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A COMPARISON OF INTERPOLATION METHODS FOR FLOOD ZONES ADJACENT TO A STREAM

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Summary

Even small streams may cause severe flooding. The evaluation of the safety of people and objects in the area of a watercourse is related to modelling of flood zones. The area of potential flood zones is calculated on the basis of a Digital Terrain Model (DTM). This paper presents interpolation methods for creating DTMs based on land surveying data. The result of sample modelling is compared with selected interpolation methods.

Keywords

flood zones • terrain modeling • interpolation method

1. Introduction

Floods are an increasingly notorious phenomenon in our climate zone. They are caused by rising water levels in rivers, as well as in the limited ability of the soil to absorb water, caused by improper flood land management and land development [Radecki--Pawlik et al. 2013]. Floods may not only cause immense financial losses but may also cause immeasurable general social losses, starting from the deformation of the terrain through the destruction of economic infrastructure and property. This causes inhibition of economic activity, agriculture, environmental pollution, and even the loss of health and life. Flooding can also cause irreversible affects on the landscape and the immediate environment of the stream.

One of the more dangerous types of flooding are freshet waves which occur mainly in July and August. The freshet arises as a result of heavy and torrential rains which are occur suddenly and are difficult to predict. They usually occur in small areas neighbouring small streams where the volume of rainfall, in a short time, prevents the stream channel from accommodating large volumes of water.

In order to reduce the risk of flooding and mitigate its consequences, efforts are being made aimed at the reconstruction and modernization of the existing hydraulic engineering infrastructure. What is important, is the creation of a monitoring system and projects defining flood risk and methods of disaster management, in times of danger. This should occur while introducing large amounts of money to restore cultural landscapes and the necessary protection against the effects of flooding, occurring in the vicinity of even small streams and bodies of water [Radecki-Pawlik 2010]. In terms of the flow of freshet waters, they may have an impact on the regulated sections of rivers channels in urbanised areas. Engineering buildings (weirs, barrages and bridges) of which the bandwidth is too low can cause flooding [Michalec and Tarnawski 2006, 2007].

A key role in reducing the risk of flooding is played by spatial information systems that inform on the location and properties of spatial objects. Its primary purpose is the acquisition and collection of data and associated attributes, as well as data sharing, analysis, and visualization. With this technology, it is possible to create numerical models reflecting the spatial data and statistics, to be used for effective flood forecasting and flood plain zoning.

2. Flood protection in legal acts

Flood protection usually includes a collection of actions intended to reduce the risk and damage caused by floods. Due to its importance, it has become a matter of constant concern to the whole of society, from the municipal level to the international community. This is evidenced by the numerous laws and standards issued by local, national and European authorities.

In 2007 the European Parliament and Council issued the Directive on the assessment and management of flood risks. Its objective was "to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community" [Directive 2007/60/EC]. It requires all EU countries to develop, a preliminary flood risk assessment, establishment of flood hazard maps and flood risk maps, as well as risk management plans.

Water Law is a main act in Poland, related to flood protection. The Act requires the preparation of anti-flood protection studies in which immediate and potential risk areas must be indicated, as well as areas requiring protection due to their economic or cultural value and type of development. It includes, e.g. information about actions that should be taken to protect people and property, in the potential and real flood risk situations. Moreover, the definition of areas of direct and potential flood hazard are given and limitations in the ways of utilizing flood levees to maintain their stability are introduced [Directive 2007/60/EC].

The obligations imposed by the Flood Directive relating, to preparation of flood hazard maps and flood risk maps contributed to the creation of the Polish legislative order: "Order of the Minister of Environment, the Minister of Transport, Construction and Maritime Economy, the Minister of Administration and Digitization and the Minister of Home Affairs of 21 December 2012, on the development of flood hazard maps and flood risk maps". The purpose of this document is to define the requirements, methods, and ways to develop flood hazard and flood risk maps in the country, as well as in international river basins [Rozporządzenie Ministra… 2012]. Flood hazard maps and flood risk maps are prepared separately for each area which is threatened by flooding. The maps include marked areas indicating low, medium, high and very high risk to people and property. The Order carefully specifies all the elements that must be included, in the data charts and from what sources the information can be extracted.

In order to minimize the size of the flooding itself and the damage caused as a result thereof, studies and projects for flood protection shall be drawn up. The main task of the projects is to determine the flood hazard areas (floodplains). These are the areas to determine the extent of flood waters, based on historical data [Payrastre et al. 2005] and hydraulic modelling [Muncaster et al. 2006, Książek et al. 2010a].

Water Law defines two types of flood-prone areas, i.e. areas of direct hazard and areas of potential flood risk. Immediate hazard zone are areas directly adjacent to the watercourse that will be flooded, if the water exceeds the edges of the crest. The potential risk areas are subject to flooding, in the event of a broken levees or overflow over the crest of the levees [Prawo wodne… 2001].

Implementation of projects defining flood hazard, in the catchment areas consists of several stages [Bartnik and Książek 2010]:

1. The initial flood risk assessment, determines the scope of the study, the identification of input data, collection of materials and analysis of historical data.
2. Land surveying works are conducted designed to provide information about the shape of the terrain.
3. Hydrological calculations allow for the construction of a hydraulic model of freshet wave transformation and determining water levels [Książek et al. 2010b].
4. The determination of flood risk zones. This involves the generation of a Digital Terrain Model (DTM) which is a reflection of the actual shape of the terrain. In addition, the prepared Digital Water Surface Model (DWSM), provides information on the elevation of the flood water level [Nachlik et al. 2000].
5. The designation of contained catchment areas that arise from merging DTM and DWSM and are not directly connected to the floodplain. This allows for the determination of the boundary of imminent flood hazard and to calculate the surface of the terrain that can be flooded at a certain water elevation.

The implementation of projects to determine flood risk in the catchment areas is of paramount importance for public safety.

3. Generating a Digital Terrain Model (DTM)

At present, the basis for all analyzes in a given area is to generate a numerical model. DTM (Digital Terrain Model) is a numerical, point elevation representation of the topographic surface of terrain, with an interpolation algorithm that allows the restoration of its shape in a specific area. An excellent reproduction of the surface elevation by means of a model is not possible, due to size limitations of the data set, as well as time and economy issues [Hejmanowska 2005]. The most common DTM structures are TINs (Triangular Irregular Network) and GRID (Raster Regular Grid) – regular grids of squares.

Digital Terrain Models are used primarily in engineering practice, investment, design, and modelling of terrestrial phenomena, in the identification of floodplains (in urban planning), and in various forecasts and analyzes. The data needed to generate the DTM can be obtained by direct land surveying or by laser scanning, photogrammetry [Kraus 2007], digitizing maps, or by the method of radio interferometry.

A number of software applications have been created that facilitates the creation of digital models. One of them is a program developed by Golden Software: Surfer. Surfer is software designed for comprehensive data visualization [Litwin et al. 2013]. It is used mainly to create maps and terrain models in two-dimensional and three-dimensional format. With arbitrarily spaced (XYZ) data, the program generates a regular mesh of values – GRID which is the basis for generating different types of maps.

The grid geometry defines its boundaries and density. The limits are determined by the minimum and maximum values of X and Y of the network and the density is related to the number of columns and rows in the grid. Also it is a measure of the node. With the increase of the mesh size, the number decreases, resulting in the terrain model becoming less accurate. The smaller the mesh, the smoother the model, with local extremes more generalized. When selecting the size of a node, the type of data, its quantity and quality and the expected accuracy of the final model should be taken into account. The program offers 12 methods for GRID model generation which differ from each other by the interpolation algorithm [Yang et al. 2004]: Inverse Distance to a Power, Kriging, Minimum Curvature, Modified Shepard's Method, Natural Neighbor, Nearest Neighbor, Polynomial Regression, Radial Basis Function, Triangulation with Linear Interpolation, Moving Average, Data Metrics, and Local Polynomial.

Interpolation algorithms are a number of parameters which can result in obtaining very different results, depending on the parameters adopted for the calculation [Erdogan 2009]. It is therefore important to carefully approach the issue of interpolation and not uncritically accept the calculation results, especially in automatic mode.

4. Example of potentially flooded area

Due to the availability of measurement data, the authors decided to present the issue based on an example of an area of the Zgórsko creek in Podkarpackie, Poland. The creek is over 40 km long, out of which the major part flows through the community of Radomyśl Wielki. The terrain is basically lowland, with an average decline in two parts per thousand.

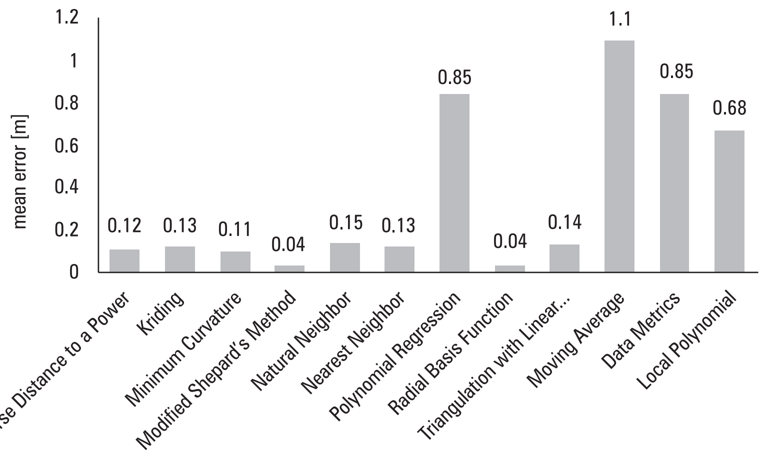
The Zgórsko stream has been monitored for two years, under the PROSPECT flood monitoring program in the village of Podborze. The system is used to monitor the level of water, in the event of a flood alert. The measurement station is located at a single point and only operates when there is a risk. In normal conditions it does not. The measurement results are transmitted from the field to base stations via a cellular network which passes the information onto units involved in the organization of operations. A visualization of measurement data is available through a web server, so that any interested person may check the water level themselves.

Land surveying was carried out, in the village Dąbrówka Wisłocka at the 3.16 km of the Zgórsko creek's length. The measurements were made after the end of channel regulation and reconstruction investments to collect up-to-date information on the spatial position of the stream and the newly created or modified elements of land development.

During the measurements, picket lines were placed at the top of the slope above the creek and at the bottom of its channel, on both sides, thereby forming a profile section. The distance between successive profiles was approximately 20 m on straight sections, and in places where bends were present, or the terrain was more varied, the distance was reduced to approximately 8–10 m. In addition, characteristic points located within 50 m from the channel were measured. The analyzed area was measured in total 328 points. The accuracy of geodesic measurements taken is consistent with the Polish standards and relevant guidelines.

In order to determine the suitability of the different methods to create a GRID with generating a digital terrain model, the average interpolation error for each of them was determined. The calculations were based on Surfer and Excel programs.

Firstly, deviations were set, i.e. the differences between the interpolated points and their corresponding values obtained from direct measurements. Then, the average error for each method was calculated. The results are presented in the chart (Figure 1).



Source: authors' study

Fig. 1. Mean interpolation error for individual methods

The smallest interpolation error for the analyzed data set was achieved by two methods: Modified Shepard's Method and Radial Basis Function with the value of 0.04 m. The mean errors for the algorithms: Inverse Distance to a Power, Kriging, Minimum Curvature, Natural Neighbor, Nearest Neighbor and Triangulation with Linear vary insignificantly from each other – up to 3 cm. Simultaneously, the highest error was found in the case of the Moving Average method – 1.1 m. Figure 2 shows the appearance of the land surface in the area of the Zgórsko creek, analyzed using 10 interpolations of contour models available in Surfer.

To further model the flood zones, a model created by the method of Minimum Curvature was selected. It is most similar to the actual terrain shape, because it has the least distortion and discontinuity lines, extend in a gentle way without creating artificial faults. In addition, it exhibits the highest degree of similarity to the basic map of the study area, and also manifests a small interpolation error.

5. Flood zone modelling

For the example presented in the previous section, an attempt was made to identify flood zones. Unfortunately, due to the lack of hydrological calculations and no data on the water levels in the previous years, it was decided to use a simplified method to determine zones only on the basis of DTM and the base map.

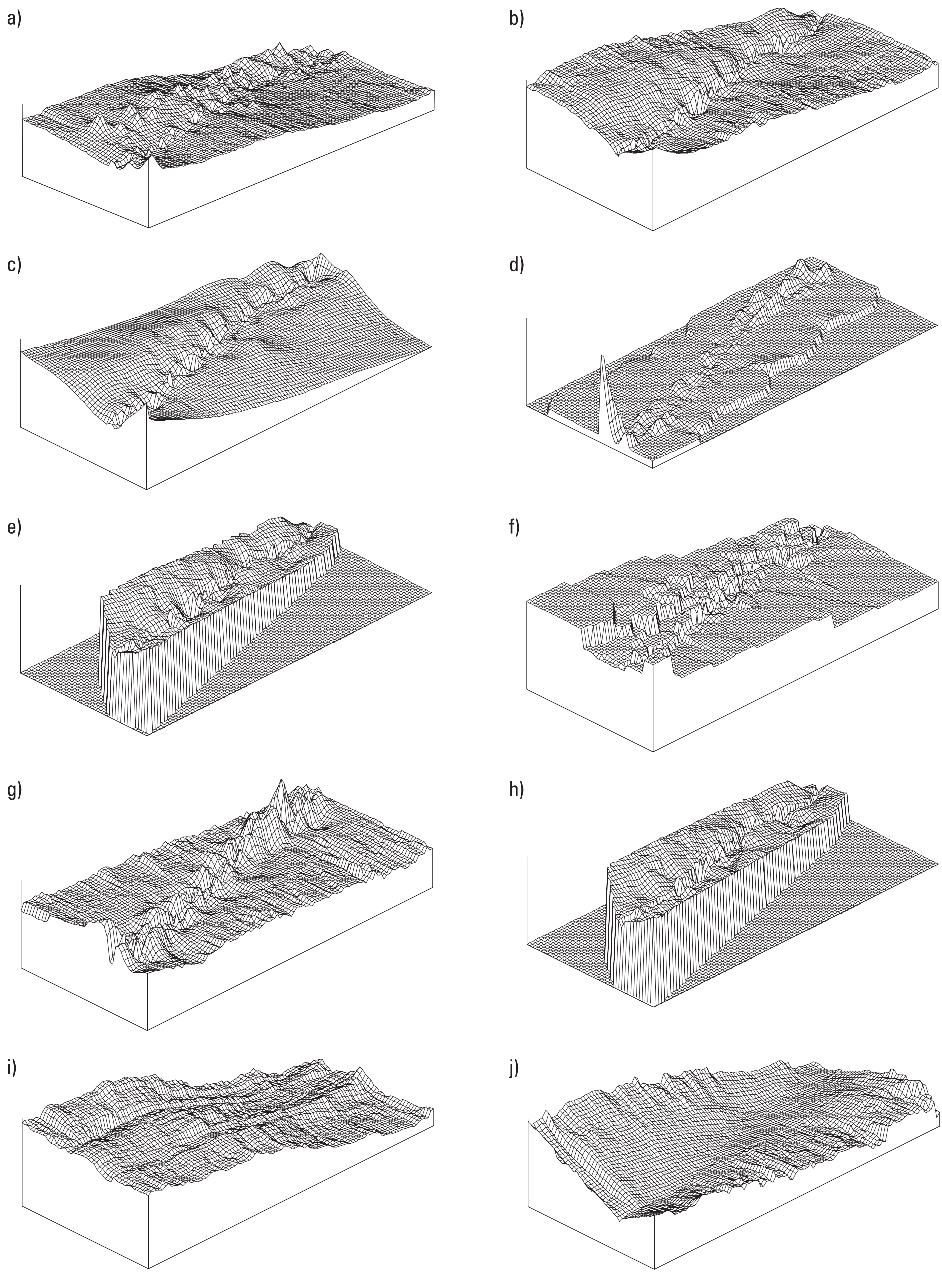
A contour map of the terrain can be generated, for example, in the Surfer. Figure 3, shows the created contour line image of the flood zones, in relation to the course of the creek channel and the distribution of surrounding infrastructure. After creating the baseline map, a contour section was selected, along with a minimum and maximum elevation and the level of contour line smoothing. Also it is possible to add other attributes such as filling the contour with colour, establishing styles, line thickness and colour, description of contour lines or the direction of the slope.

As a result of the analysis, a contour section of the area at 1.25 m was achieved. This caused the breakdown of the area into 7 flood zones (Table 1). For each zone, surface and water volume were calculated. The results of the study are summarized below (Table 1).

Table 1. Surfaces and volumes for flood risk zones

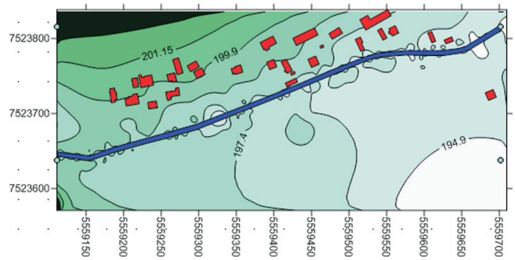
Zone	From height water [m]	Up to water [m]	Zone area [m^2]	Water volume [m^3]
I	194.90	196.15	48708.5	48981.6
II	196.15	197.40	76863.1	125828.2
III	197.40	198.65	108305.1	244460.7
IV	198.65	199.90	128214.8	394439.0
V	199.90	201.15	140750.5	563665.0
VI	201.15	202.40	149262.0	746130.9
VII		202.40 >	154068.5	1515825.1

The data contained in the table above show: How much an increase the surface covered by water with an increase in the water table elevation by each 1.25 m, counting from the lowest level reached by the crest of the creek channel, in the relevant section of the stream.



Source: authors' study

Fig. 2. Terrain models created by different methods: a) Inverse Distance to a Power, b) Kriging, c) Minimum Curvature, d) Modified Shepard's Method, e) Natural Neighbor, f) Nearest Neighbor, g) Radial Basis Function, h) Triangulation with Linear Interpolation, i) Data Metrics, j) Local Polynomial



Source: authors' study

Fig. 3. Contour map of the study area with a superimposed basemap

6. Conclusions

Determining flood zones for water streams is a very important part of the process of preventing and reducing the negative impacts of floods. In this study, depending on the assumed elevation of the water table determined on the basis of baseline section, the surface of areas exposed to flooding were determined.

The Digital Terrain Model (DTM) was prepared on the basis of data obtained from direct field measurements. Based on the selected model of interpolation, a baseline GRID mesh was generated with a recommended size of 1 x 1 m.

The GRID was interpolated by means of twelve different algorithms, in order to select the best one, the one ensuring the greatest similarity to the actual terrain, in the area of the stream. In the case of the example discussed, the results closest to the actual terrain elevation are produced with the application of the Kriging Method and Minimum Curvature. The Average Kriging interpolation error is 0.13 m and Minimum Curvature – 0.11 m. Other analyzed methods have different drawbacks and cause various distortions.

The contour map was used to define areas of a certain elevation. This made it possible to determine the projected range of the water level, in each of the zones established on the basis of the contour section. The difference in the elevation of the water table between adjacent stripes was changed every 1.25 m. As a result, the area under test was divided into seven flood zones.

The method of data preparation should be adapted to the parameters and geometry of the stream, the available measurement data, the land development near to the stream channel, and the required accuracy of flood zone determination. For the example sited in this work, the parameters were selected adequately while in other examples this could be different.

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