aggradation in the channel and initiated its deepening which caused the destruction of bridge abutments and hydrotechnical structures.

Forest succession within abandoned agricultural land caused the gradual decrease of the forest-agriculture boundary close to its natural, climatically conditioned course (only locally modified by the LULC structure). At the same time, the LULC structure in the catchment has approached closer to the one proposed in the concept of sustainable management for the Polish Carpathians (Starkel 1972).

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