Pol. J. Environ. Stud. Vol. 23, No. 1 (2014), 73-84

Original Research

Changes in Land Cover and Management of Floodplains Located in Towns Along the Oder River in the Context of Flood Risk Assessment

Ewa Głosińska[1]*, Łukasz Lechowski[2]**

[1]Department of Spatial Management, Faculty of Geographical and Geological Sciences, Adam Mickiewicz University, Poznań, Poland
[2]Department of Geoinformation, Faculty of Geographical Sciences, University of Lodz, Łódź, Poland

Received: 23 April 2013
Accepted: 3 November 2013

Abstract

This article describes the changes in the land cover and management of floodplains in towns located on Poland's Oder River, estimates flood risk and how it has been changing in these towns, and how these changes have affected the environment. The paper also includes an analysis of trends in floodplain management defined in local planning documents. The research was conducted for the period of 1995-2010 and included two towns: Kostrzyn on the Oder and Krosno Odrzańskie. The former lies in the lower course of the Oder and the latter in its middle section. The research indicates that flood risk has risen due to the continuous development of urbanized areas (both unbuilt and built-up) that used to be exploited as arable land. That had a negative effect on the environment, as well.

Keywords: floodplains, environment, land cover, land management, flood risk, towns, Oder, Poland

Introduction

Floodplain management and development have a negative influence on the environment, mainly on water management in river basins. Constructing roads and buildings, as well as the improper use of arable land (plowing along the slope, excessive grazing) and woodlands (tree harvesting) cause rapid surface runoff, intense erosion, and sediment transport [1]. Urbanization increases the occurrence of the impermeable layer in the basin area, particularly in urban drainage systems. The situation might be additionally worsened by surface runoff from suburban areas [2]. Urbanization and changes in land use decrease the capacity of the drainage systems in river basins [2]. Land development in floodplains reduces water retention and increases the surface runoff, which eventually increases the catchment runoff [3]. This results in some changes in the water cycle and flood regimes [4-6].

Vegetation in flood-prone areas is vital for the correct functioning of the environment, including the proper water circulation process. Vegetation longevity, tree stand structure, and the complexity and depth of its rooting system have a strong influence on infiltration and soil retention capacity, as well as the speed of surface runoff [7-9]. That is why floodplains are of great importance as regards retention, which was also indicated in the EU Floods Directive [10].

Due to the unique biotypes found in river valleys, the latter are environmentally valuable. For example, riparian forests growing only in river valleys are among the most endangered forest ecosystems in the world [11]. On the other hand, the trees and shrubs that grow in floodplains obstruct natural water runoff, as they decrease the cross-section of the river valley [12].

*e-mail: ewaglo@amu.edu.pl
**e-mail: lukasz.lechowski@gmail.com

Many studies concerning environmental protection and nature were conducted in floodplain areas. For example, Geneletti [13] examined the ecologicality of individual land development policies, taking into consideration such environmental indicators as the expansion into flood-prone areas. Intensive investment policy and economic activity, infrastructure, and services turned out to be extremely harmful to the environment [13]. Other research concerned the assessment of spatial development scenarios, also in floodplain areas, in the context of flood protection and nature conservation. The policy preserving valuable biotypes proved to be the most beneficial for the environment [14]. The studies also included the assessment of soil and water pollution in floodplain areas, where the content and spatial distribution of heavy metals was examined [15-17].

The term "land cover" refers to the biophysical features of a particular part of the earth's surface and is an element of its physical description (physical features) [18]. The description of land cover provides information about, for example, the vegetation (trees, grass, crops), anthropological objects (yards, built-up areas) or water bodies (lake, pond, sea) found in a given area [19]. Land cover, therefore, consists of all its distinctive, physiognomic features [20]. The term "land management," here interchangeable with "land use," refers to the functional character of a given area, which is described in socio-economic terms [21]. Land use may be understood as an outcome of certain human activities in a given area, which can be deliberate, rational or not. [22]. Thus, land management is a combination of land cover and land use [23].

The aim of this study is to define the directions of change in the land cover and management of flood-prone areas on the river Oder, to evaluate the level and the changes of flood risk in some towns, as well as their impact on the environment. The study also includes an analysis of floodplain management specified in local planning documents.

The Experimental Part

Study Area

The research included two towns located on the river Oder, in the Lubuskie voivodeship (province): Kostrzyn on the Oder and Krosno Odrzańskie. The former lies in the lower course of the Oder and the latter in its middle section. The Oder is a border river between Poland and Germany and one of the six largest river systems in Europe [17, 24].

In Kostrzyn, the river flow is longitudinal and in Krosno it is latitudinal. Kostrzyn is a municipal town in the Gorzowski powiat (district), while Krosno is both a municipal and rural town. The analysis concerned the municipal area only.

Kostrzyn is considerably larger and more populated than Krosno[1]. The flood-prone area in Kostrzyn is much larger than in Krosno – 1,319 ha and 280 ha, respectively. However, referring these figures to the overall area of both towns, Kostrzyn is threatened in 29% and Krosno Odrzańskie in 34%.

Kostrzyn on the Oder is situated in the confluence of the Warta and the Oder. On the Warta's side, the town is protected by a levee. Due to their valuable natural assets, the vast floodplains of the town are formally protected in different ways: they make up the Nature 2000 area, a landscape park and the Warta Estuary National Park. Floodplains surround the town from the southwest and southeast. In the southeastern part of town, along the Warta riverside, there is the Słońsk Reservoir (a polder) – a vast marshy land inhabited by waterfowl.

The most flood-prone area in Krosno Odrzańskie is its southern part, including the old town and the stronghold. The left-bank the town is situated relatively lower than the right-bank part. To the east there is Połupin Reservoir.

Both towns were severely flooded during the 1997 Oder flood. The area affected then mostly overlaps with today's flood-prone area.

Materials

The floodplains analyzed in this study are areas of "direct" and "indirect" flood hazard, whose ranges were specified by the Regional Water Management Authorities in Szczecin and Wrocław, in order to draw up flood hazard maps of the Oder flood-prone areas, as well as to prepare an atlas of floodplains in the Oder Valley[2].

The studied flood-prone areas can be divided into three flood zones. The first includes the areas of "direct" flood hazard for 10% waters, which can occur once in every 10 years. The second zone includes the areas of "direct" flood hazard for 1% waters, which can occur once in 100 years. The third zone includes "potential" flood areas, i.e. flood-prone areas where a flood can occur when floodwaters flow over the levee crown or the levee is damaged.

Source of information include aerial photos of the towns taken in 1995 (Kostrzyn on the Oder) and 1996 (Krosno Odrzańskie) as a part of the PHARE program, as well as the latest available orthophotographs (Kostrzyn on the Oder – 2007, Krosno Odrzańskie – 2010). In order to establish the land development forms, a vector topographic database (TBD), a topographic objects database (BDOT), and raster topographic maps from the 1990s were used.

Methods

In order to identify the forms of land cover and management in the studied area, aerial photos and orthopho-

[1]The area of Kostrzyn on the Oder is approximately 4,548 ha, with a population of about 18,110. The area of Krosno Odrzańskie is 824 ha, with a population of about 12,070 [GUS data, 2012].

[2]As a result of implementing the Flood Directive [10] in Poland in 2012, Water Law regulations have been changed [25]. One of the changes concerns the terminology used with reference to the floodplain zones in Poland. Former areas of direct flood hazard are now called areas of particular flood hazard. Currently the term potential flood hazard areas no longer exists. According to the new regulation of the Flood Directive, by the end of 2013 the new floodplain areas will be marked out on new flood hazard maps.

Table 1. Classification of land cover and land management forms.

0 Level	1st Level	2nd Level	3rd Level
Non-urbanized areas	Water areas	Water areas	Flowing water areas
			Stagnant water areas
	Woodlands, tree- and shrub-covered	Woodlands, tree- and shrub-covered	Woodlands
			Tree- and shrub-covered areas
	Agricultural area	Agricultural area	Meadows and pastures
			Arable lands
		Permanent crops areas	Orchards
Urbanized areas	Semi-developed areas	Unbuilt urbanized areas	Grassy areas
			Paved and unpaved surfaces (car parks, construction sites, ruins)
		Recreation and leisure areas	Cultivated green areas (parks, greens)
			Cemeteries
			Allotments
			Sport fields
	Developed areas	Transport areas	Vehicle transport areas (roads)
			Railway transport areas
		Built-up areas	Residential areas
			Service and trade areas
			Office building areas
			Education and social care facilities areas
			Sacral building areas
			Industrial areas
			Warehouse areas
			Transport areas
			Outbuildings areas
			Technical infrastructure development areas
			Other types of development (sheds, gazebos, greenhouses)

Source: Author's compilation based on TBD 2008 technical guidelines, BDOT.

tographs were interpreted using the visual classification method for two time periods (1996 and 2010), by means of GIS. The visual interpretation of raster is based on a manual outlining all land cover elements by the observer. The rule of polygon complementarity and topological consistency of the whole land cover must be followed. The efficiency and quality of this work largely depends on the observer's knowledge and interpretation skills [26][3].

The analysis of land cover and management was partly based on TBD and BDOT classification (Table 1). It consists of four hierarchical levels. The first three present forms of land cover and the last and the most detailed level 3 shows land management forms.

The authors of this study assume that flood risk is strictly connected with potential flood losses, which in turn largely depend on flood-prone areas management. Therefore, the flood risk assessment in the studied towns was based on the previously identified forms of land management.

The flood risk assessment was based on the ranking method[4]. In order to establish individual flood risk ranks, the potential flood losses defined in the 2012 legislation regarding flood hazard and flood risk mapping [29] were referred to. The assumption was that the higher the risk (the more extensive losses), the higher the rank. The ranking was performed on level 3, which shows land management forms (Table 2). For example, water areas were at no risk, in non-

[3]The visual classification method is a manual method of photointerpretation, apart from the group of semi-automatic and automatic methods (raster, hybrid, and object-focused methods).
[4]Learn more about the ranking method in: [28, 29].

Table 2. Ranking of land management forms in the context of flood risk.

Level 3	Rank	Risk level
Flowing waters areas	1	No risk
Stagnant waters areas	1	
Woodlands	2	Very low
Tree- and shrub-covered areas	2	
Meadows and pastures	3	Low
Orchards	3	
Arable lands	4	
Grassy areas	5	Moderate
Cultivated green areas (parks, greens)	5	
Cemeteries	5	
Allotments	5	
Sport fields	5	
Paved and unpaved surfaces	5	
Residential areas	6	High
Transport areas	6	
Outbuilding areas	6	
Other types of development	6	
Vehicle transport areas	7	
Railway transport areas	7	
Office building areas	8	
Service and trade areas	8	
Sacral building areas	8	
Industrial areas	8	Very high
Warehouse areas	8	
Technical infrastructure development areas	8	
Education and social care facilities areas	8	

urbanized areas – it was very low or low, in partly developed areas – medium and in developed areas– high or very high.

Based on the algorithm (1) below, the flood hazard index was calculated, which shows the values from 0 to 1. Value 0 signifies a lack of flood risk and value 1 means a very high risk. The flood hazard index was defined for the studied towns and their floodplain zones.

$$y = \frac{\sum_{i=1}^{n}(x_i a_k) - \sum_{i=1}^{n}(x_i)}{(k-1)\sum_{i=1}^{n}(x_i)} \quad (1)$$

...where:
y – flood hazard index
x_i –land cover area [m^2]
a_k – rank

Table 3. Ranking of floodplains areas according to its flood risk level.

Floodplains area	Rank	Risk level
Potential flood hazard areas	1	Low
Direct flood hazard areas (1%)	2	Middle
Direct flood hazard areas (10%)	3	High

number of rank $k = \{1, \ldots. l\}$
number of land cover forms $i = \{1, \ldots. n\}$

The above algorithm was used to define the level of flood hazard for individual land management forms. The flood hazard rank was established in the same way as in the flood risk assessment, which means that the higher the level a flood hazard is, the higher the rank it gets (Table 3). Consequently, the "potentially" flood-prone areas which are protected by levees are areas of low risk. The moderate risk areas are the "direct" flood hazard areas for 1% waters, which may be flooded once in 100 years. The highest flood risk occurs in the "direct" flooding hazard areas for 10% waters, because the probability of flood here is the highest (once in 10 years). The flood hazard index was defined for individual forms of land management.

In order to establish the spatial and land management policy for floodplains, a vectorization of the local planning documents was performed. The plans presenting the local floodplain area were valid for the flood zone included in the local plans of spatial management conditions and directions. Vectorization is based on the digitalization of special designation areas using GIS tools.

Results

In Kostrzyn on the Oder, the "direct" flood hazard areas (1% and 10%) are located along the Oder, while the "potential" flood hazard areas, protected by a levee, are situated along the Warta River. The area of 10-year waters is included in the zone of 100-year waters, while the "potentially" flood-prone areas are inconsistent with the "direct" flood hazard areas. Kostrzyn floodplains are mainly areas of 100-year waters, which make up about 45% of the whole floodplain.

Contrary to Kostrzyn, in Krosno Odrzańskie the "direct" flood hazard areas are situated within the "potential" flood hazard areas. Thus, the "potential" flood hazard areas make up the majority of urban floodplains (45%). Different than in Kostrzyn, the floodplains in Krosno cover the very centre of the town. This means that floodplain management in Krosno is considerably more intensive than in the vast marshes of Kostrzyn.

The changes in floodplain land cover and management, as well as the flood risk in both towns, were presented in the following order: the structure of land management and land cover forms, the main tendencies in the changes and trans-

formations of land cover and management, the changing character of buildings, the spatial distribution of the changes in land cover and management, the level of flood risk individual land management forms, flood hazard assessment, the tendencies in the land management policy and floodplain development presented in planning documents.

The Kostrzyn floodplains are mostly agricultural land, making up around 50% of the whole area (Figs. 1 and 3). Undeveloped urbanized, as well as tree- and shrub-covered areas, make up over 10%. Over the years, the percentage of agricultural land, woodlands, tree- and shrub-covered areas, and permanent crops areas has decreased, while the amount of unbuilt urbanized land has grown significantly. Recreation, leisure, and built-up areas have also increased, but to a smaller degree.

The greatest changes occurred in the cover and management of agricultural land, especially as regards meadows and pastures, which were transformed into surface waters (35% of the total change). In 30% of the agricultural land, meadows and pastures were transformed into arable land (Table 4). A fairly large part of floodplains were transformed from an urbanized, unbuilt (grassy) area into agricultural areas– meadows, pastures and arable land; to be specific, grassy areas turned into meadows, pastures, and arable lands. In 5% of the total area, tree- and shrub-covered areas turned to grassy areas.

The majority of the built-up floodplains in Kostrzyn are industrial areas (Fig. 2), and this tendency is growing due to the Kostrzyn-Słubice Special Economic Zone. Residential areas are developing slowly, and farm building has decreased, while the number of other (temporary) buildings is rising. It should be stressed that office, service and trade areas expanded more quickly than warehouse and transport areas.

Most changes occurred in the "direct" flood hazard areas in the Special Economic Zone, where industrial and technological infrastructure (e.g. a sewage plant) and warehouses with paved and unpaved surfaces were introduced in agricultural land (meadows, pastures and arable land). Changes in the "potential" flood hazard zone are mainly caused by turning agricultural areas, meadows, and pastures into residential areas, which results in the expansion of grassy land and the development of service infrastructure and paved and unpaved surfaces nearer the town center.

As a result, in the "direct" flood hazard zone there were fewer changes in land management than in the "potential" flood hazard zone, but they occurred over a larger area of

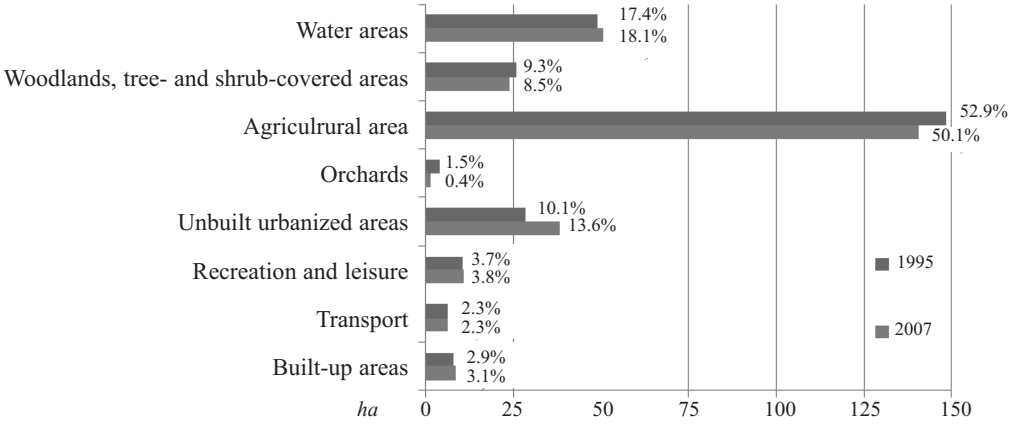

Fig. 1. Direction of change in floodplain land cover and management in Kostrzyn on the Oder in 1995-2007.

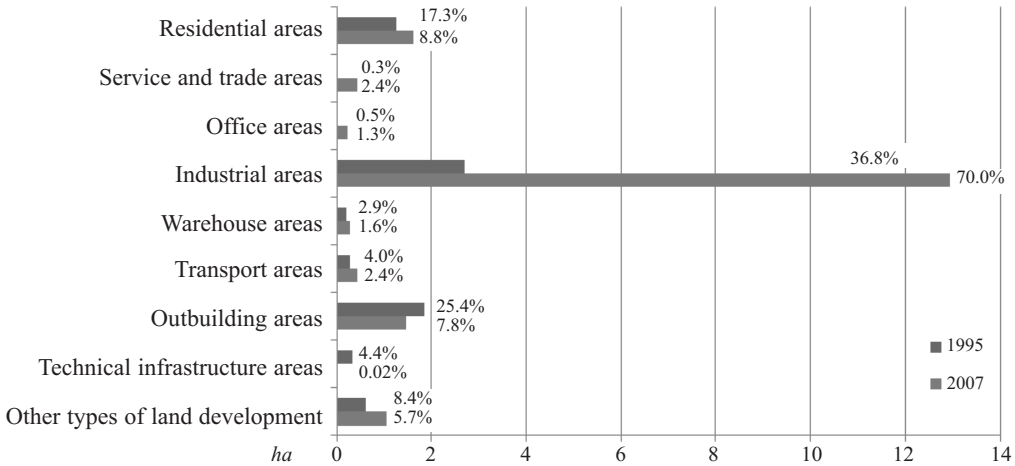

Fig. 2. Direction of change in built-up area development in the floodplains of Kostrzyn on the Oder in 1995-2007.

Table 4. Changes in floodplain management in Kostrzyn on the Oder, 1995-2007.

		2007						
		W	F	A	UU	SR	C	B
1995	W		0.46	1.37	0.15			
	F	4.98		0.94	5.72	0.65		0.0005
	A	34.21	0.45	29.64	0.64	0.51	0.04	0.001
	UU	2.09	0.39	10.68	1.35	0.4	0.001	0.23
	SR							
	C			0.25		0.08		
	B	0.01	0.04	3.94	0.36	0.12		0.29

Dark gray highlighted – the biggest changes, light gray – big changes; W – water areas, F – woodlands, tree- and shrub-covered areas, A – arable lands, UU – unbuilt, urbanized areas, SR – recreation and leisure grounds, C – transport areas, B – built-up areas

10 acres, on average. The changes in the lowest fluvial terrace, on swampy grounds, result from the high water level of the Oder and the Warta Rivers at the time photographs were taken in 1995.

In both 1995 and 2007, the growth of flood risk was accompanied by an expansion of arable land, while the importance of woodlands, tree- and shrub-covered areas decreased. Moreover, built-up, transport, recreation and leisure, and unbuilt urbanized areas could be found in the 1% water zone.

The highest flood risk was noted in non-urbanized areas (e.g. arable lands, tree- and shrub-covered areas). The moderate risk was characteristic of semi-developed areas (e.g. grassy areas, paved and unpaved surfaces) and the lowest one - of developed areas (e.g. transport and built-up areas). Over the years, the flood risk in agricultural and green areas generally decreased, and in the developed areas and on paved and unpaved surfaces) it increased.

Every time, flood risk in industrial development areas was higher than in residential and service areas (Table 5).

In Krosno Odrzańskie, like in Kostrzyn, the majority of floodplains are agricultural lands. There is also a large percentage of unbuilt urbanized areas and tree- and shrub-covered areas (Fig. 4). At the studied period, in Krosno, the percentage of arable land, woodlands, tree- and shrub-covered areas, as well as permanent crop areas decreased, while the amount of urbanized, unbuilt area grew significantly. Recreation and leisure areas, as well as those designated for development, expanded too, but to a smaller extent. As a result, changes in floodplain land cover and development in both studied towns are similar.

Krosno Odrzańskie floodplains show more diverse forms of management and are better developed than those in Kostrzyn on the Oder. As a result, changes in the land cover and management in Krosno are more varied (Table 6). It should be stressed that in the aerial photograph of Krosno taken in 1996, the water level of the Oder was not as high as in an analogous photograph of Kostrzyn from 1995. Krosno's agricultural lands were not transformed into surface water areas as much as in Kostrzyn. Agricultural lands (meadows and pastures), changed the most, as they turned into unbuilt urbanized areas (grassy stretches and paved and unpaved surfaces). Those transformations were completely different from the changes observed in Kostrzyn. On the other hand, similar to Kostrzyn, in Krosno one could

Fig. 3. Spatial distribution of floodplain land cover and management in Kostrzyn on the Oder in 2007.

Table 5. Level of risk in individual forms of land management in the floodplains area in Kostrzyn on the Oder in 2007.

Level 3	Index	Risk level
Meadows and pastures	0.74532	High
Tree covered areas and shrublands	0.11381	
Grassy areas	0.06306	Moderate
Arable lands*	0.03723	
Paved and unpaved surfaces**	0.02807	
Allotments	0.02067	
Industrial areas**	0.0158	
Woodlands	0.01302	
Vehicle transport areas	0.00881	Low
Sport fields	0.00392	
Orchards	0.00218	
Railway transport areas	0.00127	
Residential areas	0.00106	
Outbuilding areas	0.00103	
Other types of land development **	0.00081	
Transport development areas	0.00024	
Office building areas**	0.00024	
Cemeteries	0.00023	
Warehouse areas**	0.00022	
Service and trade areas**	0.00015	
Technical infrastructure areas	0.00007	
Cultivated green areas*	0	No risk
Education and social care facilities areas	0	
Sacral building areas	0	

*drop of flood risk compared to 1995
**increase of flood risk compared to 1995

Table 6. Changes in floodplain management in Krosno Odrzańskie in 1996-2010.

		2010						
		W	F	A	UU	SR	C	B
1996	W		0.05	0.58				0.27
	F			4.71	5.72			
	A	8.77	2.87	18.2	36.75	1.32		1.2
	UU			2.34	8.24	1.16		1.33
	SR				2.24			
	C							
	B			0.04	0.82			3.39

Gray highlighted – the biggest changes, light gray – big changes; W – water areas, F – woodlands, tree- and shrub-covered areas, A – arable lands, UU – unbuilt, urbanized areas, SR – recreation and leisure grounds, C – transport areas, B – built-up areas

notice significant changes in the arable area itself, which turned into meadows and pastures. It should also be stressed that occurred in the group of urbanized, unbuilt areas, where paved and unpaved surfaces were replaced by grassy areas (quite the opposite of Kostrzyn). In both towns tree- and shrub-covered areas changed into grassy areas.

In contrast to Kostrzyn, the development areas in Krosno's floodplains are mostly residential in character (Figs. 5 and 6), which is proven by the different functional character of these floodplains in both towns. However, we may observe the residential function weakening in the floodplains that form the town centre. In Kostrzyn, for a change, the residential character of floodplains is increasing. This comes from the fact the Kostrzyn's floodplains do not include the strict town centre, which is the case in Krosno Odrzańskie. As a result, the land development in Krosno is more diversified, including, for instance, sacral and educational facilities (a church and a school). The most

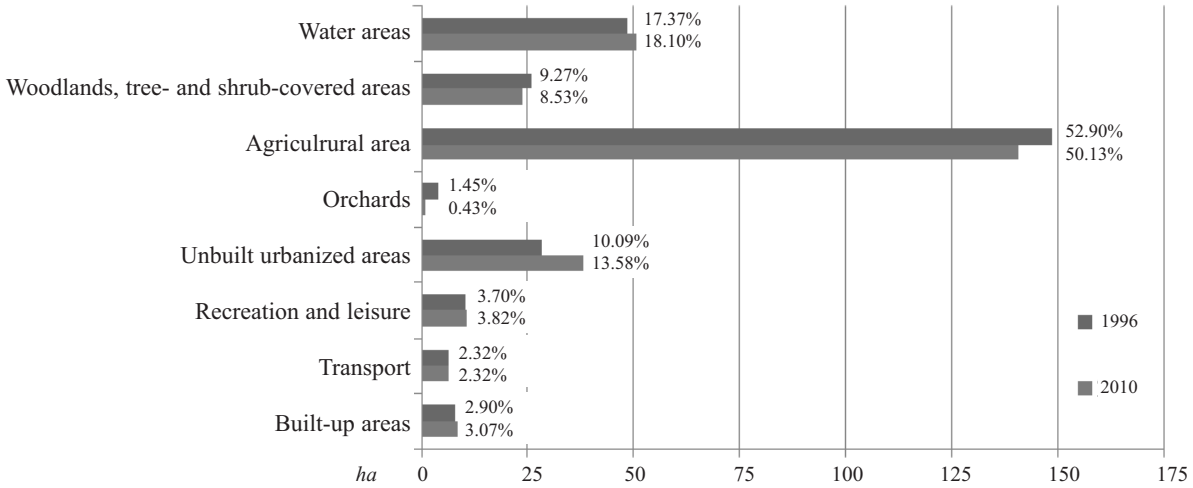

Fig. 4. Directions of changes in floodplain land cover and management in Krosno Odrzańskie in 1996-2010.

significant increase in the building area was recorded as regards service and trade facilities, followed by industrial, transport, and technical infrastructure. The same situation was observed in Kostrzyn. The warehouse area decreased. As regards the type of area development, Krosno's floodplains are more service-oriented, while Kostrzyn's floodplains are more industrial.

Taking into consideration the individual flood zones of Krosno and Kostrzyn, the majority of changes affecting small areas occurred in the "direct" flood hazard areas. However, due to heavy investment in the studied area, the main changes involved transforming arable land and orchards into green grassy areas and empty lots, as well as a reduction of tree-covered areas rather than new land development. In other words, the developed areas changed functionally, which involved adapting warehouses and housing facilities to service and production purposes. Similarly to Kostrzyn, in the potential flood hazard zone of

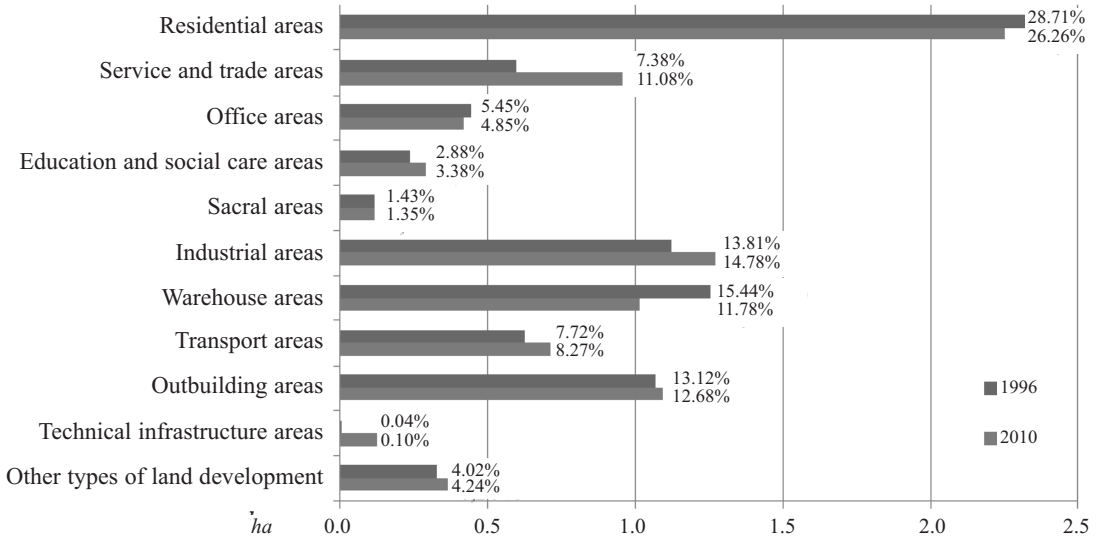

Fig. 5. Directions of changes in built-up areas development in the floodplains of Krosno Odrzańskie in 1996-2010.

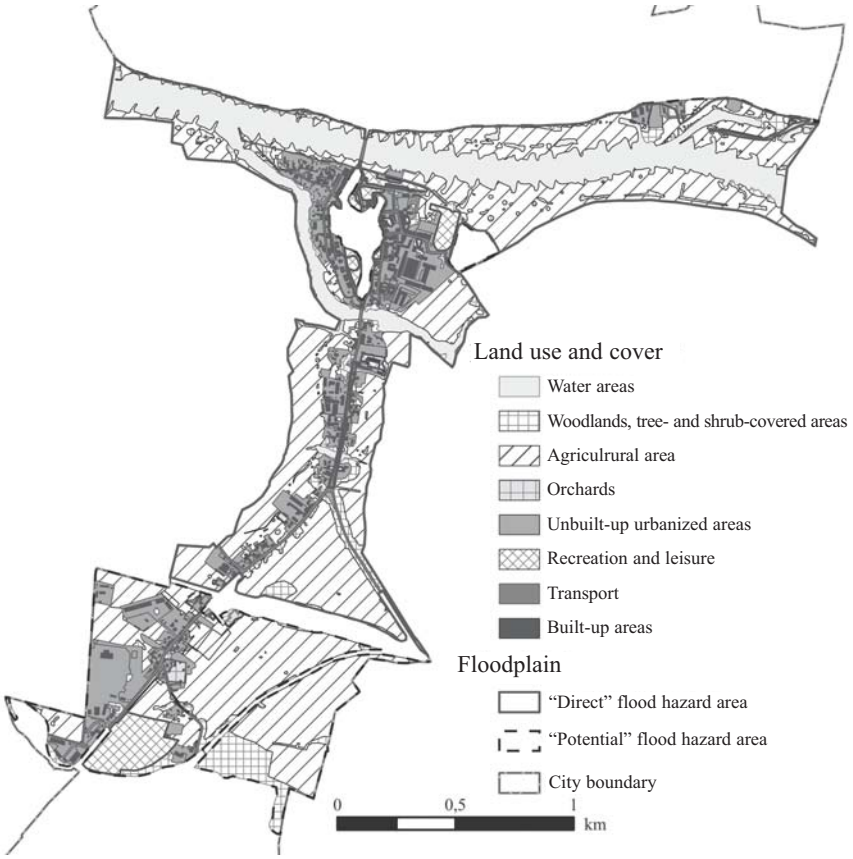

Fig. 6. Spatial distribution of floodplain land cover and management in Krosno Odrzańskie in 2010.

Krosno there were fewer changes but they affected larger areas, where arable land was transformed into meadows and pastures and the urbanized, unbuilt area increased. The direction and intensity of changes in building areas were the same as in the "direct" flood hazard zones described earlier.

Contrary to Kostrzyn on the Oder, the growth of most land cover forms in Krosno Odrzańskie was directly proportional to the increase of flood hazard. In both towns, the significance of woodlands and tree-covered areas decreased as flood risk increased. Consequently, the flood risk in Krosno differs for individual forms of land cover and management. Generally, the flood risk in transport and residential areas is higher than in industrial areas. Flood risk is also high in cultivated green areas.

The tendencies in the changes of flood hazard also differ for individual land cover and management forms (Table 6). The only common denominator is the lower flood hazard in arable lands. An opposite tendency is observed in cultivated green areas (in Krosno Odrzańskie the flood hazard grows and in Kostrzyn on the Oder it decreases), as well as in warehouse areas (in Krosno Odrzańskie it decreases and in Kostrzyn on the Oder it grows). Additionally, in Krosno, the flood hazard in orchards decreased and in technical infrastructure areas it increased.

As a consequence of the progressing development of floodplains, the flood risk in both towns has increased (Fig. 7) – in Kostrzyn on the Oder more than in Krosno Odrzańskie, which results from the significant expansion of development areas, especially industrial. Generally, however, the flood risk in Krosno Odrzańskie is higher than in Kostrzyn, due to the fact that a large part of Krosno's old town is flood-prone.

In Kostrzyn on the Oder the highest flood risk zone is the area of "direct" flood hazard, where the probability of flood occurrence is once in 100 years, while in Krosno Odrzańskie it is the area of "potential" flood hazard, situated further from the river. Both in Krosno and Kostrzyn, the most significant growth of flood risk was observed in the "potential" and "direct" flood hazard zones for 10-year waters (Fig. 8).

Considering the present directions in the spatial and land management policy for floodplains, it is predicted that in Kostrzyn on the Oder they will be exploited mostly as agricultural areas and will develop industrially as a part of the Special Economic Zone. Local spatial development plans establish new residential and service areas for this zone, as well as for the districts of Szumiłowo and Warniki. The local plan for the Kostrzyn Fortress area postulates introducing cultivated greenery into the floodplains surrounding the fortress, as well as along the Warta River. Only 10% of the floodplains in Kostrzyn are included in the current local spatial management plans.

Both in Krosno Odrzańskie and Kostrzyn on the Oder, the conditions and directions of spatial management are based on the assumption that floodplains will be mainly used as agricultural areas. The development of industrial and service areas in Krosno is planned on a much smaller scale than in Kostrzyn on the Oder. The areas designated as

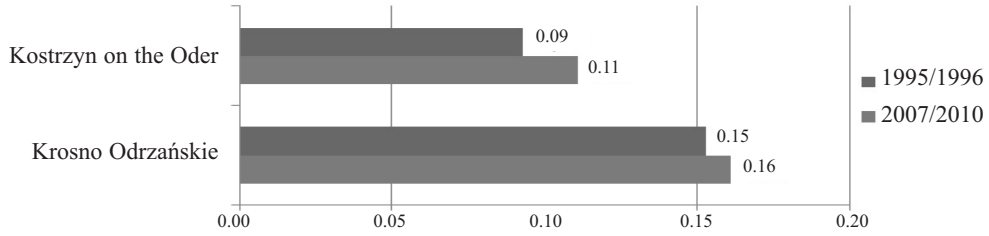

Fig. 7. Directions of changes in flood risk in Kostrzyn on the Oder and Krosno Odrzańskie in 1995-2010.

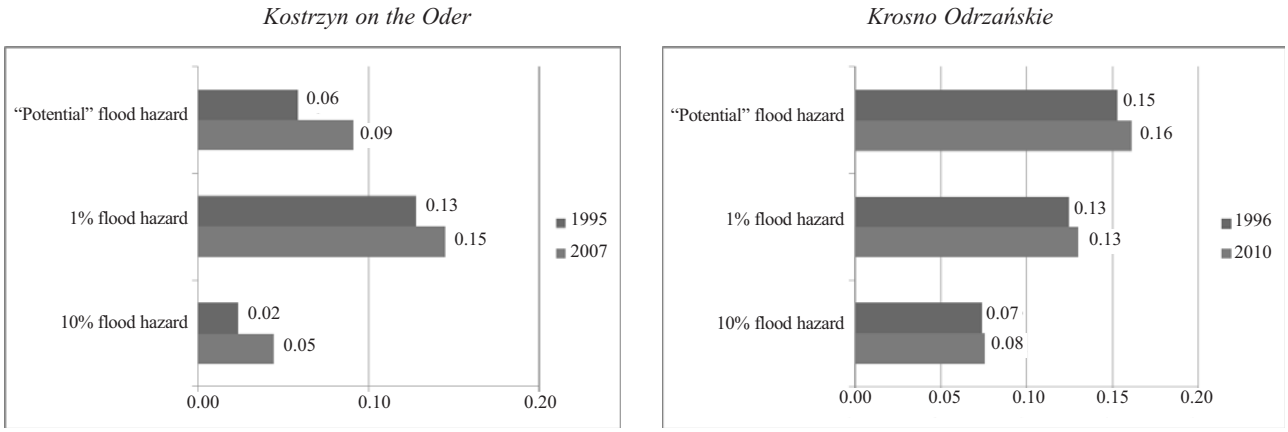

Fig. 8. Directions of changes in flood risk levels in Kostrzyn on the Oder and Krosno Odrzańskie, in individual flood zones, 1995-2010.

Table 7. Level of risk in individual forms of land management in floodplains area in Krosno Odrzańskie in 2010.

Level 3	Index	Risk level
Meadows and pastures	0.56899	High
Tree-covered areas and shrublands	0.07324	Moderate
Grassy areas	0.07051	
Paved and unpaved surfaces	0.05405	
Vehicle transport areas	0.02056	
Woodlands	0.00958	Low
Residential areas	0.00875	
Cultivated green areas **	0.00808	
Allotments	0.00673	
Industrial areas **	0.00632	
Sport grounds	0.00536	
Outbuilding areas	0.00456	
Arable lands *	0.00427	
Warehouse areas *	0.00396	
Service and trade areas	0.00273	
Transport areas	0.00262	
Orchards *	0.00197	
Office building areas	0.00154	
Education and social care facilities areas	0.00127	
Other types of land development	0.00138	
Sacral building areas	0.00068	
Technical infrastructure areas **	0.0004	
Cemeteries	0	No risk
Railway transport areas	0	

* drop of flood risk comparing to 1996
** increase of flood risk comparing to 1996

residential are to preserve and protect the existing housing infrastructure rather than to serve as new investment areas.

What is interesting is that currently there is no rational local spatial management plan for Krosno floodplains, though it is so crucial not only for the water management in the river basin, but also for people's safety and their property.

Taking all the above into account, it should be assumed that in the future the flood risk in both towns will continue to grow. It may be higher in Kostrzyn on the Oder, because current spatial development plans for this town predict considerable expansion of investment areas. In Krosno Odrzańskie, the unoccupied area is noticeably smaller. On the other hand, due to the fact that there is no current local spatial development plan for Krosno, the whole floodplain area may be developed on the strength of the local authorities' decision, which does not have to follow any spatial management recommendations. As a result, there is a strong possibility that the high flood risk area in Krosno Odrzańskie will grow. However, this increase will not be excessive, due to the limited amount of unoccupied areas.

Discussion

It has been proved that in the towns of Krosno Odrzańskie and Kostrzyn on the Oder, flood risk increased between 1995 and 2010, as a result of some unfavourable changes in the land cover and management of floodplain areas. The changes mainly involved a reduction of arable lands, woodlands, tree- and shrub-covered areas, as well as permanent crops areas. On the other hand, the area of unbuilt urbanized areas has grown considerably. Built-up, recreation, and leisure areas also slightly increased. In both towns, the floodplains are mainly arable lands. An analysis of the local spatial plans shows that further development is expected to occur in the floodplains in the future, as regards residential, industrial and service building. This increases the potential flood risk in the future.

To summarize, the study presented here indicates areas of varied flood risk levels and is the basis for defining zones that require planning restrictions. It should be used to review the current land management plans for Kostrzyn on the Oder and Krosno Odrzańskie, as well as to introduce necessary changes in order to reduce the negative economic, social, and ecological impacts of flooding.

The method of flood risk assessment used can be improved by introducing additional parameters, both as regards the risk (e.g. the depth of flood) and susceptibility (e.g. the structural type of land development, age of buildings), as it was done in the study [30].

Due to the fact that the analysis provided ample information about the local disparities in floodplains management, including residential, service, and industrial areas, the assessment of flood damage costs may be replaced by estimating the cost reduction. Considering the division into risk zones and other important planning parameters, it is possible to conduct an analysis of potential savings that may result from moving some types of investment into areas less susceptible to flooding.

The analysis of the management of flood-prone areas and the flood risk in urban areas, presented in this article, can become a useful tool in urban development planning and flood risk reduction. It may also be used in the debate between town authorities and local communities regarding the future shape of the urban tissue.

Floodplains are very often covered with riparian forests and marshy ecosystems, which are extremely valuable from an ecological point of view. The vegetation covering floodplain areas, often containing bioindicators, often depends on the frequency of flooding [14]. In Kostrzyn on the Oder, they are vast stretches of unique marshes, which are the natural waterfowl habitat, protected by the law (the Warta Estuary National Park in the Natura 2000 ecological region, or the Warta Estuary Landscape Park.

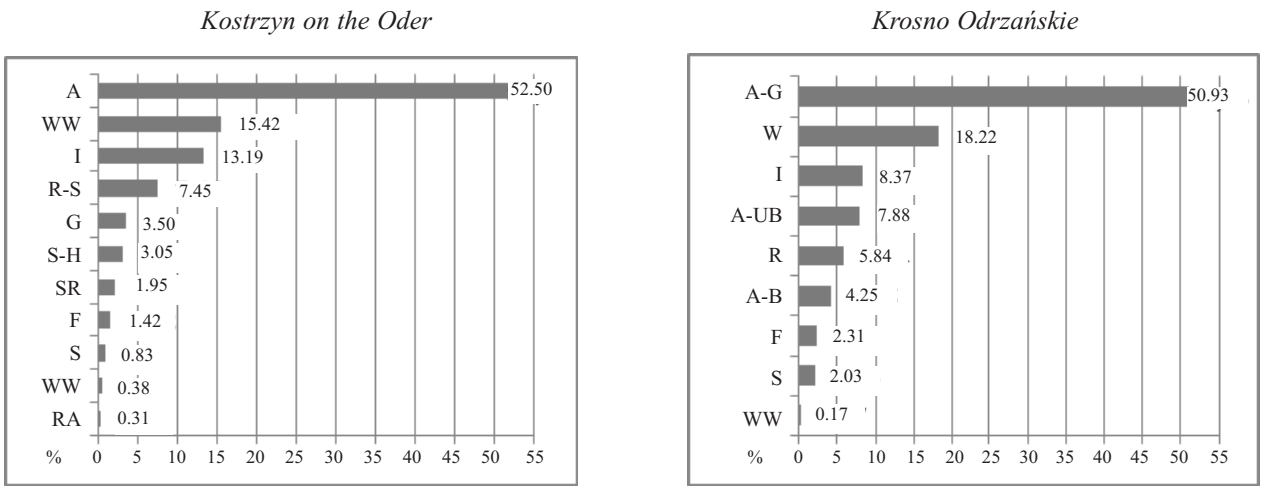

Fig. 9. Directions of floodplain management indicated in local planning documents for Kostrzyn on the Oder and Krosno Odrzańskie. A – arable lands; A-G – arable lands, meadows and pastures; A-UB – arable areas with building restrictions; A-B – arable areas with building permit; W – water areas; I – industrial areas; R – residential areas; R-S-1 – single-family houses areas; R-A – multi-family houses areas; G – cultivated green areas; S – service areas; S-H – crafts service areas; SR – sport and recreation areas; F – woodlands; WW – wastewater management area.

The directions of changes in floodplain management identified in this study indicate their negative impact on the environment. Building-up and developing floodplain areas cause an increase of surface runoff, soil erosion, and a decrease of the retentive properties of a river valley, mentioned by [1-6, 31]. As a result of river valley urbanization, flood frequency and extent increase [32-34]. Moreover, industrial and service activity has been rapidly developing in the studied area. To make matters worse, there are plans to build critical infrastructure facilities, such as sewage treatment plants, which are sources of serious pollution during floods [cf. 34].

In conclusion, such a spatial development policy run in floodplains not only increases the flood hazard (more frequent and more extensive floods) and flood risk (potentially greater flood losses) [cf. 34-37], but may also lead to serious environmental contamination caused by flooding [cf. 5, 34].

Acknowledgements

The author is a scholar within Sub-measure 8.2.2 Regional Innovation Strategies, Measure 8.2 Transfer of knowledge, Priority VIII Regional human resources for the economy Human Capital Operational Program co-financed by the European Social Fund and state budget.

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