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RESEARCH ARTICLE

FLOODPLAIN DELINEATION BASED ON ANALYSIS OF DIGITAL ELEVATION MODEL, SOIL MAPS AND OCCURRENCE OF QUATERNARY FORMATIONS

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KEY WORDS: delimitation of soil method, DEM, quaternary formations, flood risk, spatial analysis

ABSTRACT: This paper presents a GIS based method of indicating flood extent in a mountainous river basin. Only main river with the valley is object of this analysis. The approach used in this work combines analysis of digital elevation model (DEM) obtained from LIDAR data with presence of alluvial soils and quaternary formations. In addition, in this article an attempt of calculating flood wave height for delineated floodplain is presented. The results are compared with floodplains derived from one of the products of country-scale project „IT system for protection against extraordinary hazards" (ISOK) which are flood hazard maps and with the extent of The Great Flood of 1997. Indication of the area flooded during Poland's Great Flood in July 1997 is based on the hydrological data from Institute of Meteorology and Water Management – National Research Institute (IMGW – PIB).

1. INTRODUCTION

Floods are one of the most dangerous phenomena which cannot be prevented, causing immense material losses, having negative impact on the natural environment and endangering human life. After last catastrophic inundations it was noticed that existing flood protection is insufficiently effective. What is more, predicted climate changes indicate that frequency of flood events occurrence will grow. So, in response, European Union imposed an obligation on Member States to prepare effective flood prevention management which consist of providing flood risk management plans and developing flood hazard and flood risk maps. According to the Directive 2007/60/EC (Flood Directive) these maps should show potential adverse consequences associated with different flood scenarios.

In Poland, implementation of the Flood Directive regulations is ensured by the Ordinance of the Minister of the Environment, the Minister of the Infrastructure and the Minister of the Interior and Administration (Dz. U. 2013 poz. 104). In this ordinance the way of indicating areas which could be flooded is specified. Presented method uses elevation of the water surface (river levels) obtained from hydrological modelling, it is based on DEM and uses GIS achievements. The potentially flooded areas are presented as surface objects with an assigned value of the probability of flooding (Kurczyński, 2012).

In order to perform the tasks imposed by the Flood Directive, in 2010, the ISOK project was started. This project is particularly aimed to the Polish society so as everyone could have the information about the areas at the risk of flooding and to the various institutions which are responsible for spatial planning, flood protection or crisis management. To the most important benefits achieved thanks to the ISOK project, we could count:

- Minimalization of the social and economic losses caused by the occurrence of floods;
- Development of the proper spatial planning which takes the failure of the flood protection infrastructure into account;
- An increased feeling of security among the populations;
- Reducing the number of fatalities caused by natural disasters;
- Modernization of crisis management systems ensuring their better functionality.

As a part of the ISOK project, data from LiDAR strikes were obtained and they allowed to acquire point clouds with a density of 4-12 points/m^2. These data were processed to generate DEM with a GRID mesh size of 1 m which was used for hydrological modelling. Other data which was necessary to the calculations and processing was also obtained, for example:

- Digital surface model (DSM);
- Ortophotomap;
- Cross-sections of river channels
- Flow velocity of the rivers (http://www.isok.gov.pl).

In the ISOK project, both 1D (MIKE11) and 2D (MIKE21) hydrological models were used as well as 1D/2D combined model (MIKEFLOOD). As a result of 1D model calculations, in which the velocity vector has one component, the maximum elevation of the water surface and the average value of flow velocity (in the perpendicular direction to the cross-section) were obtained. By means of 2D modelling, in each node of the computational grid, the maximum level of the water surface and the flow velocity components values (x, y) were calculated. In the combined model, the river flow was modelled as 1D and the floodplain flow as 2D (Bakuła, 2012; Malinger 2012; Gharbi *et al.* 2016; Betsholtz *et al.* 2017).

Within the tasks of the ISOK project, we could distinguish creating the flood hazard maps for areas without embankments, showing the flooded area during the movement of the flood wave and flood risk maps (for areas with embankments) showing the flooded area in case of breaking the embankment. The flooded area was divided into subareas with different probability of flood occurrence – 0.2% (once in 500 years), 1% (once in 100 years), 10% (once in 10 years) – what is included on the flood hazard maps. The flood risk maps supplement flood hazard maps and present objects which are in danger of flooding with a specified probability. These maps are divided in two thematic blocks:

- Negative consequences affecting the population and potential losses;
- Negative consequences affecting the environment with consideration of land use (Kurczyński 2012, Directive 2007/60/EC, http://www.isok.gov.pl).

In Poland, the flood risk areas cover 2 billion hectares, which makes up about 7% area of the country. Most of these regions are agricultural land, which are fertile and intensively cultivated. Floods cause the most damage in southern Poland (the upper and middle basin of Odra river and the upper basin of Vistula river), where summer floods are due to intense rainfall. In Central Poland (middle Vistula, Narew, Bug, Noteć, Warta) floods are mainly caused by snowmelt. The least frequent floods occur in coastal area because of sea storms.

In 1997, during the Great Flood 500 000 hectares of arable land and grassland were flooded and over 2800 hydrotechnical objects were damaged. According to the estimation of Central Statistical Office, the losses incurred were 12.5 billion of PLN and number of fatalities was 54. This estimation does not contain losses in personal property and indirect cost which was caused by the institutions work stoppage or communication breakdowns. Consequences of this flood showed that the existing technical solutions – the infrastructure as embankments or retention reservoirs, do not provide enough flood protection and therefore other non-technical solutions should be sought. Indication of the potential flooded area is the beginning of activities that aim to be part of flood protection (Arkuszewski, 1999; Kowalewski, 2006; Romanowicz *et al*., 2014).

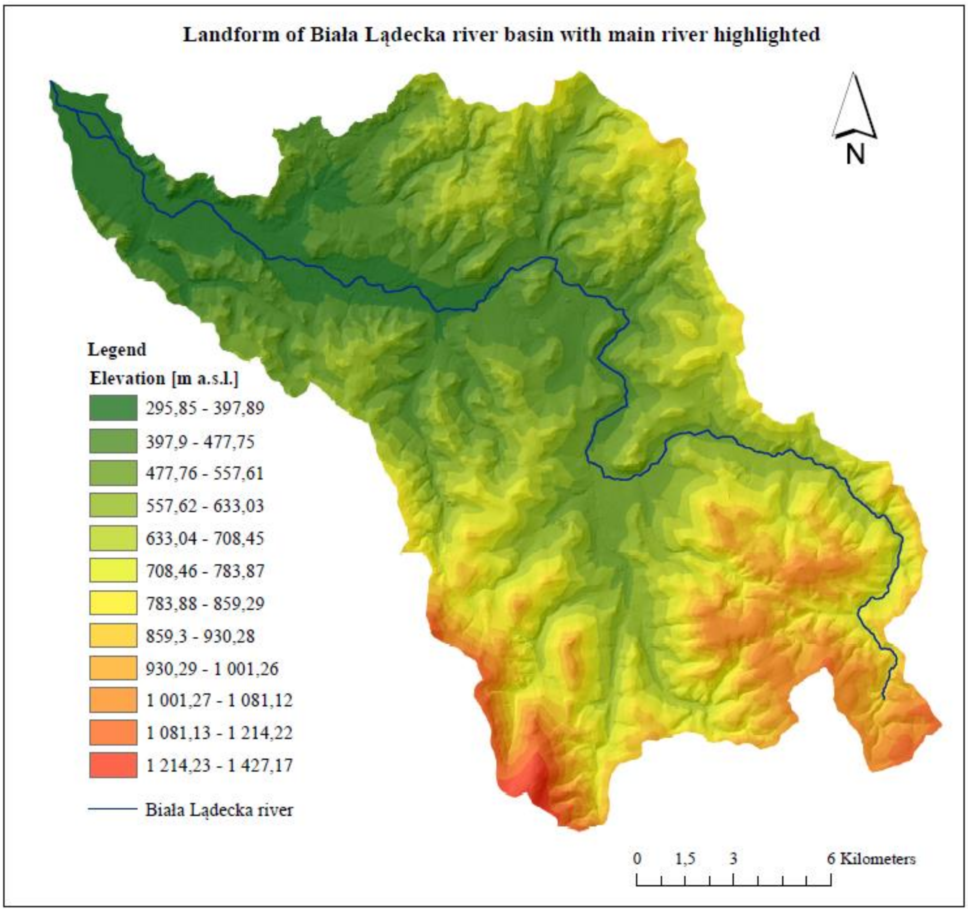


Fig. 1. Biała Lądecka river basin

2. STUDY AREA

In this approach floodplain delineation is carried out in the valley of Biała Lądecka river. Figure 1 shows the landform of Biała Lądecka river basin with the main river highlighted. The Biała Lądecka river is a left-bank tributary of Nysa Kłodzka and disembogues into it in the 135.08 kilometer of its flow. The estuary of Biała Lądecka is located 295 meters above sea level, close to Krosnowice. The river length is around 52.7 kilometers and the basin area is approximately 314.6 square kilometers. According to the map of hydrographic division of Poland both the river and the catchment are third order. The mountainous basin (above Żelazno) makes up around 301 square kilometers, which equals over 95.7% of its area (Staffa, 1994).

For the most part the valley of Biała Lądecka is being used for agriculture, small forests are found on hills, and a small part of the area are peatbogs and marshy meadows. The whole valley is densely populated, because of network of rural settlements located along the river. The largest population centers – villages in this area are Lądek Zdrój, Stronie Śląskie, Ołdrzychowice Kłodzkie, Żelazno, Krosnowice (Staffa, 1993; Staffa 1994).

Biała Lądecka is rich in water and known for frequent water rises (especially in the lower course), what is not surprising due to the fact that it drains the whole area of Bialskie Mountains, the northern part of the Śnieżnik Mountains and the south-western slopes of Golden Mountains with its numerous tributaries. The rapidly falling waters contribute to the increase of flood risk. The first flood reports date to the year 1310 and over the years, floods have caused a lot of damage for example during the flood in 1938 the dam in Stronie Śląskie and a few houses were destroyed. The greatest flood in the region's history occurred in July 1997 (Staffa, 1993; Staffa, 1994; Paprzycka, 2003).

3. PREPARING DATA

3.1. Numerical elevation data

The used numerical elevation data are saved in ARC/INFO ASCII GRID format. These files contain the elevation value of the points and they were created based on LiDAR measurement data, sorted in a regular geometric grid structure with a constant 1-meter interval. Processing of these data was the foundation for the ISOK project within the remit of the Head Office of Geodesy and Cartography. For this approach 97 raster files were obtained. The individual files are organized in sheets of 1992 Coordinate System for Poland (scale 1:5000) and the height reference frame is Kronsztadt'86.

The open-source geographic information software QGIS was used for spatial data processing. Firstly, the LiDAR elevation data consisting of 97 tiles, had to be merged into one mosaic receiving DEM. Then catchment area, shown in Figure 1, was created using GRASS plugin and tools r.fill.dir and r.water.outlet. Even though in this approach only main river valley is used, the catchment boundary is necessary to close inundation area because a drainage basin is the basic hydrographic unit which is vital for hydrological analysis.

The vectorization of the watercourse, using shaded relief map from DEM, was a next step and it allowed to get a polygon which represents the river (Fig. 1). This process provided an accurate representation of the watercourse, which is necessary to designate the height of the flood wave, where cross-sections, perpendicular to the riverbed, are needed.

3.2. Quaternary formations and soil data

Quaternary formations data were acquired by cartographic rendering of individual layer of the Detailed Geological Map of the Sudetes (scale 1:25 000) calibrated on the Topographic

Map (scale 1:10 000). The soil data were acquired as a result of calibration of soil-agricultural maps (scale 1:5000) and soil and forest habitats maps (scale 1:5000) on the map of the register of land and buildings. The data were redrawn, rendered and described in accordance with the soil map legend. It is an advantage, that the soil data are based on the land and building register, because it allows to indicate specific objects and areas at the risk of flooding.

The soil data (soil types were used) and the data showing quaternary formations together with the DEM obtained from LiDAR data were used to determine flood risk areas.

3.3. ISOK project data

The necessary data of the ISOK project were acquired from Hydroportal ISOK, which publishes flood risk and flood hazard maps in PDF format. 24 flood risk maps (scale 1:10 000) were downloaded – 8 sheets for every flood occurrence probability (10%, 1%, 0.2%). It is important to notice that the ISOK project did not cover the whole length of Białą Lądecka with its range.

Every sheet was vectorized – the flood ranges for individual flood occurrence probabilities as well as the cross-section points used in the ISOK project were vectorized. A data base of 159 cross-section points with the flood water height for the three probability values, was created. As a result of the vectorization 3 polygons were obtained, showing the maximal flood extent with different probabilities of occurrence. Every point was given three attributes: flood water height with the occurrence probability once in 10, 100 and 500 years. During the vectorization same scale of 1:500 was preserved, which resulted in the same level of detail in the representation of the floodplain boundaries. These data were processed in order to compare the flood extent, indicated in this approach to those designated as part of ISOK project.

3.4. Hydrological measurement and observation data

Hydrological measurement and observation data from two gauging stations located on Biała Lądecka: Żelazno and Lądek Zdrój, were downloaded from the Institute of Meteorology and Water Management – National Research Institute Internet page. Monthly data regarding the water level in the years 1990-2017 were analyzed and periods with the highest water level were chosen and daily data for these periods was acquired. These data were processed in order to compare the maximal water level from the gauging stations and the predicted value during probable floods.

Among the maximal values of monthly water levels, acquired from two gauging stations: Żelazno and Lądek Zdrój, in the years 1990-2017, which were shown on figures (Figure 2 – Żelazno, Figure 3 – Lądek Zdrój), four water rises which occurred in July 1997, August 2006, September 2007 and the turn of June and July 2009, were recorded. Additionally, the gauging station in Lądek Zdrój recorded a water rise in January 2003, which has not been recorded in Żelazno. The X axis on the listed graphs represents the following months from January 1990 to December 2017. The highest water level recorded in Żelazno was 430 centimeters in July 1997. At that time the water gauge in Lądek Zdrój recorded a water level of 365 centimeters.

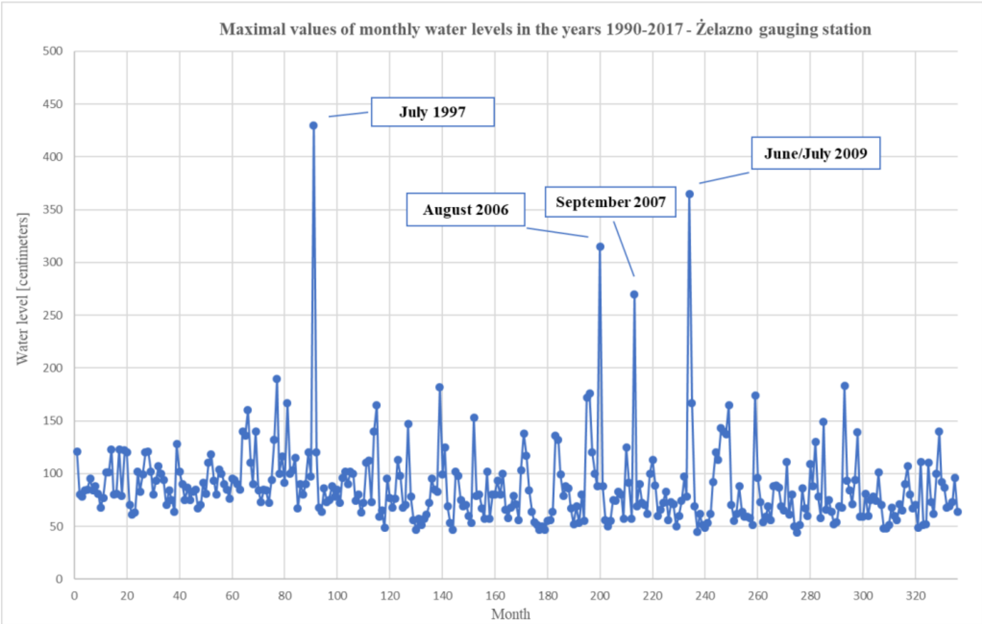


Fig. 2. Maximal values of monthly water levels – Żelazno gauging station

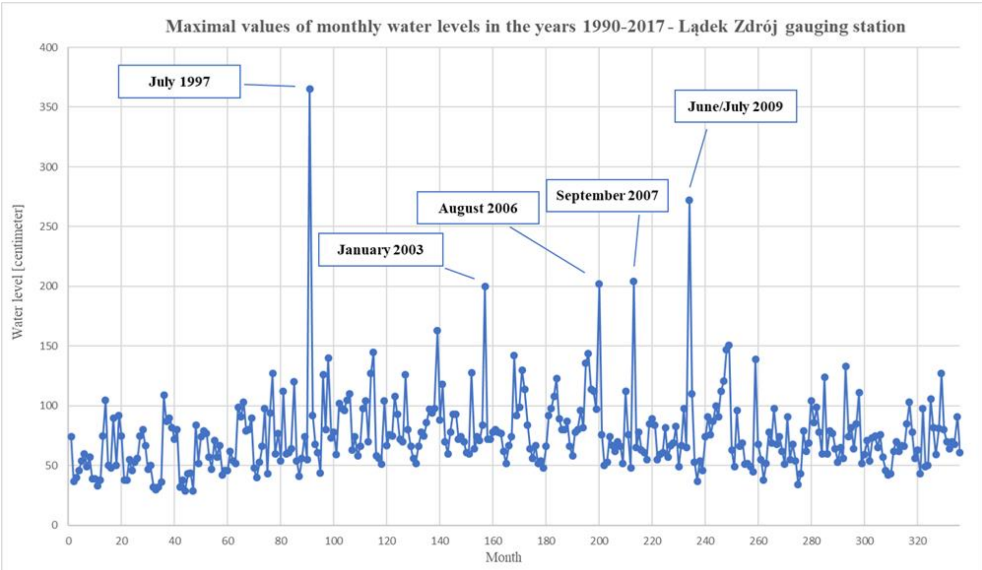


Fig. 3. Maximal values of monthly water levels – Lądek Zdrój gauging station

4. METHODOLOGY AND RESULTS

4.1 Determination of the area at the risk of flooding

The use of the delimitation of soil method to determine the extent of flood provides an economical alternative to the hydrological modelling approach. In the used method flooded areas are determined by the using of 2D soil data, considering the occurrence of alluvial and organic soils (Děd, 2013; Sangwan, 2013; Górecki et.al., 2014).

Delimitation of soil method was enhanced by a comparison with a quaternary formations map, a graphic presentation of land relief by shaded DEM, which shows slopes limiting the bottom of the river valley and detailed elevation contour data for the valley (with a 1-meter interval). The determination of the flooded area was based on manual drawing of the polygon with the use of the data listed above. The rendering covered the whole river length. The Figure 4 shows the determined extent of the flood risk area, with the land relief as a background.

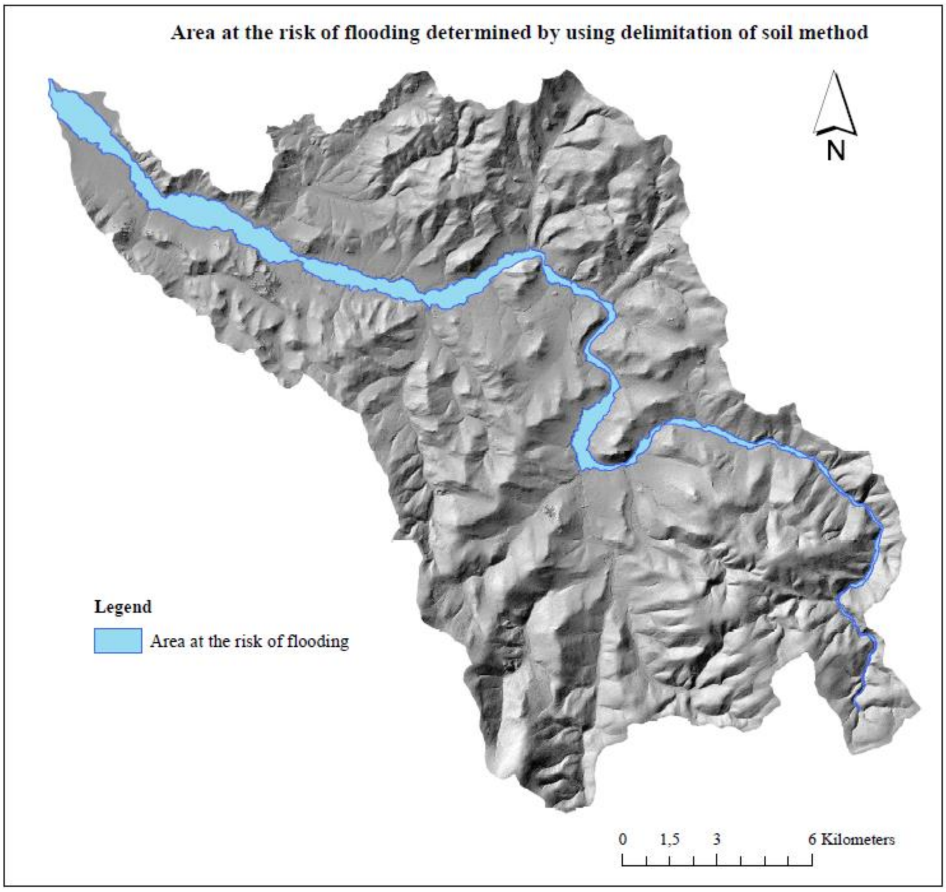


Fig. 4. Area at the risk of flooding determined by using delimitation of soil method

Designated flooded area covers 14.62 square kilometers. In the area of designated flood risk different types of land use occur, what is shown in Table 1. It is noticeable that a large part of this area is built-up and urbanized – 28%. Arable land, meadows and orchards make 58% of the area and the forestation of the Biała Lądecka valley is only 4.17%.

Table 2 presents area and percentage values of occurrence of various soil types found in the area of flood risk. The highest percentage is made up by alluvial soils – over than 83%.

Table 1. Land use in the designated area of flood risk

Land use	**Area [m^2]**	**Percentage [%]**
Forests, tree stands and bushes	609506	4.17
Meadows	1524003	10.42
Grasslands	2873050	19.65
Arable land	3922814	26.83
Orchards	130773	0.89
Flowing waters	1275493	8.73
Fallow lands	73978	0.51
Built-up area	2726240	18.65
Urbanized area	1313414	8.98
Different areas	169542	1.16
Sum	**14618812**	**100.00**

Table 2. Soil type found in the designated area of flood risk

Soil type	**Area [m^2]**	**Percentage [%]**
Podzolic and pseudo-podzolic soils	53727	0.37
Proper brown soils	879042	6.01
Leached brown soils and acidic brown soils	1409983	9.64
Mud-peat soils and peat-mud soils	41145	0.28
Proper alluvial soils	12119031	82.90
Brown alluvial soils	21137	0.14
Alluvial gley soils	32162	0.22
Gley soils	52994	0.36
Muck-mineral soils and mucky soils	9590	0.07
	14618812	**100.00**

Table 3 presents allotments of quaternary formations, which show, that the greatest part of the area of flood risk is made up by fluvial gravels and river sands, clays and silts of flood terraces (0.5 to 3.0 meters above river level) as well as fluvial sediments in general: alluvial soils, tills, sands and gravels from flood terraces 0.5 meters to 1.5 meters above river level (38.08% of the area). In this region, on an area of 0.24 square kilometers quaternary formations do not occur.

Table 3. Quaternary formations in the designated area of flood risk

Quaternary formations	Area [m^2]	Percentage [%]
Deluvial tills with rock rubble	70386	0.48
Loess-like dusty tills	13648	0.09
Fluvial sands & gravels and clays & silts of flood terraces 0.5-3.0 meters above river level	7655144	52.37
Fluvial sands & gravels of flood terraces 6.0-15.0 meters above river level	203012	1.39
Fluvial sands & gravels of accumulation terraces 2.0-6.0 meters above river level	379247	2.59
Fluvial gravels of flood terraces 15.0-20.0 m over river lever (Nysa Kłodzka river) and 20.0-40.0 meters above river level (Wilczka river)	8081	0.06
Fens on river sediments	302193	2.07
Fens	917	0.01
Fluvial sediments in general (alluvial soils, tills, sands and gravels) of flood terraces 0.5-1.5 meters above river level	5566681	38.08
Landslides	729	0.00
Screes and talus	11012	0.08
Alluvial fans	171101	1.17
Creeps of weathering covers	520	0.00
Lack of quaternary formations	236141	1.62
Sum	**14618812**	**100.00**

4.2. Calculation of flood wave height

For the flood wave height calculation cross-sections perpendicular to the riverbed were needed. Cross-section points from the ISOK project were used for this purpose. Elevation values of the points where the cross-sections intersect with the boundaries of the flooded area were measured with the SAGA geoalgorithm *Add raster values to points* in the QGIS software. The next step was the calculation of the length of cross-section lines divided by a cross-section point. The last step was the calculation of the flood wave height using linear interpolation.

Table 4. Calculated flood wave height (for 21 of 159 cross-section points) compared to the ISOK project values

No. of cross-section point	**Flood wave height from ISOK project (10% flood chance)**	**Flood wave height from ISOK project (1% flood chance)**	**Flood wave height from ISOK project (0.2% flood chance)**	**Calculated flood wave height**
40	329.78	331.30	331.79	332.68
41	331.97	333.30	333.80	334.78
42	333.09	334.62	335.40	337.36
43	334.04	335.46	336.20	**339.79**
44	334.68	336.26	336.88	337.95
45	335.46	337.06	337.56	338.80
46	337.99	339.47	340.22	341.83
47	338.51	339.87	340.67	341.18
48	339.43	340.83	341.77	344.49
49	340.24	341.62	342.63	345.10
50	341.17	342.71	343.50	346.32
51	341.90	343.39	344.67	**350.54**
52	342.67	344.48	345.59	**349.92**
53	343.38	345.15	346.01	**354.73**
54	344.79	346.21	347.05	350.98
55	346.08	347.60	348.55	351.13
56	347.31	348.62	349.68	**350.03**
57	348.57	350.12	350.89	**355.32**
58	349.62	350.91	351.65	352.74
59	350.46	351.62	352.32	**358.77**
60	351.21	352.47	353.17	355.60

The height values considered incorrect make up 18.24% of all points. Determining if the flood wave height value is incorrect was done by comparison with the height of flood water with the occurrence probability 0.2% (from ISOK project) and by the inspection of water levels in two neighboring cross-section points – it is impossible for the water height of one point to be grater or lower than in the previous and next point. What is more, the water level in the cross-section points should increase with receding from the river mouth. Table 4 shows some cross-section points (21 of 159) with calculated flood wave height which are compared to the ISOK project values.

The fragment (Figure 5) of the graphic rendering, necessary for interpolation shows the determined area of flood risk, cross-section points, cross-section lines perpendicular to the riverbed (with cross-section numbers according to Table 4) and the points of intersection with the boundaries of the flooded area. It is noticeable, that some of the cross-section lines are receding or preceding the adjacent lines (for example the lines 43, 51, 56, 57). In addition, the location of the cross-section points on the river, which are placed on the slopes limiting the area of potential flooding, has a major impact on the computing process. Linear interpolation with such asymmetry results in failure. This phenomenon can be seen for example on points 51, 52, 53. The use of cross-sections perpendicular to the riverbed gives the best results in the points numbered 44, 45 and 46. In these points with minor asymmetry the cross-section lines neither recede nor precede from the neighboring profiles.

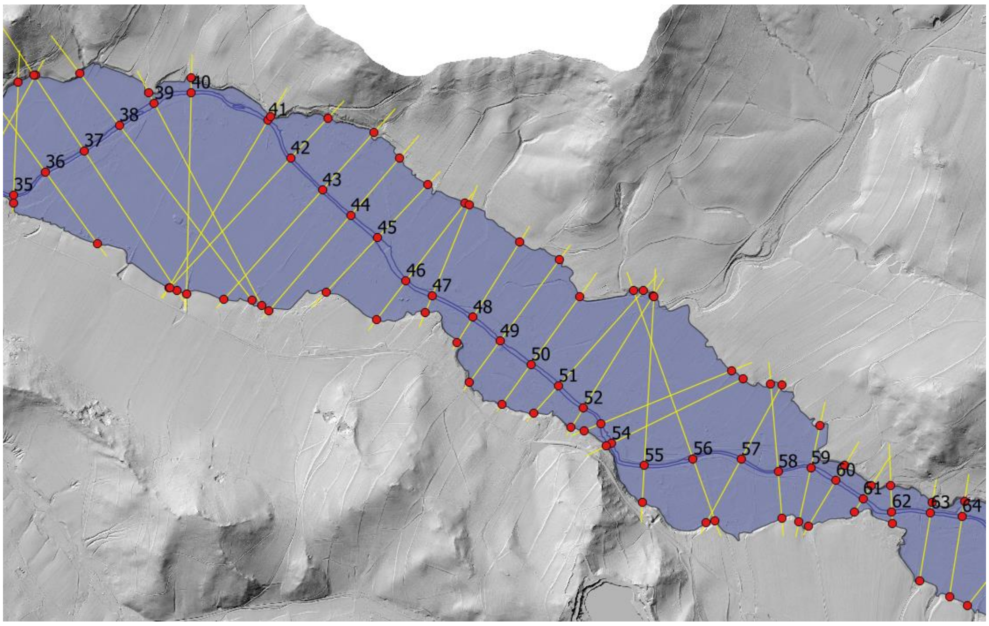


Fig. 5. Cross-sections used for calculating flood wave height

5. COMPARISON

5.1. Comparison of designated flooded area with the inundation caused by flood wave with a specified height

The coverage of the flooded area with a specified flood wave height and the determined flood area boundary was investigated. In order to do this, 12 break points on the river, which had the highest risk of getting an incorrect flood wave height value, were chosen. These points are shown in Figure 6. They were chosen, due to the decrease of distance between the banks and the compressing of the profile in these places, which leads to an increase in water height. The areas between the point are structural basin valleys, where the water can decompress and overflow a larger area.

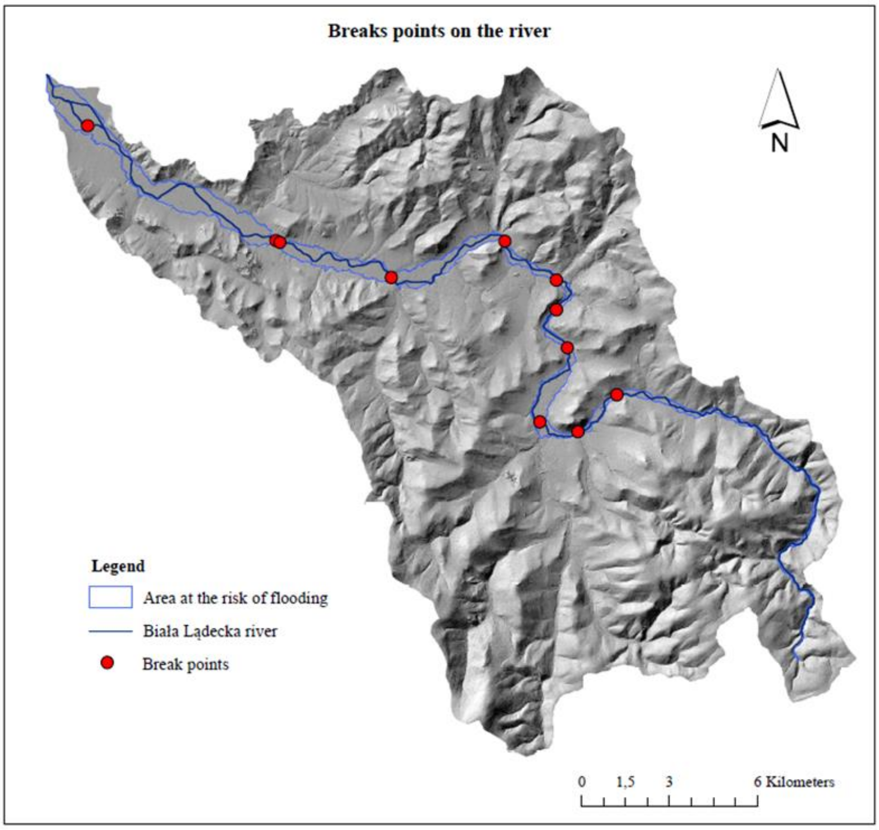


Fig. 6. Chosen breaks points on the river

Buffers with a radius of 800 meters were used around every point and utilized as borders in the rendering of 3D models presenting the area around the points. The models were intersected by a plane imitating the flood water with flood wave height values corresponding to the linear interpolation results. Apart from the break points, the models also show the range of the flooded area, determined with the delimitation of soil method and the vectorized river. The Figure 7 presents a graphic representation of the workflow: model of the area around the cross-section point number 17, intersected by a plane located at the height of 312.08 meters. The rest of the investigated points is shown in Table 5, where the graphic presentations include:

- the extent of flooded area determined with the delimitation of soil method – represented by a thick dark blue line;
- the vectorized river – represented by a thin dark blue line;
- the chosen cross-section points – represented by red;
- the flooded area, when the height of the flood wave is equal to a specified value (the elevation of the plane) – represented by light blue

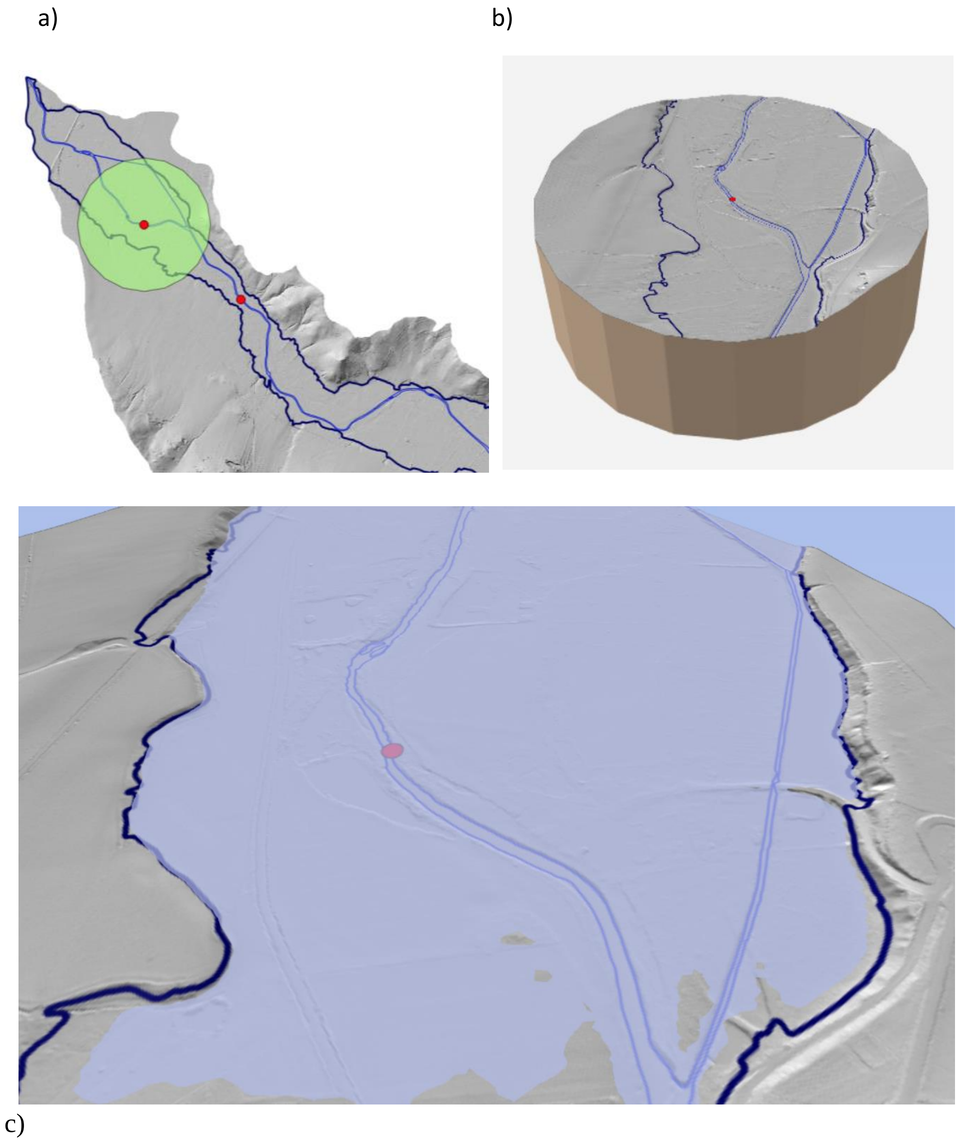
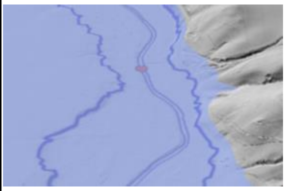
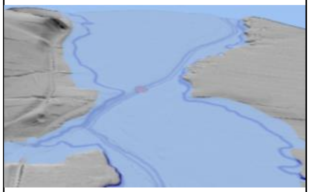
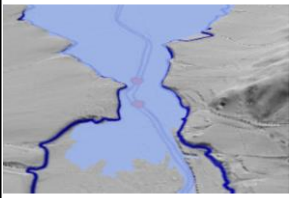
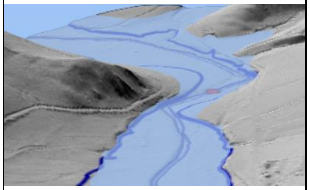
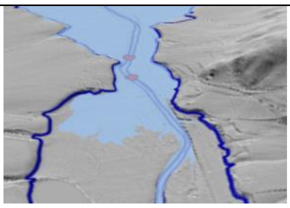
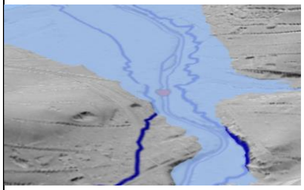
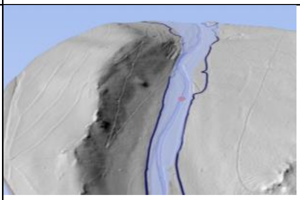
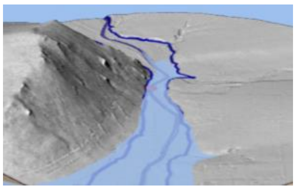
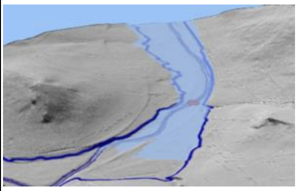
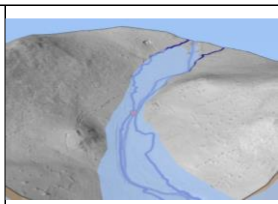
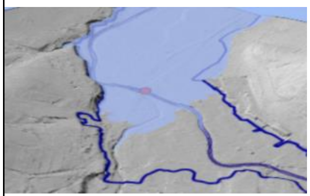


Fig. 7. Workflow: a) Buffer creation; b) Generation of 3D models presenting the area around the points; c) Intersection of the models by a plane imitating the flood water

Table 5. Graphical presentation of comparison designated flooded area and inundation caused by flood wave with a specific height

No. of cross section	Plane height [m]	Graphical presentation	No. of cross section	Plane height [m]	Graphical presentation
28	334.49		86	386.28	
61	355.50		105	419.14	
62	386.28		113	438.45	
122	447.09		147	502.49	

129	459.31		159	536.79	
141	485.51				

In order to get a better point of view, the graphic renderings in Table 5 do not share the same perspective.

5.2 Comparison of the flood extents

The comparison of ISOK project flood zones with the extent determined with the delimitation of soil method makes an important part of this approach, because it presents an alternative solution to the method used in the ISOK project and allows to evaluate the correctness of the used method.

The flood risk zone determined with the delimitation of soil method covers a larger area than the ones determined within the ISOK project. The determined boundary of potential flooded zone in the investigated area goes over higher elevations, which causes the higher values of flood wave height for the cross-section points than the calculated values in the ISOK project. Figure 8 shows the boundaries determined in this approach as well as in the ISOK project. The darkest color represents the boundary of the area with the highest flood probability (once in 10 years). The decrease of flood probability is represented with the brightening of the color and the boundary determined with the delimitation of soil method is represented with the brightest shade

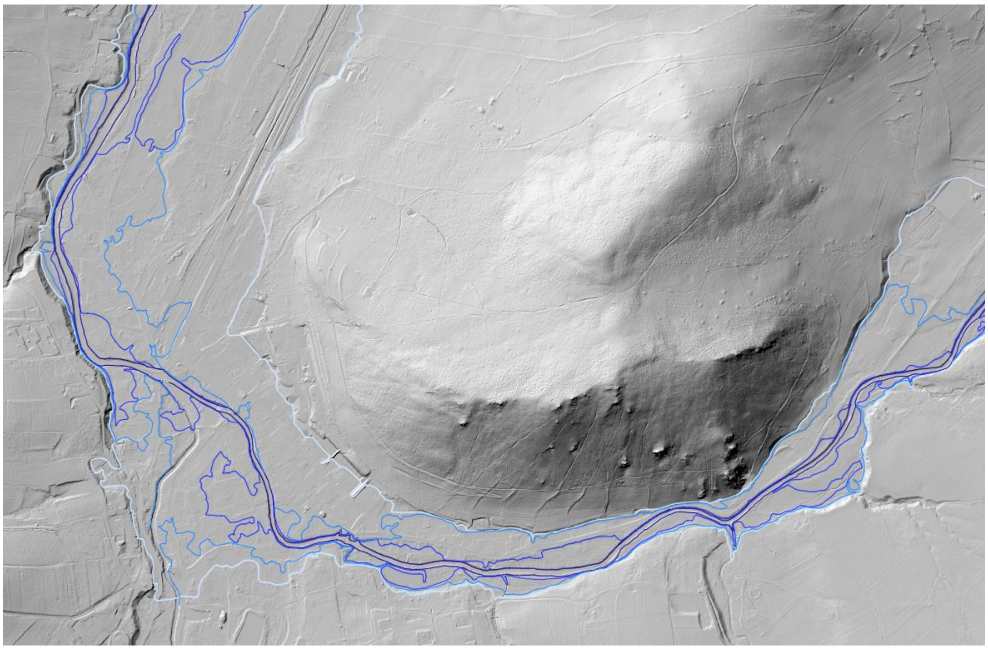


Fig. 8 Flood extents: ISOK project vs. delimitation of soil method

5.3 Comparison of the determined boundary of flooded area with the extent of Great Flood in July 1997

IMGW-PIB data regarding the location and altitude of the zero ordinates of gauging stations Żelazno and Lądek Zdrój as well as measurement and observation data, which allowed to choose the maximal flood water height, were used to compare the determined boundary of flooded area with the extent of Great Flood in July 1997. These data made it possible to determine flood water level in the gauge points. The flood water in the gauging station Żelazno in July 1997 reached a maximum value of 320.98 meters above sea level and in the gauging station Lądek Zdrój 424.13 meters above sea level. The comparison of the area flooded at that time with the determined boundary of the flood risk zone is shown on Figure 9 (Żelazno) and Figure 10 (Lądek Zdrój). It can be seen that the determined boundary covers the flooded area from 1997 almost perfectly.

6. CONCLUSIONS

The delimitation of soil method is an alternative solution in the determination of flood extent. Compared to formulation of new hydrological models, the use of this method allows to save financial costs and time. An important part of this approach was the cartometric analysis of the DEM, which provided detailed information about the relief of the valley bottom and the slopes limiting it which allowed for a precise determination of the flood range.

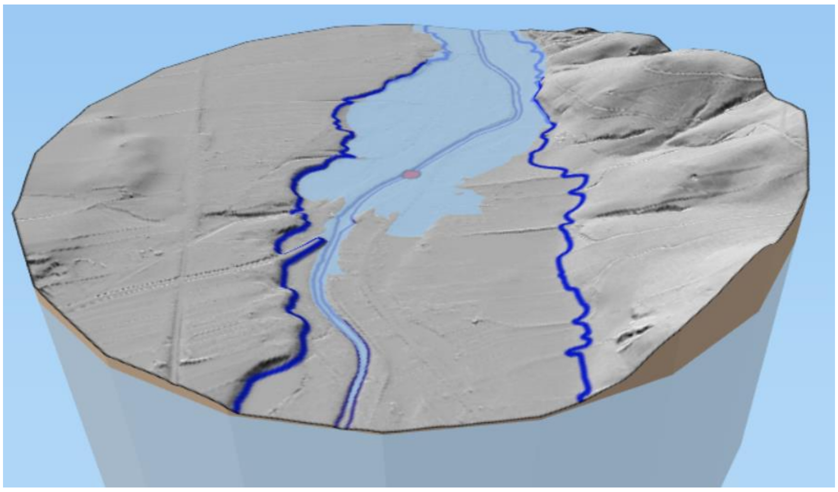


Fig. 9 Area flooded during the Great Flood in July 1997 with highlighted flood extent determined by delimitation of soil method (Żelazno gauging station)

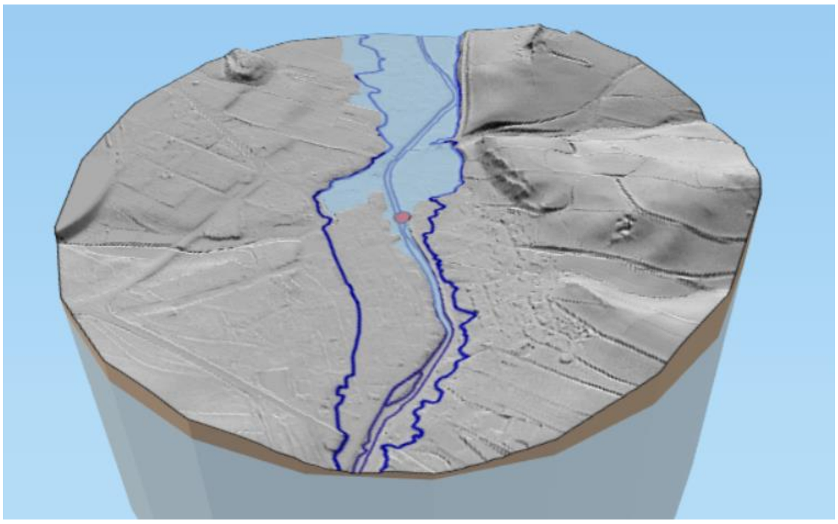


Fig. 10 Area flooded during the Great Flood in July 1997 with highlighted flood extent determined by delimitation of soil method (Lądek Zdrój gauging station)

In the determined area of flood risk, there are 83% of alluvial soils. The fact, that soil types other than alluvial soil occur on the area of flood risk may surprise and it is caused by a soil formation processes called denudation (the fall of mineral material of hillside to the river bottom). The occurrence of organic soil types is caused by the accumulation of muds and peats in the depressions of the river valley. Clays and sands form as a result of the erosion of gneiss and granite, which occur in a large part of the basin. The silts in the valley of Biała Lądecka formed due to the wind activity – glacial aeolian deposits.

The use of DEM and GIS software made the atomization possible of the calculation of flood wave height for the determined flood zone boundary. Additionally, the data obtained from LiDAR strikes, allowed for a high precision of the DEM. However, 18% of incorrect results suggest, that the approach of determining cross-sections perpendicular to the riverbed, was not precise. It is noticeable, that the incorrect results occur in areas where the profile line recedes from the neighboring profiles. What is more, the use of such cross-sections led to the occurrence of major length asymmetry between the left and right sides of the profile, which had a negative impact on the interpolation.

One of the main tasks was the comparison of the results with the flood risk zones determined in the ISOK project and the flooded area in 1997. Thanks to this comparison it was possible to state, that the determined boundary of flood risk is at higher altitudes than the flood extent with an occurrence probability once in 500 years received as a part of the ISOK project. What is more, the determined boundary of the maximal overflow overlaps almost perfectly with the flooded area extent from July 1997. Thanks to this it can be presumed, that the presented area of flood risk could occur with probability 0.1%, what means that determined flood extent can statistically occur once in 1000 years.

This approach stands out, because of the using of the land and building register, which allows to distinguish the parcels at the risk of flooding. The combination of this results with an owner data base, could make for an innovative system of risk information and be useful for insurance purposes.

The method described in this research has some weaknesses, particularly in the human-modified areas for example where flood embankments or relief channels were built. Due to the fact that in the past flood events occurred in mentioned areas we can find alluvial soils which are the basis of the determination of the potential flooded area. In this approach man-made changes that may affect the results were not included.

In the future, a method allowing for a precise determination of flood wave height based on the flooded area extent should be developed. In order to do this, the possibility of determination of the valley's medial axis could be investigated. What is more, in further research hydrological modelling could be applied (using different type of hydrological model than in ISOK project) that could show potential discrepancies between ISOK project and obtained results.

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