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AN ESTIMATION OF POTENTIAL FLOOD LOSSES IN THE CONTEXT OF FLOODPLAIN DEVELOPMENT CHANGES USING GIS[*]

This paper aims to define the amount of changes in potential flood losses on the basis of spatial distribution patterns of floodplain development using GIS tools. A procedure for potential flood loss estimation has been developed in which GIS tools have been applied. A procedure for calculating flood losses applied in Polish legislation has been used. According to this survey, in Gryfino, which is situated on the Odra river in years 1996–2007 potential hazard of flood loss grew as a result of grow of floodplain areas development.

Keywords: *floodplain development, flood losses, flood risk, Gryfino, GIS*

1. Introduction

In Poland there are very few publications that concern the estimation of potential flood losses as an research issue. Due to the mandatory implementation of Floods Directive, the problem of flood hazard and flood risk is noticed more and more often.

Floods are regarded to be the most commonly occurring natural disasters in the world (Barredo 2007, Berz et al. 2001 cited in Ristic et al. 2012). They may be caused not only by natural phenomena (such as climatic, morphologic, hydrographic ones) but also agents of anthropogenic nature (e.g. irrational forestry and agriculture management, uncontrolled urbanization, lack of control over the erosion processes and over flood protection activities) (Ristic et al. 2012). The increase in frequency of natural and anthropogenic extreme phenomena focuses the attention of researchers on their ecological and economic consequences (see Guzzetti et al. 2005 cited in Ristic et al. 2012, Schmidt et al. 2006, Lerner 2007).

Having the floodplain areas developed more and more intensively, catastrophic floods have become much more frequent. As a result, higher tangible (loss

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of property) and intangible losses (loss of life) have been noted in recent years (see Walczykiewicz 2002).

The increase in flood damages of latest decades is generally caused by human activities in floodplains, which make both people and their properties more prone to flood (Luino et al. 2012). Development of lands vulnerable to flooding may also result in the increase of flood protection costs, especially when this applies to urban areas at risk (Waananen et al. 1977 cited in Luino et al. 2012). According to international observations and insurance companies analysis both increase in of people affected by flooding and economic loss increase indicate significant changes in flood risk (Schanze 2012).

The general higher trend of flood losses results from improper floodplain management. As an example, further continuous and intensive development of human activity in the Rhine River basin is expected, which may lead to higher flood losses (Zebisch et al. 2005 cited in Becker et al. 2013, Thieken 2009). Similarly, such negative urban development processes concerning floodplains may be identified in other European countries. Italian surveys carried out by F. Luino et al. (2012) revealed buildings and infrastructure to be more and more frequently located in the riverside areas. Consequently, as flood water is raised the natural course of flood waters is disturbed causing flood water to pile up dangerously (Luino et al. 2012).

One of the key terms of this paper is „land development". It should be precisely defined as „intentional adaptation of area, (caused by human activities) in order to meet its specific function. In a broad sense of this word it should be understood as particular investment conditions of an area characterized by certain degree of adaptation to human needs (Słońska, Sobieska 1988). This expression refers only to the functional land characteristics and is identified with the description of its surface from the social and economic point of view. In this research „land development" is strongly linked to the term of „land use", which can be defined as the purpose for land exploitation (Kostrowicki 1959). „Land cover" expression, in turn, means biophysical surface characteristics of the site (Ciołkosz, Poławski 2006), surface features, which can be recognized on the basis of its physiognomic characteristics (*Wytyczne techniczne...* 2008). Land development (land use) is therefore the concatenation of „land cover" with land use (Jakkola, Mikkola 1999).

The way floodplains are developed significantly affects the amount of flood losses. The estimation of potential flood losses is part of flood risk assessment. In order to integrate different spatial and statistical data that are crucial for estimation of potential flood losses (e.g. land development, economic statistics such as value of assets at risk, spatial extent of areas exposed to flooding) GIS tools are commonly used. This paper aims to determine the amount of change in potential flood losses in Gryfino in years 1996–2007 on the basis of spatial distribution patterns of floodplain development using GIS tools.

2. Estimation of potential flood losses in the context of flood risk assessment

Potential flood losses are frequently identified with the concept of flood risk, while they are just one of the aspects of flood risk assessment, which highlights the economic consequences of flood. In order to specify its risk level E. Koomen et al. (2011) calculated potential flood losses and while analyzing spatial distribution of different land use patterns they determined, how many people were exposed to flood in the floodplain they surveyed. T.E. Downing et al. (2001), in turn, identify flood risk as expected losses, which result from a particular hazard.

The concept of flood risk consists of three components: hazard, exposure and vulnerability (Crichton 1999). Flood hazard is defined as potential flood extent, which has taken place or has been delineated using mathematical statistics principles in order to present specified probability of specific water stages (Kitowski 2010). Flood exposure determines the nature and degree to which particular elements of the environment, such as geographical location are exposed to flood. Such location may either diminish or increase degree of flood exposure (Parry et al. 2007, DEFRA, EA, 2006). Flood vulnerability, in turn, concerns the characteristics of features and objects prone to flooding and allow in determining their potential to generate damages (Sarewitz et al. 2003). In this paper an analysis of economic vulnerability is carried out, which refers to the financial losses caused by damages of assets, basic materials and goods. Apart from the economic aspect of vulnerability, also social and ecologic ones can be found in literature on the subject (Messner, Meyer 2005).

Over the years many methods of flood risk assessment have been developed. What is more it seems that the modeling of potential flood damages and losses is still gaining in importance. Nowadays, in order to estimate tangible and intangible losses many spatially and temporally distributed data of population are taken into account (Kang et al. 2005 cited in Aubrecht et al. 2009). Moreover, information about land development (De Roo et al. 2006 cited in Aubrecht et al. 2009), historical events (Pielke et al. 2002 cited in Aubrecht et al. 2009) and depth inundation (Aubrecht et al. 2009) are also commonly used.

According to C. Aubrecht et al. (2009) the evaluation of flood effects focuses mainly on direct economic losses using damage function. This function depends on amount of losses, depth inundation and types of building use. Both these factors are commonly used to differentiate flood damages and they are generally taken into consideration as flood losses are assessed (Merz et al. 2004 cited in Aubrecht et al. 2009).

The principles of this method were applied in research work of C. Aubrecht et al. (2009) in which their classification of buildings, in terms of their use was combined with simulations of flood inundation using Geographic Information System (GIS) applications. These building classes are considered to be the most important agents that affect flood costs (Blong 2003 cited in Aubrecht et al. 2009).

There are many methods of building classification upon their functions and use purposes. One of them takes advantage of the diverse sources of spatial and related to geographical location datasets such as land development plans, topographic maps, addresses and data on companies. As they are integrated on the basis of spatial location, GIS tools may be applied in order to aggregate all the sources of information. As an example, C. Aubrecht et al. (2009, see also Aubrecht et al. 2008) proposes a model of data integration developed in Model Builder application, which is part of the ArcGIS platform. Studies conveyed by C. Aubrecht et al. (2009) show explicitly, that having all data sources of building functions integrated is essential for a better estimation of losses. It also makes the prediction of flood damage costs better. As the results of various scenarios of flood risk were compared to reference the amount of real flood damage costs, data concerning the detailed spatial and statistical information on building usage level was found to be much more precise and the overestimation of losses was the lowest. As claimed by C. Aubrecht et al. (2009) this method of flood risk assessment mentioned above may be developed by introducing additional agents regarding both flood hazard (inundation depth) and vulnerability (type and age of building). In recent years, such studies have been carried out by E. Van der Hoeven et al. (2009) and many other scholars.

F. Luino et al. (2012) introduce a different approach to flood risk assessment. They suggest to start the research procedure by classification of land use forms. Then, all classes should be grouped due to their flood vulnerability. In this step the following agents must be examined and analyzed: (a) population density of permanent residents and temporarily staying at certain parts of the day, (b) existence of machinery and private property, (c) existence of social and recreational activities, losses resulting from agricultural zone damages, (d) existence of environmental value areas. On the basis these data, in the opinion of F. Luino et al. (2012) residential and community facilities should be in the first group (level 1), that comprises all the elements of the highest flood vulnerability. In the second group (level 2) there should be industrial and commercial buildings (including hotels). Finally, agricultural buildings, recreational buildings and sport centers are the least flood susceptible objects and should go to the third group (level 3). Ultimately, the matrix of dependencies between the three flood zones of different inundation intensity (probability of flood occurrence) and areas of different flood susceptibility should be created. This matrix is used as one of the components of flood risk assessment – potential damage level – could be examined (Luino et al. 2012). Based on F. Luino's matrix (Luino et al. 2012) it can be stated that residential areas and community facilities that are located in the flood zone of very high or high inundation intensity (of the highest flood hazard) are considered to have high flood risk level. On the other hand, agricultural zones, sport centers and recreational areas that are situated in the flood zone of the lowest inundation intensity are regarded to have the lowest risk level.

Flood risk assessment analysis should also involve data the extent of historical floods. Such analysis, which comprises both the matrix mentioned above and historical data on flood extent, may be a very useful tool for complex, urban development planning and the reduction of flood risk (Luino et al. 2012).

3. Area of study and methods

The studies, which are presented in this paper were carried out in the inundation zone of Gryfino – city located in the lower course of the Oder river in West Pomeranian Voivodeship. Before the Oder reaches Gryfino city it branches into the East Oder and the West Oder. Only the former one passes longitudinally through the city. Because of the high environmental values, flood zones lying within the city are legally protected as part of Natura 2000 network and Lower Oder Valley Landscape Park.

As inundation zones, two direct flood hazard areas and one potential flood hazard zone were taken into account in this research. Their extents were delineated by the Regional Water Management Board in Szczecin[1]. Direct flood hazard area involves land, whose its inundation probability is either 10% (flood may occur once a decade) or 1% (refer to 100-year flood). The potential flood hazard zone depicts areas accidentally prone to flooding as e.g. flood wave overflows embankment crown or levees damaged. It should be noted that areas of 1% annual chance of flood cover direct flood hazard zones with a 10% probability of flood occurrence (once a decade). In turn, the potential flood hazard zone is separable from all direct hazard areas.

The aerial photos taken in 1996 under the PHARE Program and orthophotomap made in 2007 under LPIS Program were used as land cover forms could be recognized and analyzed. For land development classification Topographic Database (TBD), Database of Topographic Objects (BDOT) and raster topographic maps from the 90s of 20th century were used. Land cover and land development analysis was conveyed on the basis of authorial classification where classes referred partially to TBD and BDOT categories (tab. 1). This was

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[1] In 2012 in Polish the Law, Water Law Act was changed as a result of Floods Directive implementation. Consequently, the names of particular floodplain zones were changed. The former direct flood hazard area was defined as a special flood hazard area. Also the term of potential flood hazard zone was replaced. The new flood zones are going to be delineated till the end of 2013 as a part of flood hazard maps, in order to implement the requirements of the European Floods Directive.

arranged hierarchically into four levels, where the first three presented land cover forms, while the most detailed, last one related to land development.

Table 1

Classification of land cover and land development forms

0 Level	1st Level	2nd Level	3rd Level
Unurbanized areas	Water areas	Water areas	Flowing water areas Stagnant water areas
	Woodlands, tree-covered and shrub-covered	Woodlands, tree-covered areas and shrublands	Woodlands Tree-covered areas and shrublands
	Agricultural area	Arable crops areas	Meadows and pastures Arable lands
		Permanent crops areas	Orchards
Urbanized areas	Semi-invested areas	Non-built-up, urbanized areas	Grasslands Hardened and non-hardened yards (car parks, construction sites, ruins)
		Recreation and leisure areas	Urban open space (parsk, greens) Graveyards Allotments Sports fields
	Invested areas	Transport areas	Road areas Railway areas
		Built-up areas	Residential areas Commercial areas Business districts Education and social care areas Religious buildings areas Industrial areas Transport buildings areas Outbuildings, development areas Technical infrastructure areas

Source: own elaboration based on TBD, BDOT.

In this study it was assumed that the amount of potential flood losses depend on land development patterns of floodplains. Flood losses were estimated using the method of potential flood hazard assessment which is applied while official flood risk maps are designed. This method is specified in the Regulation of the

Minister of Environment, Minister of Transport, Construction and Maritime Economy, Minister of Administration and Digitization and Minister of the Interior dated 21 December 2012 on preparation of flood hazard and flood risk maps. It differentiates potential flood losses based on land use classification and assigns distinct value of assets to each class. In case of residential, industrial and transportation areas, also inundation depth is taken into consideration as a loss function.

Based on these data, in this paper, the amount of unit potential losses for each land use form was calculated using algorithm (1), and then the aggregated value of potential flood losses for every land use class was estimated applying algorithm (2).

$$Sp_{ij} = W_i \cdot f(h_j), \tag{1}$$

where:

Sp_{ij} – amount of unit potential losses for each land use form regarding its inundation depth ranges,

W_i – value of assets in specified land use class,

$f(h_j)$ – loss function which links each land use class with its inundation depth ranges, where j – inundation depth range.

$$S_{pi} = \sum_{j=1}^{4} Sp_{ij} \cdot A_i\ , \tag{2}$$

where:

Sp_i – aggregated value of potential flood losses for each land use class,

Sp_{ij} – amount of unit potential losses for each land use form regarding its inundation depth ranges, where i – land use class, j – inundation depth range,

A_i – area of particular land use class.

Classes applied in the Regulation were much more generalized than the classification of data gathered for research purposes. Therefore, it was necessary to standardize both classifications on the basis of a less precise one. Thus residential areas included: residential areas, outbuilding development areas and grasslands, which surround residential zone. The industrial zone comprised of: industrial areas, commercial areas, business districts, transport building areas, technical infrastructure areas, hardened and non-hardened yards. Also grasslands which enclose all those areas were also included to that group. In turn, transportation class consisted of lands under roads and railways, forests involved woodlands, tree-covered areas and shrublands, recreational and leisure areas contained urban open space, graveyards, allotments and sport fields, agricultural areas comprised meadows and pastures, arable lands and orchards, water zone enclosed both flowing water and stagnant water areas. Because data on inundation depth couldn't be acquired, arithmetical average of loss function, which was set in Regulation individually for each class, was applied. It was stated that for residential areas it is 53%, for industrial ones it is 50% and for transportation areas the loss function is set to 9%.

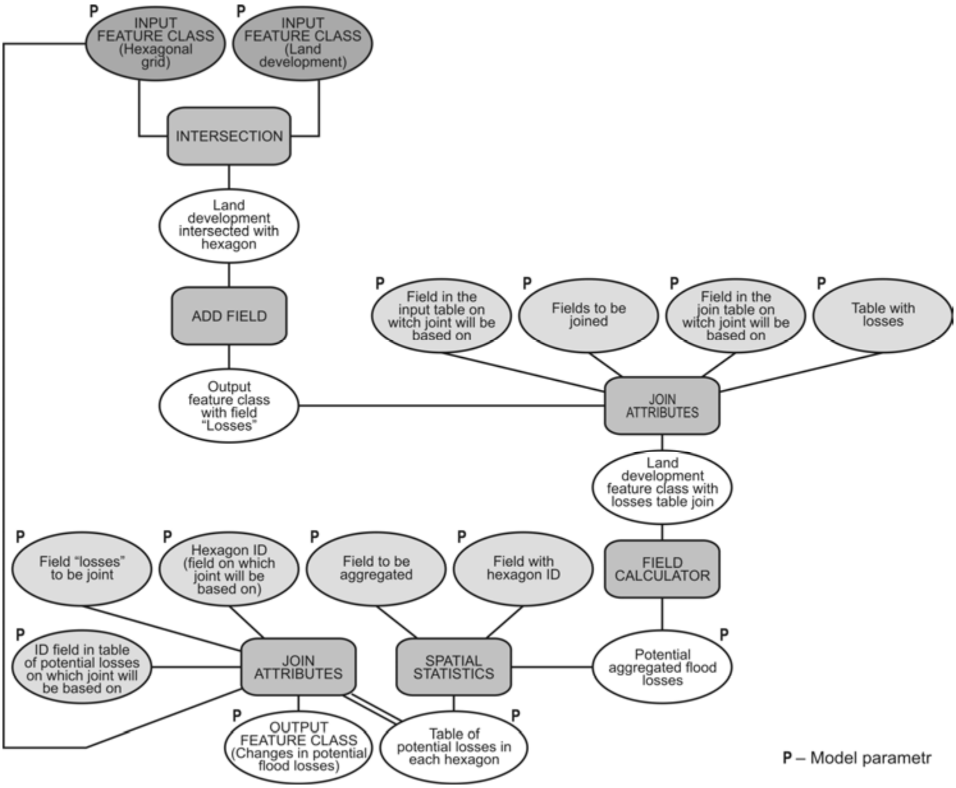

Fig. 1. Workflow of potential flood losses estimation using ArcGIS Model Builder
S o u r c e: own elaboration

For the identification of land cover and land development patterns manual photointerpretation of aerial imagery and orthophotomaps for two time periods (1996 and 2007) was conducted using GIS tools. This manual interpretation involves land cover and land development digitalization which complies to rules of mutual self-complementary of polygons, topological consistency and accuracy (Ciołkosz et al. 1999). The result of manual photointerpretation was used to draw thematic maps of land development patterns in Gryfino separately for 1996 and 2007. As a result, a map of land development changes could be released. That map was used as input for potential flood losses temporal analysis. For such analysis the same reference fields in every single map presenting time data is required. Therefore as a tile, polygons made a hexagon with an area 0.5 ha were applied. As C.P.D. Birch et al. (2007) showed, having hexagonal tiling the analysis accuracy is more precise and its visualization is much better. The average length of a hexagon's edge to its geometric mean center is about 2.9% lower than in case of a square grid of the same area. Also the individual points of the hexagon's edges are spaced from their geometric mean center more evenly, compared to a square grid. This means that hexagonal tiling reflects the nature of the phenomena better than a square grid, especially if the shape of particular land development features is diversified and intersects many tiles (Birch et al. 2007).

In that study the hexagonal grid layer, was generated using a Geospatial Modeling Environment application. This grid was intersected with a map of the land development patterns separately for 1996 and 2007. In effect, new layers that involved spatial data on particular land development forms in each hexagon were created. Then, a table of unit potential losses for every land use form standardized to 1 ha of area (see Sp_{ij}) was joined to both layers. In those joints, codes of land development forms worked as field keys. Having the area of particular land development forms in each hexagon calculated, a Summary Statistics tool from ArcGIS application could be applied to estimate the aggregated value of potential flood losses per hexagon (Sp_i). Based on the hexagon ID number such a results table could be generated and then, attached to the original hexagonal grid layer. In that way a thematic map with values of potential flood losses per hexagon, separately in the years 1996 and 2007 could be drawn up. When spatial distribution of intensity changes in potential flood losses could be identified and estimated, the differential map was created. In that map, the value of potential flood losses per hexagon in 2007 was subtracted from a corresponding hexagon with data from 1996.

The analysis of potential flood losses was carried out with the use of a Model Builder, which is part of the ArcGIS platform. This application provides tools which allow to string together sequences of geoprocessing tools in one workflow (ArcGIS Help). As a result, the research procedure can be performed more quickly, since some steps of research procedure may be automated (fig. 1).

4. Results

The steps of research analysis described above, starting from intersection of hexagonal grid with land development forms and ending at attachment of table with aggregated data on value of flood losses in each hexagon to the original hexagonal grid layer, was done automatically. It is the versatility and repeatability of models created in Model Builder, that make them interesting and worth applying. What is more, they may be used in the studies of different phenomena and various disciplines. Also such workflows may be re-used when examining other layers or feature classes. Stringing together sequences of tools in this application also protects researcher from making of human errors while data sources are being processed.

As land development patterns of Gryfino's floodplains were analyzed, the domination of meadow and pasture areas was observed (about 44%). When referring to unurbanized zone, also tree-covered areas and shrublands played important role (10%). In semi-invested class it was grasslands, defined as biologically active surface of built-up plots, which covered 2% of the floodplains. Likewise, hardened and non-hardened yards, described as landfills, parking areas and construction sites enveloped 2% of the area studied. Floodplains found not to be significant for recreation purposes. Only 1% of total floodplains were used as allotments and sports fields. There were also no parks, boulevards, graveyards in the research area.

Building development, located within the flood zone of Gryfino was found to be strongly diversified due to the fact that the western and central parts of the city were at risk of flooding. In the floodplains, mostly outbuildings development, commercial, transport and residential zones were reported, which covered about 1.5% of its total area (fig. 2).

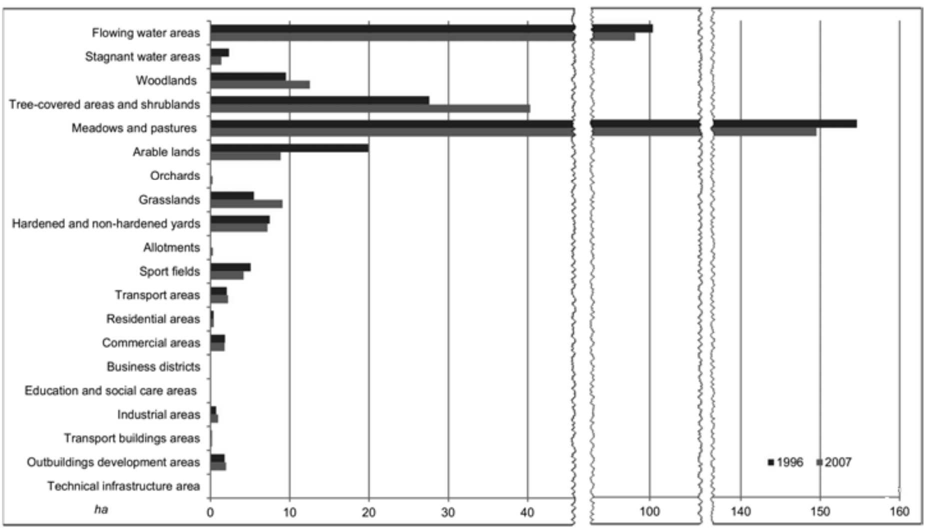

Fig. 2. Land development of floodplains in Gryfino in 1996 and 2007
S o u r c e: own elaboration

In the area of study, it was the flood hazard level, which was determined by extents of flood zones with different probability of flood occurrence, that affected structure and intensity of land development forms. It was reported that direct flood hazard areas were mainly covered with meadows and pastures, while in the potential flood hazard zone much more built-up areas were observed. According to those findings it can be stated that in Gryfino between 1996 and 2007, an economic aspect of flood risk level was inversely proportional to the intensity of land use and land development.

Having temporal changes in amount of potential flood losses in Gryfino between 1996 and 2007 analyzed, an increase in the intensity of invested areas was observed. That growth resulted from the development of new built-up areas (residential, industrial, transport and outbuilding), increase of grasslands and roads at the cost of meadows, pastures and arable lands. It was also reported that some meadows and pastures turned into tree-covered areas and shrublands. Most of those changes were noticed in the northern and southern parts of the potential flood hazard zone, where more unurbanized, open spaces could be found (fig. 3).

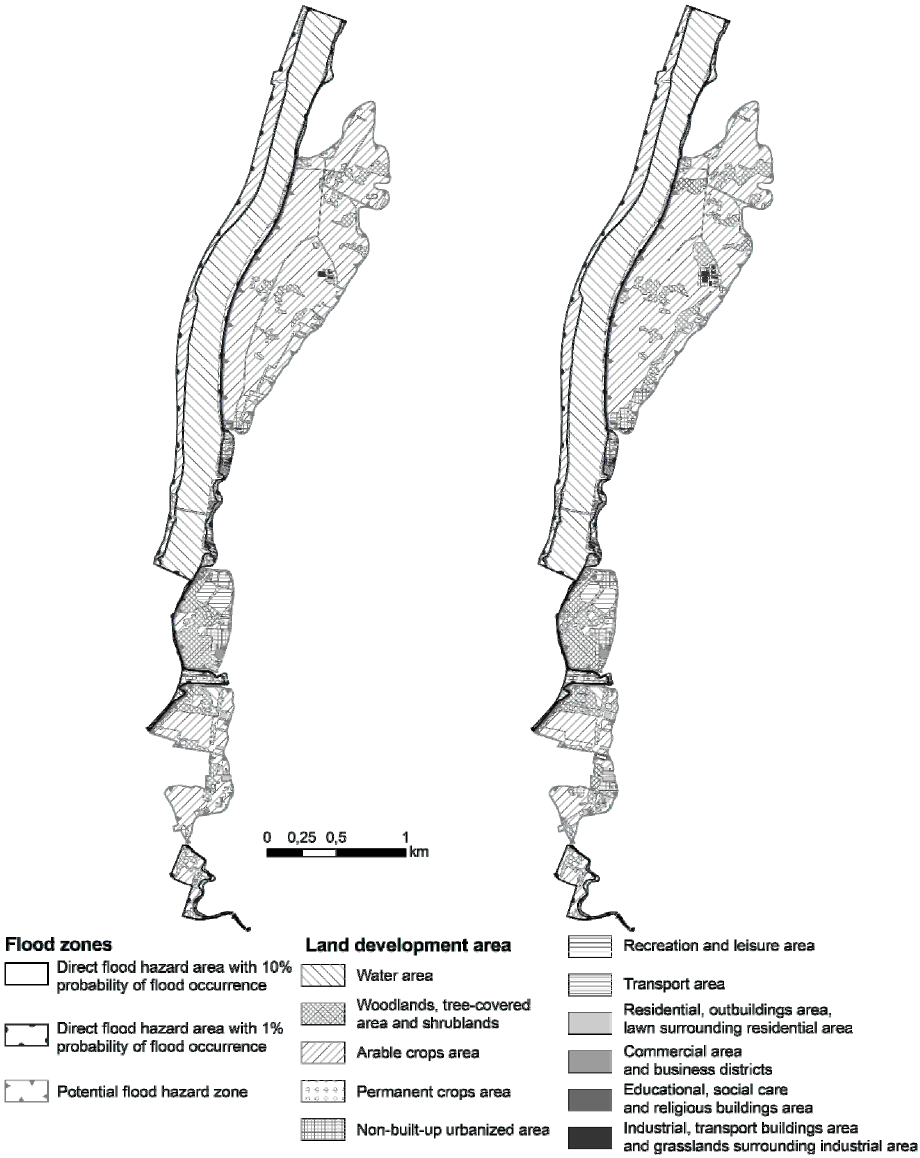

Fig. 3. Land development of floodplains in Gryfino in 1996 (a) and 2007 (b)
S o u r c e: own elaboration

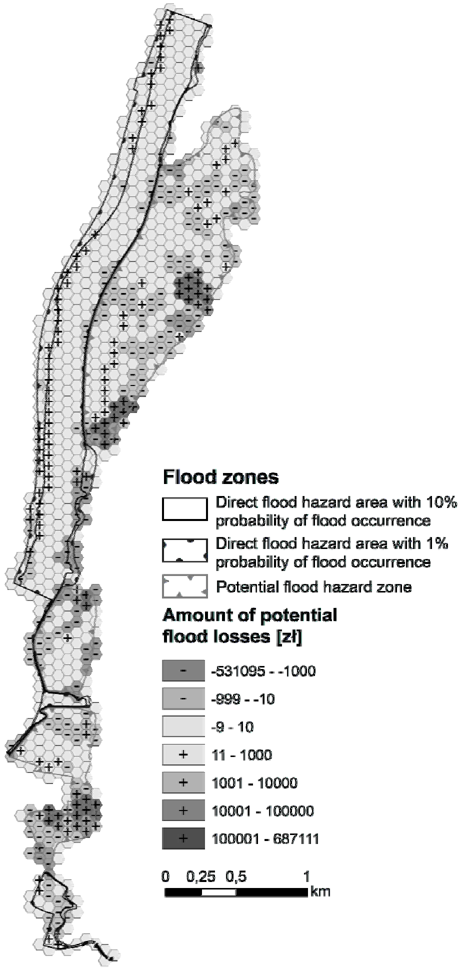

Fig. 4. Amount of changes in potential flood losses in Gryfino between 1996 and 2007
Source: own elaboration

Due to the intensification of land development in the area of study, the value of potential flood losses increased. In 1996 the estimated cost of those losses was 30.15 mln zl, while in 2007 it was 36.20 mln zl. The highest growth was recorded in potential flood hazard zones, where the vast majority of buildings were placed (fig. 4).

5. Conclusion

This study indicates that an increase of potential flood losses in Gryfino between 1996 and 2007 took place, which mainly resulted from the continuous development of new investment areas in the floodplains. These results confirm that general negative urban processes affect directly zones at risk of flooding. Worse still, the irrational policy of the Gryfino authorities causes not only growth of potential flood material losses but also increases exposure of people lives to flooding.

In conclusion, such maps of a flood risk level, expressed by potential flood losses has not only cognitive but also utility value. The first of this results may be applied when some zones referred to floodplains require further planning restrictions, e.g. non-building zone should be entered. Furthermore, such findings can be used to review existing planning studies, in order to better adjust them to local conditions.

The use of Geographic Information System applications provides set of tools and applications that accelerate and simplify research workflow. What is more new tools and workflows may be developed. Thanks to the GIS environment various spatial data (e.g. land development) and statistical data (such value of assets at flood risk) may be integrated, having analysis of potential flood losses estimation and spatial visualization of its results much more precise.

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SZACOWANIE POTENCJALNYCH STRAT POWODZIOWYCH W KONTEKŚCIE ZMIAN ZAGOSPODAROWANIA OBSZARÓW ZALEWOWYCH PRZY WYKORZYSTANIU GIS

Celem artykułu jest określenie zmian wysokości potencjalnych strat powodziowych na podstawie analizy rozkładu przestrzennego form zagospodarowania obszarów zalewowych, przy wykorzystaniu narzędzi GIS. Opracowano procedurę szacowania potencjalnych strat powodziowych przy wykorzystaniu narzędzi GIS, stosując sposób obliczania strat obowiązujący w polskim ustawodawstwie. Badania wykazały, że w latach 1996–2007 w mieście Gryfino, położonym w Polsce nad rzeką Odrą, wzrosło potencjalne zagrożenie stratami powodziowymi na skutek wzrostu intensyfikacji zagospodarowania obszarów zalewowych

Słowa kluczowe: *zagospodarowanie obszarów zalewowych, straty powodziowe, ryzyko powodziowe, Gryfino, GIS*

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