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Marta BOROWSKA-STEFAŃSKA

FLOOD RISK ASSESSMENT IN SELECTED COMMUNES OF THE ŁÓDŹ REGION

Marta Borowska-Stefańska Ph.D. – *University of Łódź, Poland*

Correspondence address:
Faculty of Geographical Sciences
Institute of the Built Environment and Spatial Policy
Kopcińskiego 31, 90-142 Łódź
e-mail: borosia@op.pl

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ABSTRACT: The aim of the article is to assess the present level of land development of flood risk areas in selected communes of the Łódź province in the context of potential negative consequences for people, the natural environment, cultural heritage and economic operations. The research includes urban as well as urban and rural communes (9 communes in total) of the Łódź province which display high and very high flood risk levels according to the methodology used in *Flood protection operating plan for the Łódź province from 2013* (*Plan operacyjny*… 2013). Uniejów and Warta have the highest synthetic flood risk levels due to the surface occupied by buildings and areas assigned to individual risk categories. In turn, Łowicz and Tomaszów Mazowiecki (town) display the highest general flood risk level due to diversification of buildings and areas of individual risk categories.

KEYWORDS: land use, areas exposed to floods, Łódź region, GIS, index of flood risk.

OCENA RYZYKA POWODZIOWEGO W WYBRANYCH GMINACH WOJEWÓDZTWA ŁÓDZKIEGO

ZARYS TREŚCI: Celem artykułu jest ocena aktualnego stanu zagospodarowania terenów zagrożonych powodziami w wybranych gminach województwa łódzkiego, w kontekście potencjalnych negatywnych konsekwencji dla ludzi, środowiska przyrodniczego, dziedzictwa kulturowego i działalności gospodarczej. Do badań wybrano gminy miejskie i miejsko-wiejskie (łącznie 9 gmin) województwa łódzkiego, które uzyskały duży i bardzo duży poziom ryzyka powodziowego według metodologii zastosowanej w *Planie operacyjnym ochrony przed powodzią dla województwa łódzkiego z 2013 roku*. Syntetyczny poziom ryzyka powodziowego ze względu na powierzchnię zajmowaną przez obiekty i tereny przypisane do poszczególnych kategorii ryzyka jest najwyższy w Uniejowie i Warcie. Natomiast ogólny poziom ryzyka ze względu na zróżnicowanie obiektów i terenów poszczególnych kategorii jest najwyższy w Łowiczu oraz Tomaszowie Mazowieckim (mieście).

SŁOWA KLUCZOWE: użytkowanie ziemi, tereny zagrożone powodziami, województwo łódzkie, GIS, wskaźnik ryzyka powodziowego.

2.1. Introduction

The aim of the research is to assess the current state of land use of flood risk areas, considering potential negative consequences for people, the natural environment, cultural heritage and economic activity as exemplified by four urban communes of Kutno, Łowicz, Sieradz and Tomaszów Mazowiecki as well as by five urban and rural communes of Działoszyn, Poddębice, Sulejów, Uniejów and Warta.

Spatial development is the condition of space, including land, buildings, technical, social and economic infrastructure facilities as well as the environment, resulting from all kinds of activities aimed at a man-made durable change in physical properties of land introduced in order to satisfy people's needs in a direct or indirect way (Regulski 1985). The current state of spatial development is examined on the basis of analysis of land use (Bromek, Mydel 1972). The term „use" is understood by Liszewski (1997: 61) as „(…) using something, benefiting from something in a rational way which brings possibly greatest advantage". Consequently, almost every human activity is reflected in the land and „(…) performs a clearly defined and diverse function" (Liszewski 1978: 17).

The work uses research into land use so as to evaluate the current state of land use of flood risk areas.

In this article the research includes areas particularly exposed to the risk of flooding on which the probability of flooding is medium and amounts to 1% (*Ustawa Prawo wodne…* 2001). These areas were drawn by directors of Regional Water Management Authorities and form an integral part of study on flood protection. Due to its location on minor drainage divide between the basins of the Vistula and Oder, the Łódź region is governed by the Regional Water Management Authority in Poznań (the basin of the Oder) and Warsaw (the basin of the Vistula river). The research was started in 2011 when there were no flood risk maps in effect and no potential flood risk areas were designated in the study on flood protection for the Oder's basin within the Łódź province. This is why the author decided to conduct land use analysis within 1% water[1]. It must be stressed, however, that analysis was conducted into lowland rivers where the course of flooding has a different character as compared to upland and mountain river catchments. Flood plains in valleys of these rivers tend to be wide and in the majority of cases they are divided by levees which separate the inter-embankment zone from the valley in the zone of the land side of the levee. There are many cases of intensive land development of areas potentially threatened with flooding in the zone of the land side of the levee (Majda et al. 2012). As a result of assuming 1% water area for the research, flood plains behind the levee were excluded from the analysis.

[1] Data from studies on flood protection were supplemented with information from Spatial Planning Office of the Łódź province, in particular in reference to the range of flood risk areas in Poddębice.

The development of flood hazard areas is also related to the notion of flood risk which is normally defined as the product of hazard (physical and statistical flood aspects), exposure (who and what is threatened with flood) and sensitivity (susceptibility of development elements to the hazard and ability to counteract and eliminate the consequences of the catastrophe) (Apel et al. 2009). Interaction of these three elements gives rise to the so-called „risk triangle" (Crichton 2007).

The character, type and value of the existing land development on the flood hazard areas determine the level of losses which may occur in the form of damage or destruction of facilities resulting from flooding (Chojnacki 2000). The total risk comprises the expected death toll, the injured, material loss and disruptions to economic activity in connection with the natural phenomenon. To put it in the simplest possible way, this is the probability of a flood event and consequences connected with it. They may be desirable or not (UN DHA 1992; Granger et al. 1999). These definitions were adopted in the Floods Directive (2007, art. 2, point 2) where the notion of flood risk is understood as „the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event".

In Poland the problem of development of flood hazard areas and assessment of losses due to flooding is dealt with by the National Water Management Authority (Polish: KZGW), the Institute of Meteorology and Water Management (Polish: IMGW), the Head Office of Land Surveying and Cartography (Polish: GUGiK), the Crisis Management Centre (Polish: RCB) and the National Institute of Telecommunications. There is a project entitled „IT System of the Country's Protection against extreme hazards", which resulted in preliminary assessment of flood risk, flood hazard maps and flood risk maps. Flood hazard maps and flood risk maps were published at the end of 2013, yet guidelines providing for them were established already in the Regulation of the Minister of the Environment, the Minister of Transport, Construction and Marine Economy, the Minister of Administration and Digitalization and the Minister of Internal Affairs as of 21 December 2012 on elaboration of flood hazard maps and flood risk maps. These documents had to be elaborated in accordance with the provisions of the Floods Directive (http://www.kzgw.gov.pl/Dyrektywa-Powodziowa.html). The main aim of this document is to reduce the flood risk and minimize the consequences of floods, adequate management of the risk which may be posed by floods for human health, the environment, economic activity and cultural heritage as well as preparation of citizens to deal with a flood event (Rotnicka 2011). This is the only document which clearly refers to flood risk assessment in Poland.

The first attempt to assess risk flood levels within the Łódź province was made by the Security and Crisis Management Department of the Provincial Office in Łódź and its results were included in *Flood protection operating plan for the Łódź province* (*Plan operacyjny*… 2013). The problem of river valley development in central Poland is also discussed in publications by Kobojek (2009, 2010, 2013). The problem of flood risk assessment is also discussed in publications by Borowska-Stefańska (2014, 2015a, 2015b, 2015c, 2015d, 2015e).

2.2. Research area

Flood protection operating plan for the Łódź province (*Plan operacyjny*… 2013) points in total to 21 communes from the area of the province which are characterized by high or very high flood risk levels. For further research both urban and urban and rural communes were selected from this group. They are situated in the water catchments of three main rivers:

1) the Warta river – Działoszyn (an urban and rural commune on the Warta river), Sieradz (a town on the rivers of Warta and Myja), Warta (an urban and rural commune on the Warta river), Poddębice (an urban and rural commune on the rivers of Warta and Ner), Uniejów (an urban and rural commune on the Warta river);

2) the Pilica river – Sulejów (an urban and rural commune on the rivers of Luciąża and Pilica), Tomaszów Mazowiecki (a town on the rivers of Pilica, Wolbórka, Czarna and Piasecznica);

3) the Bzura river – Kutno (a town on the Ochnia river), Łowicz (a town on the Bzura river) (Fig. 1).

Tomaszów Mazowiecki lies in the eastern part of the Łódź province on the Pilica river in the vicinity of the hydrologic node formed by the rivers of Wolbórka, Czarna Bielina and Piasecznica. Within the boundaries of the town there is a lower section of the Pilica river as well as lower sections of valleys of its tributaries (*Studium*… 2009). The width of the valley floor of the Pilica river in Tomaszów Mazowiecki is diversified, and in the southern and central part it varies from 0.3 to 1 km, whereas in the northern part at the mouth of the Wolbórka river it reaches 1.7 km (Trzmiel 1986). Levees were built fragmentarily along the rivers of Wolbórka and Czarna. Their total length within the town's boundaries is 4,030 m, out of which 2,660 m comprises the right-bank levee of the Wolbórka river, 770 m falls to the left-bank levee of the Wolbórka river, and 600 m forms the left-bank levee of the Czarna river. The flood risk area there covers 761.59 ha, which represents 18.33% of the town territory. The terrain of flood plain areas is diversified hypsometrically, descending in the north-eastern direction. Elevations range from about 163 m above sea level in the western and southern parts to 153 m above sea level in the place where the Wolbórka river debouches to the Pilica river (Borowska-Stefańska 2015c). Upstream the town on the Pilica river there is the Sulejowski Reservoir. Due to its construction water levels on the river are more stabilize and, with its proper operation, floods on the area of Tomaszów Mazowiecki are highly unlikely (*Studium*… 2009). In the event

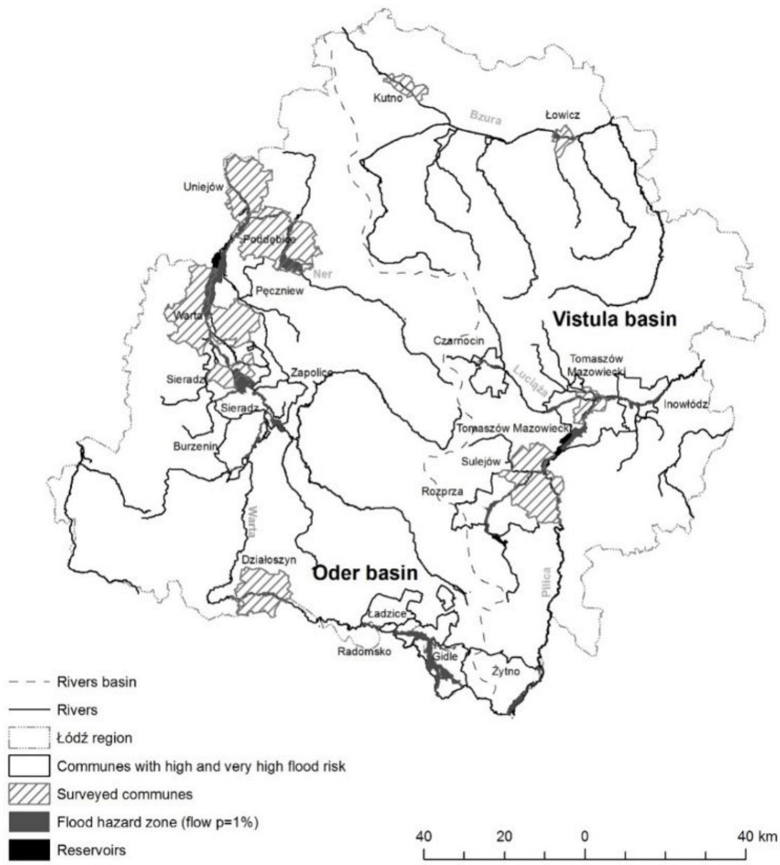

Figure 1. Flood hazard zones in surveyed municipalities of Łódź region
Source: author's own study based on data from Voivodship Office in Łódź and WZMiUW (2012), and M. Borowska-Stefańska (2015d).

of damaging the dam of the reservoir in Smardzewice (8 km from the town), there is a possibility of catastrophic flooding if we consider maximum water damming levels (*Plan operacyjny*… 2013).

Kutno is situated in the northern part of the Łódź province on the Ochnia river which runs from north-west to south-east. The areas located along this river are exposed to the risk of flooding. Their area is 292.6 ha, which is 8.59% of the territory of the town. The historic centre is protected by levees on both sides of the river (*Studium*… 2012). They are 2,000 m long, including 1,210 m of the left-bank embankment, and 790 m of right-bank levees. In places not protected by levees the width of the flood plain is from 300 to 500 m. The flood plain descends in the south-eastern direction where absolute elevations are approximately 100 m above sea level (Borowska-Stefańska 2015c).

Łowicz is located in the narrowing of the Warsaw-Berlin ice-marginal valley on the Bzura river in the northern part of the Łódź province. Within the town the hydrographic network is formed by the rivers of Bzura, Zwierzyniec, Uchanka, Bobrówka, a network of canals and drainage ditches (*Studium*… 2003). The present layout of the town's river network is totally artificial (Kobojek 2009). The Bzura river was regulated on the section from Łowicz to Łęczyca in the 19th century and the current course of the river bed in the town was shaped between 1925 and 1942. In 1943 a levee of about 2 km was constructed south of the river. Regulation and melioration works led to lowering of ground water levels by at least 0.5 m. In the 1980s floods in Łowicz did not occur, due to which a view persisted on the safety of some areas situated within the flood plain. This resulted in development of the area of the land side of the levee (Kobojek 2013). The surface of the area particularly exposed to the risk of flooding is 396.24 ha, which represents 16.91% of the town's area. North of Łowicz the width of the flood plain is about 700 m. The valley floor in the central part narrows to about 300–400 m. It was additionally embanked and in the inter-embankment zone its width is mere 150 m (Brzeziński 1990a). The surface of the flood plain descends in the eastern direction where elevations reach about 82.5 m above sea level. The difference in relative elevations is as little as 2.5 m (Borowska-Stefańska 2015c).

Sieradz is situated in the western part of the Łódź province in the water catchment of the Warta river. The hydrographic network within the town's boundaries is formed by the rivers of Warta, Żeglina, Myja, Krasawa and Niniwka. The Warta river in Sieradz is 8 km long and its river bed is regulated (*Studium*… 2012). The surface of the flood plain is 740.17 ha, which represents 14.4% of the towns area. Almost the whole Warta river was embanked. The levees there are 8,940 m long, out of which 6,860 m forms the right-bank levee whereas the left-bank levee is 2,080 m long. Embankment also protects areas located on the Żeglina river. Their total length is 4,815 m, out of which the right-side levee comprises 2,115 m and the left-side one is 2,800 m long. On the territory of Sieradz in the place where the Żeglina river debouches to the Warta river the flood plain is very wide, reaching 2 km. In the inter-embankment zone the valley floor is merely 300–400 m wide. The surface of the flood plain descends in the north-western direction where heights reach about 128.75 m above sea level. The difference in relative elevations reaches 9 m.

The commune of Działoszyn lies in the south-western part of the Łódź province in the water catchment of the Warta river. Within the boundaries of the commune the river has a natural, heavily meandering river bed, flowing from east to west and dividing the area in question into two parts: northern and southern. (*Studium*… 2006). The area of the so-called 100-year water occupies 726.09 ha, which represents about 6% of the area of the commune of Działoszyn. The width of flood risk area ranges from 200 m to as much as 1 km. The analyzed area descends in the western direction where absolute elevations reach 173.75 m above sea level. The difference in relative elevations is about 9 m.

The commune of Poddębice lies in the north western part of the Łódź province in the water catchment of the Warta. The hydrographic network on its territory is formed by the rivers of Warta, Ner, Pisia, Bełdówka and Brodnia. The Warta river forms the western boundary of the commune and it is embanked: the length of the left-bank levee is 3,215 m. The width of the flood plain reaches 1 km. The river bed is unregulated. The Ner river runs from south-east to the north. The southern part of the valley floor is very wide, reaching 4 km, whilst in the central and northern parts it narrows to about 1 km. The Pisia river (regulated, left-bank tributary of the Ner river) and the rivers of Bełdówka and Brodnia (its right-bank tributaries) debouch to the Ner river within the commune boundaries (*Studium*… 2000–2001). The surface of the area exposed to the risk of flooding is very large and amounts to 3,671.87 ha, which represents 16.4% of the commune's area. The lowest-lying area is situated along the Warta river in the western part of the commune where absolute elevations reach 106.25 m above sea level. The highest point is situated along the Ner and its tributaries where elevations reach 130 m above sea level. The difference in relative elevations is considerable, reaching about 24 m.

Sulejów is situated in the south-eastern part of the Łódź province on two rivers: the Pilica and the Luciąża. Besides within the commune there is also the Sulejów Reservoir (he second largest artificial reservoir in the province) (*Studium*… 2008). The valley floor of the Pilica river and the Luciąża river within Sulejów is from 200 to 500 m wide (Brzeziński 1990b). The surface of the area of the so-called 100-year water is 1,022.29 ha, which represents 5.43% of the commune's area. The elevations range from 166 m above sea level in the northern part to about 177 m above sea level in the southern and western part. The difference in relative elevations is about 10 m, the terrain descends in the northern direction to the Sulejów Reservoir.

Uniejów is an urban and rural commune located in the north-western part of the Łódź province on the Warta river (Borowska-Stefańska 2014, 2015e). A considerably long section of the Warta river is embanked and the length of left--bank levees amounts to 12,300 m, while right-bank levees are 9,100 m long. The surface of the flood risk area in Uniejów is 729.42 ha, which represents 6.07% of the area of the whole commune. The width of the flood plain ranges from about 200 m in the northern part to 1 km in the southern, which results from the fact that the flood plain was embanked and consequently only a fragment of it was subject to analysis. On the analyzed area absolute elevations range from 98.75 to 107.5 m above sea level. The terrain descends in the northern direction.

The town and the commune of Warta is situated in the north-western part of the Łódź province on the Warta river. The hydrographic network there is formed by the Warta river and its tributaries – the Niniwka river and the Struga river from Bartochów. The Warta river flows from south to north, forming the Jeziorsko Reservoir (the biggest artificial water reservoir in the province) on the 504+000 km of its course (*Studium*… 2007). These rivers were embanked an the total length of levees is over 18,000 m, 54% of which comprises the left-bank levee and 46% the right-bank levee. The width of the flood plain oscillates between 500 m to 600 m, and this is only a section of the flood plain (the inter-embankment area). The surface of the area particularly exposed to the risk of flooding is 1,919.37 ha, which is 7.6% of the whole commune. Absolute elevations vary from 121.25 to 123.75 m above sea level. Height differences are indistinct, reaching 2 m. The terrain descends in the northern direction.

2.3. Methodology

In order to analyze the current land development of flood risk areas the author uses land inventory which was conducted on the area of Tomaszów Mazowiecki, Kutno, Łowicz, Poddębice and Uniejów between 2012 and 2013. The basis for these analyses was formed by the Database of Topographic Objects (Polish: BDOT), which, as it was pointed out, reflects up-to-date land development. This is why detailed research in the remaining communes was not carried out. Layers of coverage and land development from the Database of Topographic Objects were integrated with the aim of scrutinizing present land development on the areas particularly exposed to the risk of flooding. Area coverage complexes in the Database of Topographic Objects include the most important surface situation details of the area distinguishable on the basis of their physiognomic features. The facilities which belong to this class describe the given area in an exhaustive manner. Land development complexes are surfaces which are homogenous as far as their function is concerned. This group comprises mostly all social and economic infrastructure facilities. They give supplementary vital information on land development (*Wytyczne techniczne*… 2008).

The superimposition of these two layers gave a detailed picture of land use on the areas particularly exposed to the risk of flooding.

Tools from Geographic Information Systems were employed to analyze both land use structure on flood risk areas and its assessment. Geographic Information Systems are used, for instance, to solve geographical problems, providing tools to feed, integrate, manage, analyse and visualize spatial data (Ziółkowski et al. 2011). In order to assess diversification of land development of flood risk areas in the analyzed communes, an indicator of horizontal land use intensity was calculated. Horizontal intensity is a measurement reflecting the coverage of land with technical buildings measured in the plane of land surface. The degree of such coverage shows intensity of geographic space transformations being a result of man's investment activity. Horizontal land use intensity is measured by the percentage of built-up areas in the whole researched area (Liszewski 1977: 87).

In the absence of a single effective methodology of flood risk assessment, the author has proposed its own methodology for determining its level. On the basis of analysis of current development of flood hazard areas in the selected communes of the Łódź province, facilities and areas generating flood risk were identified. Due to their considerable differentiation within the limits of 100-year water four categories were distinguished:

- social facilities in which there might be a large number of people on a permanent or temporary basis,
- cultural heritage sites and natural value areas,
- facilities potentially representing a hazard to the environment and people,
- areas generating economic losses.

Categories of flood risk

The group of social facilities includes:

- residential buildings (both single family and multi-family buildings),
- hospitals,
- schools,
- kindergartens,
- hotels,
- health institutes.

The category of cultural heritage facilities and areas of natural value comprise:

- Natura 2000 areas,
- nature reserves,
- nature parks,
- zoos,
- areas and buildings of historical monuments, in particular those covered by the forms of monument protection which are referred to in article 7 point 1 of the Act as of 23 July 2003 on the monument protection and care (*Ustawa o ochronie zabytków*… 2003),
- monuments placed on the World Heritage Site list which is referred to in article 11 point 2 of the *Convention Concerning the Protection of the World Cultural and Natural Heritage adopted in Paris on 16 November 1972 by the General Conference of the United Nations Educational, Scientific and Cultural Organization on its seventeenth session* (*Konwencja*… 1976),
- open-air ethnographic museums and museums entered into the National Register of Museums which are referred to in article 13 of the *Act 1996 on museums as of 21 November* (*Ustawa o muzeach*… 2012).

In the group of facilities which may potentially represent a risk both to people and the environment in the event of a flood include:

- sewage purification plants,
- filling stations,
- pumping stations,

– landfill sites,
– waste management plant,
– animal farms.

Assessment of tangible losses was accomplished using the Database of Topographic Objects. Under the Regulation of the Minister of the Environment, the Minister of Transport, Construction and Marine Economy, the Minister of Administration and Digitalization and the Minister of Internal Affairs as of 21 December 2012 on elaboration of flood hazard maps and flood risk maps in order to specify potential property loss on flood hazard areas, the following land use areas should be distinguished: housing estates, economic activity areas, transportation areas, forests, recreation sites, agricultural land, waters, the remaining areas for which flood losses are not determined.

Flood risk assessment on areas of particular flood hazard is a task of great importance as it makes is it possible to conduct activities connected with anti-flood protection in a rational way (Szypuła 2001). It refers to assessment of the extent of damage of all categories for individual flood scenarios in the spatial system, and its effectiveness is largely dependent on topographic data available (Nachlik 2011).

In all distinguished categories the author made assessment of flood risk from the minimum level (1) to very high (5), where the base field was a hexagon of the surface of 0.5 ha[2]. Subsequently a map was created which included a synthetic assessment of flood risk levels on the researched areas.

In the group of social facilities, cultural heritage and areas of natural value as well as facilities potentially representing a hazard for the environment and people, the area which they occupy in every hexagon was taken into consideration while assessing the flood risk level[3]. The hexagon area (0.5 ha) was divided into 5 equal classes (every 0.1 ha): the larger the surface within the hexagon occupied by buildings or facilities of the given risk category, the higher its level. If facilities or areas occupied the area of up to 1,000 m^2 in the hexagon (yet no more than 0), they received minimal risk level (1), from 1,001 to 2,000 m^2 – very low risk level

[2] The areas exposed to floods in all the researched communes were divided in the Geospatial Modelling Environment programme into hexagons of the surface of 0.5 ha. The hexagon size was adjusted in such a way so as to fit as many full figures within the boundaries of the analyzed area as possible.

[3] Assessment of flood risk levels were made under the assumption that the depth of flooding ranges from 0.5 to 2 m. This resulted from the specificity of floods on the area of the Łódź province. Consequently, in three categories of flood risk it was decided to take into account the surface of the facilities attributed to every selected group. In the case of buildings flooding within the analyzed range of water depth will take place only to the level of the first storey. Consequently, the analysis does not consider the number of storeys.

(2), form 2,001 to 3,000 m² – medium risk level (3), from 3,001 to 4,000 m² – high risk level (4), >4,000 m² – very high risk level (5).

Assessment of economic losses was made analyzing 7 selected areas of land use in every hexagon. The value of individual losses for residential areas, economic activity areas and transportation areas is closely related to the depth of water, and consequently to the extent of property value loss (Table 1).

Table 1. The degree of loss of property due to the function and the depth of water

Class of land use	Loss function value f (h) [%] in the range water depths 0,5 < h ≤ 2 m
Residential areas	35
Economic activity	40
Transportation areas	10

Source: *Rozporządzenie Ministra Środowiska…* (2013).

The potential value of economic losses was determined for the depth of water in the range of 0.5–2 m. It is only when three elements are taken together: land use, depth of water and property value (which for residential and economic activity areas varies according to the province) that potential losses counted in money can be assessed (Table 2).

Table 2. The value of property loss in the Łódź region due to land use class

Class of land use	The value of assets in the range water depths 0,5 < h ≤ 2 m
Residential areas	101,83 zl/m²
Economic activity	331,68 zl/m²
Transportation areas	43,60 zl/m²
Forests	80 zl/ha
Recreational areas	5,1 zl/m²
Arable land	1 428 zl/ha
Grassland	674 zl/ha

Source: *Rozporządzenie Ministra Środowiska…* (2013).

The method of assessing property proposed in the Regulation was based on the methodology used in Germany (Drożdżal et al. 2009). It must be remembered, however, that due to fluctuations in prices these data must be updated so as to preserve comparability of the amount of damage and loss (Chojnacki 1994).

While assessing the risk connected with potential economic losses the area occupied by selected land use classes was calculated in every hexagon. Then the property value was estimated for each of them and summed up within the base field (hexagon). The maximum risk level was assumed to be the value of losses for economic activity areas. The maximum value of losses in the hexagon was 1,658.4 thousand PLN. Five equal ranges of property value were established (every 331.68 thousand PLN) and for every of them the level of risk was established ranging from minimal to very big, receiving a picture of flood risk levels according to economic loss.

In order to differentiate communes according to flood risk levels the share of hexagons in the given extent of risk was analyzed for 100-year water in every distinguished category. Only hexagons of the surface exceeding 0.4 ha were taken into account since only within their boundaries it was possible to receive the highest flood risk level. These hexagons whose surface was smaller were removed from the analysis. Subsequently a ranking of communes was elaborated in every category of flood risk according to the pattern:

$$P = \frac{\sum U * Ri-go}{5}$$

where:

P – risk level in the given category,

U – share of hexagons of the given category of flood risk in the area of 100--year water of the given commune,

$Ri-go$ – extent of risk in the given category of flood risk,

5 – number of risk levels[4].

As a result of these calculations values for all communes were obtained in every distinguished category and they were ranked in descending order in accordance with the obtained values and on this basis a ranking of communes was elaborated according to the flood risk. Finally, synthetic flood risk level was analyzed on the floodplain. In this classification the position of the given commune according to the flood risk level was taken into consideration in every distinguished category. The position of the commune indicated the number of points where the fewer the points, the higher total risk level (Borowska-Stefańska 2015a, 2015d).

[4] The level of flood the given category goes up together with the increase in the share of hexagons of the highest level of this risk. The pattern was elaborated by the author of this article.

2.4. Results

Analysis of current development of areas particularly exposed to the risk of flooding in the scrutinized communes of the Łódź province showed that the dominant group comprises areas without any buildings. Communes in the Vistula basin, such as Tomaszów Mazowiecki, Kutno and Łowicz, are characterized by the biggest horizontal intensity of development of flood plains. In the remaining communes buildings represent a small percentage yet despite this losses caused by floods are reported. Consequently, it is very important to assess flood risk within flood plains and introduce a ban on further development.

In Tomaszów Mazowiecki approximately 14% of flood risk areas is designated for mainly technical and production development, while in Kutno it is 7.5% and in Łowicz 4.5%. In the remaining communes this indicator does not exceed 3%: Działoszyn 2.8%, Sieradz 2.4%, Uniejów 1.9%, Poddębice 1.5%, Sulejów 0.7%, Warta 0.02%. Communes with existing levees achieved the lowest values of the indicator of horizontal development intensity within the so-called 100-year water. There are no new buildings in the inter-embankment zone (Borowska-Stefańska 2015d).

2.4.1. Flood risk categories

For all the selected categories of flood risk the author specified the surface occupied by buildings and areas classified to certain groups, and in the case of economic losses also their amount (Table 3). Subsequently, flood risk levels were assessed in the communes for each category. Flood risk areas were divided into hexagons of 0.5 ha, the percentage of buildings and areas in individual groups was calculated for each hexagon and a ranking of communes was established with the use of the author's original method.

2.4.2. Social facilities

Facilities in which people may stay temporarily or permanently occupy about 7 ha in total within the boundaries of flood plains of the analyzed communes. The highest risk level in this category can be found in Kutno. It is followed by Tomaszów Mazowiecki, Łowicz, Działoszyn, Poddębice, Sieradz, Uniejów, Sulejów. Only in Warta commune there are no facilities from this category.

The analyzed communes are dominated by single-family dwellings. Over 100 residential buildings located mainly on the Ochnia river's left bank were inventoried in Kutno. In Tomaszów Mazowiecki single-family dwellings are located along the rivers of Czarna and Piasecznica (82 buildings) as well as Wolbórka (59 buildings). In Łowicz on the area of the so-called 100-year water there are both single-family dwellings (about 150 buildings) and multi-family

Table 3. Flood risk categories according to the surface and losses within 1% water of the analysed communes of the Łódź province

River basin	Munici-palities	Area of flood hazard zone (ha)	Social facilities (ha)	Cultural heritage sites and natural value areas (ha)	Facilities potentially repre-senting a hazard to the en-vironment and people (ha)	Economic losses (thous. zł)
Warta	Działoszyn	726,09	0,55	283,56	1,43	43 357,10
	Sieradz	740,17	0,37	2,93	–	18 342,73
	Poddębice	3 671,87	1,20	492,10	1,36	49 186,98
	Uniejów	729,42	0,61	729,42	–	19 588,42
	Warta	1 919,37	–	1 919,37	0,31	1472,29
Pilica	Sulejów	1 022,29	0,19	754,70	–	8 486,48
	Tomaszów Mazowiecki	761,59	1,72	86,32	41,83	301 285,99
Bzura	Kutno	292,6	0,94	–	1,28	42 863,91
	Łowicz	396,24	1,36	189,63	3,27	32 626,75
Sum		10 259,64	6,94	4 458,03	49,48	517 210,65

Explanation: (–) phenomenon does not exist.

Source: author's own study (2013).

buildings (3 blocks of flats) (Borowska-Stefańska 2015c). In Działoszyn the total number of over 50 residential buildings were inventoried north of the Warta river. In Poddębice on the flood plain of the Warta river there are 9 residential buildings, 5 along the Pisia, over 100 on the Ner river and its tributaries, mainly on the rural area in Stary Pudłów and Nowy Pudłów. There are only 3 residential buildings in Sieradz on the Myja river as compared with 16 west of the Żeglina river and 11 in the place where the flood plain is the widest. In the case of Sulejów on the area particularly exposed to the risk of flooding there are in total 22 residential buildings, out of which only one on the Pilica river and the rest along the Luciąża river.

Residential buildings are mainly located in places where the flood plain is wide or in valleys of smaller rivers.

The group in question also comprises schools (the commune and town of Tomaszów Mazowiecki), a nursery school (Łowicz), hotels (Uniejów, the town of Sieradz), Health Institute (Uniejów) (Borowska-Stefańska 2015a, 2015d).

2.4.3. Cultural heritage sites and high nature value areas

Protected areas dominate in the group of cultural heritage sites and high nature value areas. They occupy the largest space from all the categories: about 4,400 ha. Protected areas are located mainly in urban and rural communes of Uniejów (Natura 2000 area), Warta (Jeziorsko Nature Reserve, Natura 2000 – bird areas), Sulejów (Sulejów Lanscape Park), Działoszyn (Natura 2000, Załęcze Lanscape Park), Poddębice (Natura 2000 area). Besides that protected areas may be found in Łowicz (Natura 2000 area), Tomaszów Mazowiecki (Spała Lanscape Park, Natura 2000, Niebieskie Źródła Nature Reserve). This category also includes cultural heritage sites, such as an ethnographic park, Castle Hill (the town of Sieradz), the Open-air Museum of the Pilica River (the town of Tomaszów Mazowiecki), a zoo (Poddębice), Uniejów castle, a miller's homestead (Uniejów). In this category the highest risk levels are to be found in Uniejów and Warta followed by Sulejów, Łowicz, Działoszyn, Poddębice, Tomaszów Mazowiecki and Sieradz. There are no facilities or areas from this category in Kutno (Borowska-Stefańska 2015a, 2015d).

Areas of high nature value are often subject to construction of buildings and linear facilities as well as changes in land use. This phenomenon is really detrimental from the environmental point of view, but there is still no social acceptance for protection of high nature value areas (Borowska-Stefańska 2013). Consequently, there is a potential threat that in the event of flooding such high nature value areas will lose their properties, which is why they are taken into consideration in flood risk assessment (assuming the worst case scenario as the influence of high water levels on these areas is definitely beneficial).

2.4.4. Facilities potentially threatening the natural environment and people

Facilities generating possible adverse consequences for the natural environment and people take up a space of about 49 ha in total in the analyzed communes. Water purification plants and filling stations tend to dominate in this group. The highest risk level in this category occurs in Tomaszów Mazowiecki followed by Łowicz, Kutno, Działoszyn, Poddębice and Warta. There are no facilities potentially threatening the natural environment and people in the event of flooding in Sieradz, Uniejów and Sulejów.

Water purification plants were identified within the so-called 100-year water in the following five communes: Działoszyn, Łowicz, Tomaszów Mazowiecki, Poddębice and Warta. These are localized in the northern part Poddębice, in the eastern part in Łowicz, in Tomaszów Mazowiecki in the place where smaller rivers debouch to the Pilica river, in the southern part of Działoszyn and in the town of Warta on a rural area in the vicinity of the Jeziorsko Resevoir.

Filling stations are situated on flood plains of two communes: Działoszyn – in the southern part of town (east of the water purification plant) and Łowicz – in the south-western part of the Bzura flood plains.

The category in question also comprises a pumping station (Tomaszów Mazowiecki), waste treatment plant and a company recovering and neutralizing waste (Kutno).

The largest surface of facilities belonging to the discussed category was inventoried within the boundaries of Tomaszów Mazowiecki. They can be found in places where there is no levee and valley floors are wide (Borowska-Stefańska 2015a, 2015d).

2.4.5. Economic losses

Flood risk levels due to financial losses are the highest in Tomaszów Mazowiecki. It is followed by Kutno, Łowicz, Działoszyn, Uniejów, Sieradz, Poddębice, Sulejów and Warta. This is the only category of flood risk which refers to all the communes.

Tomaszów Mazowiecki has the biggest potential value of losses expressed in the Polish zloty amounting to 301,285.99 thousand PLN. This town is characterized by the highest horizontal intensity of land development within flood plains. The biggest potential losses there may occur in the event of flooding of the area situated on the rivers of Czarna and Piasecznica (the total amount of losses is 148,505.85 thousand PLN). They are generated by companies producing fabrics and carpets (situated on the Wolbórka river), ceramic tiles (on the rivers of Czarna and Piasecznica) and water purification plant (137,429.29 thousand PLN). In the commune of Poddębice financial losses may amount to 49,186.98 thousand PLN, which is connected with considerably large surface of residential buildings on the flood plain (Borowska-Stefańska 2015b, 2015c).

In Działoszyn the aggregate amount of potential financial losses on the flood plains is 43,357.1 thousand PLN, from which over a half (25,723.319 thousand PLN) refers to production and service companies located in the central part of the commune. In the event of flooding quite high losses may be suffered also in the case of residential buildings (11,250.93 thousand PLN) and water purification plant (4,069.87 thousand PLN).

The maximum amount of losses in Sieradz is 18,342.73 thousand PLN in the event of flooding within the so-called 100-year water. This is generated by single--family residential buildings, a sports and recreation centre, a nursery school and the Castle Hill which are situated on a wide flood plain in the spot where the Żeglina river debouches into the Warta river.

The facilities generating the highest financial losses in Kutno are dispersed. They are situated on the outskirts of the area particularly exposed to the risk of flooding and they include, for instance, construction companies as well as residential.

In Łowicz the highest potential financial losses are generated by the water purification plant, filling station and single and multi-family residential buildings (Borowska-Stefańska 2015a, 2015b, 2015c).

The lowest flood risk connected with financial losses can be found in the communes of Warta and Sulejów. This results from the lowest horizontal intensity of development of flood plain areas.

2.5. Synthetic flood risk level

Finally, the general flood risk level was evaluated in the analyzed communes of the Łódź province. Firstly, risk levels in every hexagon was researched for all flood risk categories considering the surface which they occupy. In this classification the first place was occupied by the towns of Warta and Uniejów, followed by Sulejów, Łowicz, Działoszyn, Tomaszów Mazowiecki, Poddębice, Kutno and Sieradz. This is influenced by existence of high nature value areas which may lose their properties in the event of flooding. The synthetic flood risk level was also analyzed in communes according to differentiation of buildings and areas assigned to the distinguished categories on flood plain areas. In this classification the position of the given commune was taken into account according to flood risk level in every category (Table 4). The position of communes was determined by the number of points: the fewer the points, the higher the risk level in total. In this case the biggest risk is in Łowicz and Tomaszów Mazowiecki. This classification reflects in a far better way the synthetic flood risk level, which is confirmed by both analysis of current land development and flooding in the past.

Table 4. Synthetic flood risk level in the analyzed communes of the Łódź province according to differentiation of buildings and areas assigned to the distinguished risk categories

Commune	Total number of points obtained in all the rankings levels of flood risk
Łowicz	18
Tomaszów Mazowiecki (town)	18
Kutno	23
Działoszyn	24
Uniejów	26
Poddębice	33
Sieradz (town)	40
Warta	48
Sulejów	52

Source: M. Borowska-Stefańska (2015d).

Flood risk analysis is of vital importance and allows both the government administration authority and local authorities to implement an adequate flood protection policy. To achieve this it is valuable to know both the general flood risk level and its differentiation within the area particularly exposed to the risk of flooding, owing to which it is known which places are in particular prone to negative consequences (Borowska-Stefańska 2015a, 2015d).

2.6. Conclusions

The current state of land use allows to draw a conclusion that in the event of flooding the biggest damage may occur in Tomaszów Mazowiecki and Łowicz, which results mainly from the horizontal intensity of flood plain use. On the areas in question buildings are situated mostly in places where the flood plain is wide, on the sections which are not embanked and on the flood plains of smaller rivers. The method presented in this work may be applied in particular on the areas where floods do not cause huge damage and there is no detailed information about its consequences from the historical perspective. It is possible to draw conclusions on flood risk levels on the basis of the present land development plans, which is particularly important in implementing an adequate flood protection policy.

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