GIS SYSTEM FOR 3D VISUALIZATION OF HYDRODYNAMIC MODELING OF FLOOD FLOWS IN RIVER VALLEYS

Edyta Hadaś[1]

Abstract

Currently available and common techniques of spatial data acquisition enable to acquire three-dimensional data with high precision, accuracy and reliability Simultaneously, Poland is developing ISOK – the IT system dedicated for protection against extreme hazard (especially floods) that is a valuable source of high-quality spatial data and maps.

To avoid the limitation of static, two-dimensional cartographic presentation of the flood phenomenon, the concept of 3D GIS system was developed, that is dedicated for spatial data integration and 3D visualization of floods. It uses ISOK products, as well as external hydrodynamic modeling system, 3D models of building and vegetation obtain from laser scanning. Data management and processing is performed using ArcGIS 10.0 software.

The paper describes briefly the ISOK system, important issues related with hydrodynamic modeling and data integration. It shows also the preliminary results of 3D flood visualization in large scale, with 3D buildings and trees.

Keywords

GIS, flood, 3D, hydrodynamic modeling, ISOK

1 ISOK - IT SYSTEM OF COUNTRY PROTECTION AGAINST EXTREME HAZARDS

Since 30 July 2010 Poland is developing the IT system of country protection against extreme hazards (ISOK) which is focused on flood threat. The development of the system is directly a consequence of The Floods Directive – a legislation in the European Parliament on the assessment and management of flood risks, with a legislative completion date of December 2011. The main objective is to identify areas at significant risk and to limit the economic expansion over this areas, by determining the flood threat and risk. The main products of the ISOK are: preliminary flood risk assessment, flood threat and risk maps, meteorological threat maps, other threats maps, georeferential database of topographic objects, digital terrain model and numerical model of land cover, digital ortophotomap and a map of hydrographic polish division in the scale of 1:10000.

Flood threat maps are the result of mathematical hydrodynamic modeling of the flood. They present the areas threatened with the flood with three probabilities of occurrence: 0.2% (once in 500 years), 1% (once in 100 years) and 10% (once in 10 years). In addition to the boundaries of threatened areas, threat maps contain information on water depth (see Fig. 1), direction and speed of water flow (see Fig. 2), thus determining the danger level for people and the water impact on buildings.

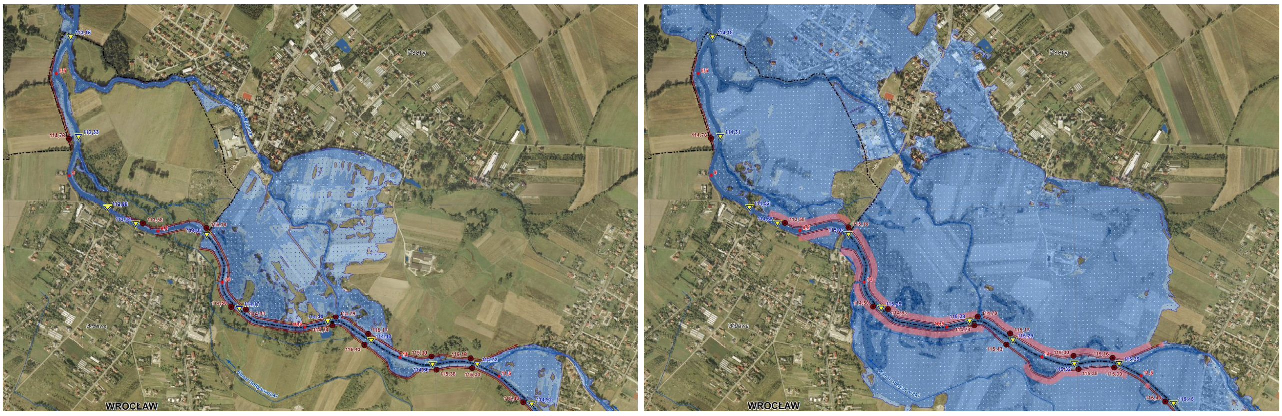

***Fig. 1** ISOK flood threat maps with water depth for 10% (left) and 1% (right) probability of occurrence (www.isok.gov.pl)*

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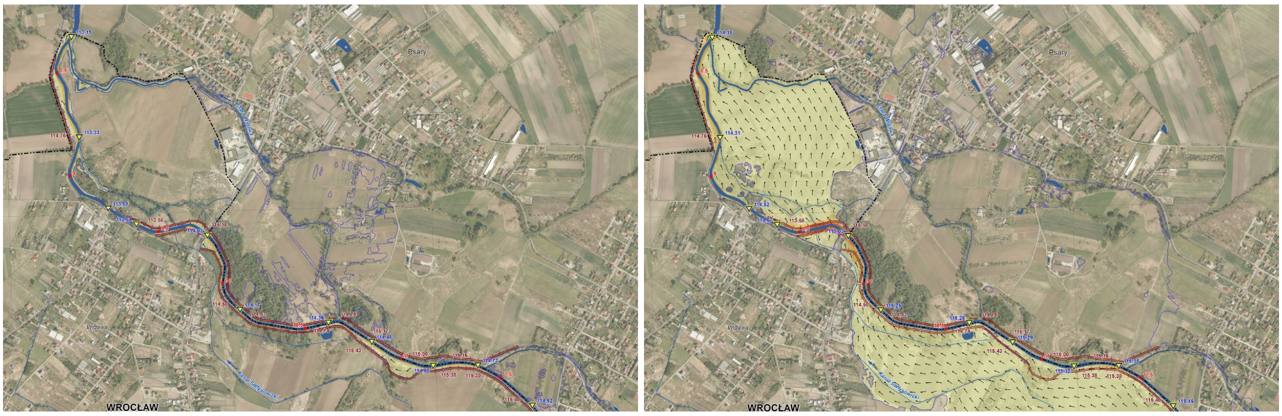

Fig. 2 *ISOK flood threat maps with water flow directions and velocities for 10% (left) and 1% (right) probability of occurrence (www.isok.gov.pl)*

Both digital terrain model (DTM) and digital surface model (DSM) are obtained with Airborne Laser Scanning. For 94 Polish cities, scanning was performed with the resolution of 12pts/m^2, and for non-urban areas 4-6pts/m^2. Obtained point cloud allows to create DTMs and DMSs with the 10-15cm accuracy of height component. Products are available in commonly accepted data formats e.g. ESRI GRID, ASCII xyz.

High-resolution (10cm pixel) digital orthophotomap is available for the area over 20000km^2, covers 203 cities and urban areas particularly vulnerable to the occurrence of extreme floods and for which the occurrence of the flood will cause a greatest impact on citizens and business.

2 FLOOD MODELLING AND VISUALIZATION

2.1 Hydrodynamic modeling

To make a flood visualization, not only the geospatial data (terrain model, buildings, vegetation, textures) is required, but also the information on the height of water level over the represented area. This can be obtained from in field measurements of the actual water level using LIDAR techniques [9] or from hydrodynamic modeling [6]. The accuracy of the flood simulation is strictly related to the accuracy of DTM and the type of hydrodynamic modeling. Insufficient geometric detailed DTM affects the flood modeling results and may lead to serious misrepresentation, that may have catastrophic consequences in the case of a real flood [2]. However, the terrestrial and airborne laser scanning provides data capture adequate to create a DTM with a precision sufficient to perform reliable hydrodynamic modeling [3] [7]. Hydrodynamic modeling can be of type 1D, 2D or 3D [8].

2.2 3D flood visualization

Existing platforms of 3D visualization of flood simulation include many simplifications, therefore they are not very reliable source of information about the threat. The main drawback is the lack of a proper hydrodynamic modeling. The range and height of the flood wave is formed by imposing a fragment of the plane surface over a DTM. The surface represents only the mean water level and intersects also other 3D objects. These objects, in particular buildings and vegetation, are not the elements determining the flood flow but serve only to enhance the attractiveness of the final visual effect. The geometry of the buildings and structures is usually well represented and supplemented with high-resolution textures from real photos. Simultaneously, the geometry of vegetation is simplified by replacing the 3D geometry with flat or highly generalized objects, or event totally ignored (the only information is provided with the textures e.g. orthophotomap). Such simplified modeling in combination with the low quality of DTM and 3D objects geometry may lead to misrepresentation of the flood (e.g. no water in the riverbed or water overflow through embankments) and omission of important information (e.g. reliable water level around bridges and residential areas).

Research on the use of remote sensing for modeling 3D objects are carried out for a long time. Greatest importance in obtaining information about their geometry has laser scanning. The examples of semi-automatic and automatic modeling of 3D buildings are presented in [4], and of 3D vegetation in [5]. The results are suitable to be applied in GIS systems designed for 3D visualization of the results of flood simulation based on the two- or three-dimensional hydrodynamic modeling. However, they can not only be used for visualization but also as a valuable complement to a geospatial data used for the hydrodynamic modeling. They can be used directly as obstacles for water or indirectly by a representation with the flow resistance coefficients calculated on the basis of the 3D geometry.

3 GIS SYSTEM FOR 3D VISUALIZATION OF HYDRODYNAMIC MODELING OF FLOOD

3.1 Data sources and dimension conversions

Currently available and common techniques of spatial data mining enable to acquire three-dimensional data with high precision, accuracy and reliability. The amount of information is sometimes too large to effectively process, analyze or present the data, therefore the generalization is required. At the same time, the existing two-dimensional data sources (e.g. maps and spatial databases) are still valuable sources of information. Therefore, using the data from different sources, there is a need to integrate them (determine the accuracy of object geometry, semantics of the attributes) and, when combining 2D and 3D data, to bring them to the common number of dimensions. It is very important to maintain in transformed set as much information from original data as possible. For robust and semi-automatic data processing, the development of a model of data flow between geoprocessing tools is required.

Particularly useful for hydrodynamic modeling and flood visualization are the following data sources:

- 2D: flood threat maps and flood risk maps from ISOK, topographic objects database (BDOT), Numeric Map of Forests, detailed map, soil and agricultural maps, the results of hydrodynamic modeling, Corine Land Cover, OpenStreetMap maps
- 3D: digital terrain model and other products from processing (ground and airborne) laser scanning, results of direct land surveying, the results of hydrodynamic modeling, results obtained with remote techniques (e.g. InSAR)

3.1.1 2D data conversion into GIS 3D objects

Obtaining the height component of spatial object require to use the information that exist as an attribute in database, annotation on the map, contour or feature (color, pattern, color intensity). Depending on the object type and the purpose of its further use, it is required to determine the quality of the height component. For hydrodynamic modeling, the key of importance is the terrain topography and hydraulic engineering objects. Less accurately known can be the height of buildings and vegetation (e.g. forests), through which the water will not overflows. Other text or graphical information can be converted into attribute of objects in GIS 3D database.

3.1.2 Reduction of 3D GIS object dimensions

While reducing the number of dimensions, it is very important to preserve the information about the height component using other forms of representation. It is particularly important for the water level and the terrain. The representation should also be consistent with the principles of cartographic representation and generalization. Detailed information about the height can be stored as object attributes and additionally presented in generalized form as annotations, contours and colors.

3.2 The conception of GIS system for flood modeling and 3D visualization

To exploit the potential of currently available spatial data for hydrodynamic modeling and 3D visualization of the results, the conception of 3D GIS system was developed (Fig. 3). Spatial data used for hydrodynamic modeling are mainly obtained from ISOK, however they may be supplied with remote sensing (LiDAR), land surveying or other existing data, e.g. they can be supplied with real or predicted meteorological and weather data to simulate flood in real conditions. Products require prior integration and processing (e.g. 3D modeling, generalization). The most important for both modeling and visualization is the quality of DTM with breaklines (e.g. embankments) and spatial objects such as buildings, cubature structures and vegetation [8].

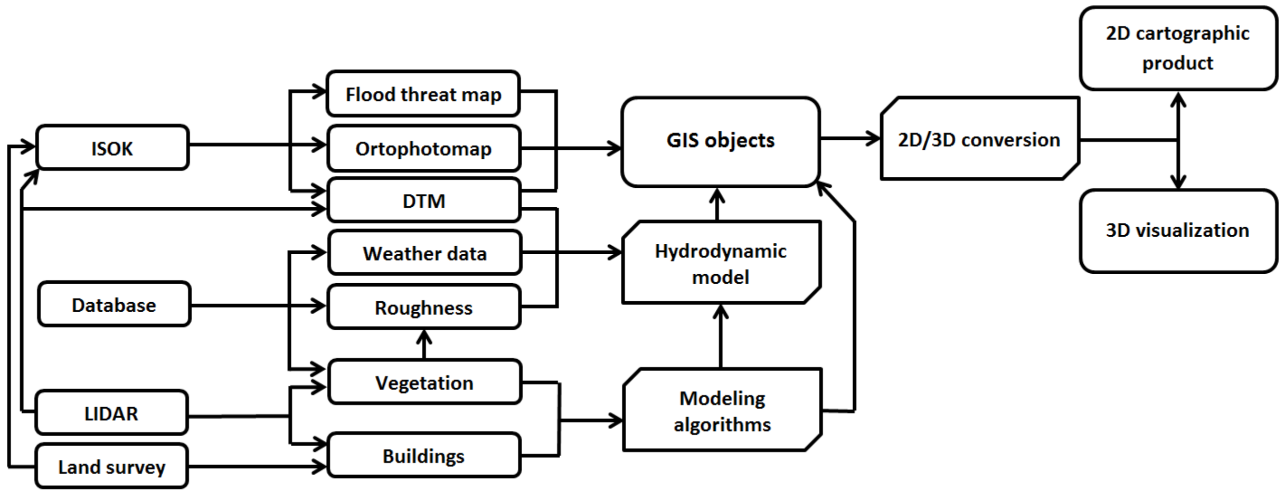

Fig. 3 *Concept schema of 3D visualization of hydrodynamic modeling results using the products from ISOK project*

3.3 Preliminary results

Based on the scheme described above, the integration and visualization of flood wave was performed for the area of Widawa river valley (Fig. 4 and 5). High-resolution DTM generated from airborne laser scanning point cloud obtained from ISOK was used. The DTM was covered with orthophotomap. Geometric data was supplemented by models of buildings and trees that were freely available in Google 3D gallery, however they can be replaced with objects obtained from other sources, e.g. ground laser scanning or other databases. By introducing 3D buildings into DTM, one can perform more analysis related directly with the human life threat at different flood scenarios [1]. For such a prepared fragment of reality, the results of hydrodynamic modeling were presented for various intensities of the flood wave.

***Fig. 4** Example of flood 3D visualization for the area with buildings and vegetation*

***Fig. 5** Example of flood 3D visualization in large scale – the change of water level over time*

The advantage of three-dimensional presentation is the wider group of potential recipients of such development, especially for less experienced people or those for whom the interpretation of two-dimensional materials is difficult or do not appeal to their imagination. The 3D visualization allows to increase the scale of the phenomenon presentation and to analyze risk at the higher level of details. It is also possible to present information, that is not directly available in two-dimensional studies (e.g. flood level of the building). The disadvantage is still the incompatibility with the accepted principles of cartographic representation. The model is only a simplification, which does not always coincide with the actual range and level of flood wave. Increasing the attractiveness of the visual presentation may constitute a risk of public over-confidence to the presented results.

There is currently no concept of inclusion of flood threat maps and flood risk maps into 3D geoportals. This would allow the presentation of the results also in the interactive and dynamic (time-varying) form, which is inconvenient to achieve using analogue maps.

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