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Advanced river flood monitoring, modelling and forecasting

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ABSTRACT

The paper presents the state-of-the-art in flood forecasting and simulation applied to a river flood analysis and risk prediction. Different water flow forecasting and river simulation models and systems are analysed. An advanced river flood monitoring, modelling and forecasting approach is introduced. It extends the traditional approach based on modelling river physical processes by integration of different types of models and technologies such as input data clustering and filtering, digital maps of a relief and river terrain, data crowdsourcing, heterogeneous data processing, hydrological models for time scale modelling water flows and geo-simulation, inundation visualisation and duly warning on flooding. A case study on river flow forecasting and simulation for river flood risk analysis and management is given.

1. Introduction

Flooding is one of natural disasters that often cause significant economic losses, human and social tragedies. Therefore, flood forecasting and its effective control is always a huge challenge for governments and local authorities [4]. Forecasts of river flow may be developed in the short term, over periods of a few hours or a few days, in the medium term, for several weeks, and in the long term, up to nine months [9]. An efficient flood alarm system based on a short-term flow forecasting may significantly improve public safety, mitigate social damages and reduce economic losses associated with floods.

Floods may be caused by different reasons, such as snow and ice melting in rivers in the spring causing freshet; heavy raining in the neighbouring areas, and wind-generated waves in the areas along the coast and river estuaries. In Latvia, springtime ice drifting and congestion can cause a rapid rise in water levels of the Daugava, Gauja, Venta, Dubna and Lielupe rivers [19]. The risk of flooding along the Daugava River is relatively high, and in most flood sensitive areas (e.g., in Daugavpils district) it may occur even twice a year. Floods in Riga and Jurmala districts located in the deltas of the Daugava and Lielupe rivers and on the Gulf of Riga coast may be caused by the west wind during 2–3 days at a speed greater than 20 m/s followed by winds in the north-west direction. As a result, the reverse water flow from the Gulf of Riga into the Daugava and Lielupe rivers may significantly rise to flood levels in these areas.

The EU Directive 2007/60/EC on the assessment and management of flood risks states that it is feasible and desirable to reduce the risk of adverse impacts of floods, especially for human health and life (http://ec.europa.eu/environment/water/flood_risk/). Flood risk management generally involves flood monitoring, risk assessment and forecasting of the flood inundation areas. Flood monitoring can be performed by using satellite images which allow detecting river overflows and provide data for flood damage modelling and assessment.

Flood forecasting is a challenging field of an operational hydrology, and a considerable amount literature has been written in that area in recent years. A water flow forecast presents an asset for flood risk management to reduce damage and protect an environment [25]. Reliable flow forecasting may present an important basis for efficient real-time flood management, including flood monitoring, control and warning. The integration of monitoring, modelling and forecasting becomes important in the construction of alert systems. Nowadays, the application of remote sensing and GIS software that integrates data management with forecast modelling

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1877-7503/

tools becomes a good practice [10,14,21,23]. Additionally, different flooding scenarios may be simulated based on the results of forecasting models to allow analysing dynamics of the river floods and evaluating their potential effects in the near future.

This paper provides the state-of-the-art in the field of river flood modelling and forecasting [19], as well as describes advanced river flood monitoring, modelling and forecasting techniques developed within the research project ESTLATRUS/2.1/ELRI-184/2011/14 INFROM "Integrated Intelligent Platform for Monitoring the Cross-border Natural-Technological Systems" [18]. Different water flow and flood forecasting models have been used and compared – traditional regression-based forecasting techniques, symbolic regression [3], and cluster analysis of dynamic water flow data and identification of typical dynamic patterns. Among flood monitoring models, hydrodynamic and hydrological models have been reviewed and compared. A new approach to integrated river flow monitoring, modelling and forecasting has been developed and advanced by integrating different models and technologies for improving flood risk forecasting, based on analysis of heterogeneous data received from different information sources. The development of the flood monitoring and forecasting system is based on the recent progress in the sphere of spatial modelling and simulation, modern geoinformation systems (GIS) and earth remote sensing technologies.

2. The state-of-the-art

There are several models and systems that allow predicting flood risk outputs by the remote sensing technology, GIS, hydraulic and hydrology modelling. In this paper, flood forecasting and simulation models and techniques that are used for river flow predictions and flood risk output generation are reviewed.

River flood monitoring and control require measurement and notification of the water level, velocity, and precipitation. Input data for precipitation forecast are meteorological data and weather forecasts as the most important components of a flood forecasting and early warning system [6,22,26]. In practice, river flood forecasting is based on mining historical data and specific domain knowledge to deliver more accurate flood forecasts. Effective flood monitoring and control use space and ground-observed data received from satellites and terrestrial (meteorological, automatic rain gauge, and climatological) stations. These data may be represented as images, terrain information, and environmental information, i.e., soil type, drainage network, catchment area, rainfall, and hydrology data. Data representation and processing proven technologies and expertise are offered in [27].

Besides, expert knowledge may be integrated into the flood risk assessment procedure, producing river flood scenarios to be simulated, and measures for flood damage prevention or reduction. When risk outputs are calculated, decisions for preventive actions can be made based on flood risk maps, flood forecast maps, flood emergency response maps, and based on detection and monitoring for early warning mitigation and relief.

A traditional approach to flood modelling is based on modelling of river physical processes which describe the water motion or the hydrological cycle. In this context, flood monitoring models may be classified as hydrodynamic and hydrological models.

Hydrodynamic models represent the motion of water flow using the so-called Navier–Stokes equations, which describe the motion of fluid substances in physics.

Hydrodynamic river flow processes might be also represented by a variety of different models based on geological surroundings, for example, the conceptual HBR model [15], ANN-based runoff predictors with a fuzzy classifier of the basin states [5], hydrodynamic deterministic models improved by uncertainty coping to produce the probabilistic hydrological forecast [13].

A conceptual model of the river may be described in different ways due to a different scope of the model [4,7,22]. One of common simplifications of the hydrodynamic river flow processes is achieved by lumping of the processes in space and limiting the study area to the region affected by the flood control. The lumping of the processes in space is done by the simulation of the water levels only at the relevant locations. These locations are required to be selected at upstream and downstream points of each hydraulic regulation structure and places along the river [4].

Hydrological models are simplified conceptual representations of the hydrologic cycle. Hence, they are considered to be more suitable for water flow modelling in flood monitoring. Hydrological models used in the forecasts can be grouped as follows [7]: (1) *stochastic hydrological black-box models* that define input-output relations based on stochastic data and use mathematical and statistical concepts to link a certain input to the model output; and (2) *conceptual or process-based models* that represent the physical processes observed in the real world. While black-box models are empirical models and use mathematical equations without regard to system physics, conceptual models apply hydrological concepts to simulate the basin or river behaviour.

Stochastic hydrological models are more popular in literature due to their simplicity. Among them, linear perturbation models, HEC models and neural network-based flood forecast systems are considered to be the most efficient tools in practice [7]. In particular, linear perturbation models assume that the perturbation from the smoothened seasonal input rainfall and that of discharge are linearly related. However, the rainfall-runoff relationship was recognised to be nonlinear, and coupling fuzzy modelling and neural networks for flood forecasting that do not assume input-output model relationship to be linear was suggested in [5]. In the Hydrologic Engineering Centre (HEC), numerical models for simulation of hydrologic and hydraulic processes are used. HEC models solve the Saint-Venant equations using the finite-element method. The primary surface water hydrology model is HEC-1 Flood Hydrograph Package, which can simulate precipitation-runoff process in a wide variety of river basins. The predictive power of HEC models is also discussed in [4,11].

Conceptual models usually have two components [25], that is, a rainfall-runoff module, which transfers rainfall into runoff through water balance in the river hydrological components, and a routing module, which simulates the river flow. Conceptual models, such as Soil Moisture Accounting and Routing (SMAAR) model, NAM and Xinanjiang models, which have the number of parameters 5, 13, 15, respectively, were applied to seven river basins in Sri Lanka [7]. Data requirements for modelling were formulated, and the calibration and validation of models were performed. The results obtained demonstrated the applicability of all models, but NAM and Xinanjiang models were found more appropriate as flood peaks were represented by separate parameters in these models.

The results of flood forecasting based on the traditional modelling approach heavily depend on the preciseness of weather forecast (precipitation, wind direction and strength, etc.).

There are several major river modelling software tools including HEC-RAS, LISFLOOD-FP and TELEMAC-2D. The HEC River Analysis System (HEC-RAS) allows performing one-dimensional steady flow, unsteady flow, and water temperature modelling and solves the full 1D Saint-Venant equations for an unsteady open channel flow. The implementation of HEC-RAS models requires large datasets. LISFLOOD-FP is a raster-based inundation model specifically developed to take advantage of high resolution topographic data sets [2] and adopted to a 2D approach. TELEMAC-2D is a powerful and open environment used to simulate free-surface flows in two dimensions of a horizontal space [8]. At each point of the mesh, the programme calculates the depth of water and the two velocity components. The model solves 2D shallow water

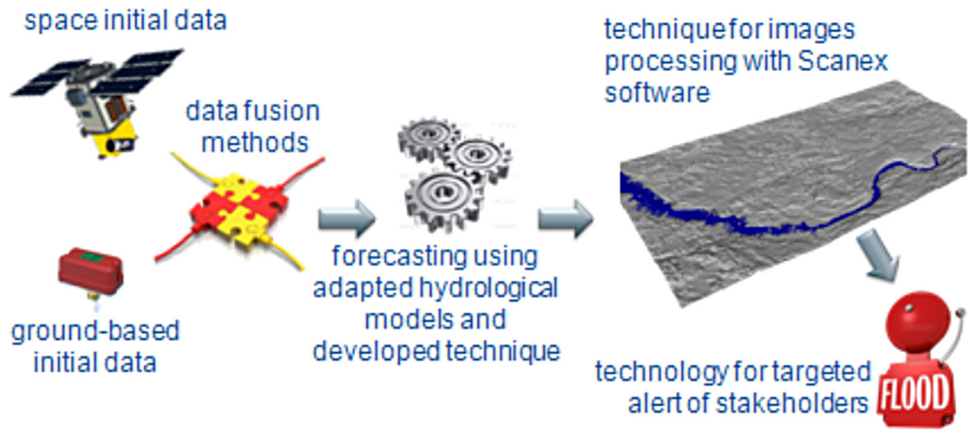


Fig. 1. Short-term forecasting based on integration of space and ground-based data.

(also known as Saint-Venant equations or depth average) equations for free surface flow using the finite-element or finite-volume method and a computation mesh of triangular elements (see, also http://www.opentelemac.org).

The predictive performance of three models, that is, HEC-RAS, LISFLOOD and TELEMAC, is analysed in [12]. The different predictive performances of the models stem from their different responses to changes in friction parameterisation. Performance of 1D HEC-RAS model gives good results, which are comparable with those received from more sophisticated 2D approaches adopted by LISFLOOD-FP and TELEMAC-2D. In addition, HEC-RAS models allow building long-term flood forecasts, but require large input datasets and need substantial time and costs to collect them. These models reflect moving in recent years from a 1D approach (represented by the US Army Corps of Engineers HEC-RAS model) towards 2D finite element (TELEMAC-2D developed by Électricité de France) and raster-based (LISFLOOD-FP) models.

LISFLOOD-FP [17] is a coupled 1D/2D hydraulic model based on a raster grid and capable of simulation dynamic flooding and floodplain inundation in a computationally efficient manner over complex topography. 'Flooding is treated using an intelligent volume-filling process based on hydraulic principles and embodying the key physical notions of mass conservation and hydraulic connectivity'. The model is capable of simulating grids up to 106 cells for dynamic flood events and model large areas at fine special resolution of 10–100 m cell sizes. Also, it can take advantage of new sources of terrain information from remote sensing techniques. LISFLOOD-FP models are applicable for short-term forecasting and require a minimum amount of input data to produce an acceptable result. LISFLOOD-FP software has been used in several European research projects and successfully approbated.

3. Advanced approach

In the current paper, the traditional flood model-based forecasting approach based on modelling river physical processes is advanced by integrating different models and technologies for improving flood risk output prediction such as input data clustering and filtering; digital maps of a relief and river terrain; data crowd sourcing; forecasting models; different hydrological models for time scale modelling water flows; computer simulation for modelling the river behaviour; visualisation tools; geographic information systems (GIS); and techniques for flooding scenario generation and comparison [19].

Real-time flood monitoring [20] is based on the integration of heterogeneous data from both space and ground-based information sources (Fig. 1). Taking into consideration the floodplain width and the speed of flooding processes, satellite and aerospace monitoring allows regularly overlooking large areas and providing high efficiency information on the research object. Additionally, to get a holistic view of the current situation, remote sensing is supplemented by data obtained from ground-based monitoring devices.

Clustering of dynamic historical data allows identifying typical dynamic flooding patterns in the real-life situations which have occurred in the past and might be expected in the future.

A symbolic regression-based forecasting model is integrated into short-term forecasting of the river flow discharge and monitoring in a specific real-life situation. Here, the main challenges are a small number of input factors and a small set of flow measurements. For developing a symbolic regression-based forecasting model, genetic programming within HeuristicLab [1] is used. A trend-adjusted exponential smoothing is applied to predict the water levels in the river.

Hydrological models are advanced by realistic physical models that are derived from topological maps and represent geo information of the river and its neighbouring areas.

Data crowd sourcing is used for calibration of a hydrological model based on comparison of the actual situation with forecasted. Additionally, regression-based metamodels using river simulation results allow performing sensitivity analysis of input factors influencing the river water levels and inundation areas, and improving understanding of the model behaviour and interpretation of the flood forecasts [3].

GIS and the earth remote sensing technology present the most powerful tools emerged in the hydrological field, which allow for the collection and analysis of environmental data as well as provide a platform for integrating space and ground-based data for flood monitoring and modelling. Observed data support the creation of information through modelling, and the information evolves into knowledge through visualisation and analysis of digital elevation pictures and finally supports analysis of flooded geographic areas.

Finally, automatic generation and analysis of flooding scenarios will allow analysing dynamics of the river floods and evaluating their potential effects in the near future to support preventive actions to mitigate impacts of floods.

4. Flood monitoring and forecasting system

The real-time flood monitoring and forecasting system is developed within the above described approach and is based on the integrated use of ground-based and aerospace data. The system allows operational forecasting of the river water levels, discharges and inundation areas, and provides prior notification of the citizens on emergency situations at the GeoPortal and/or by using

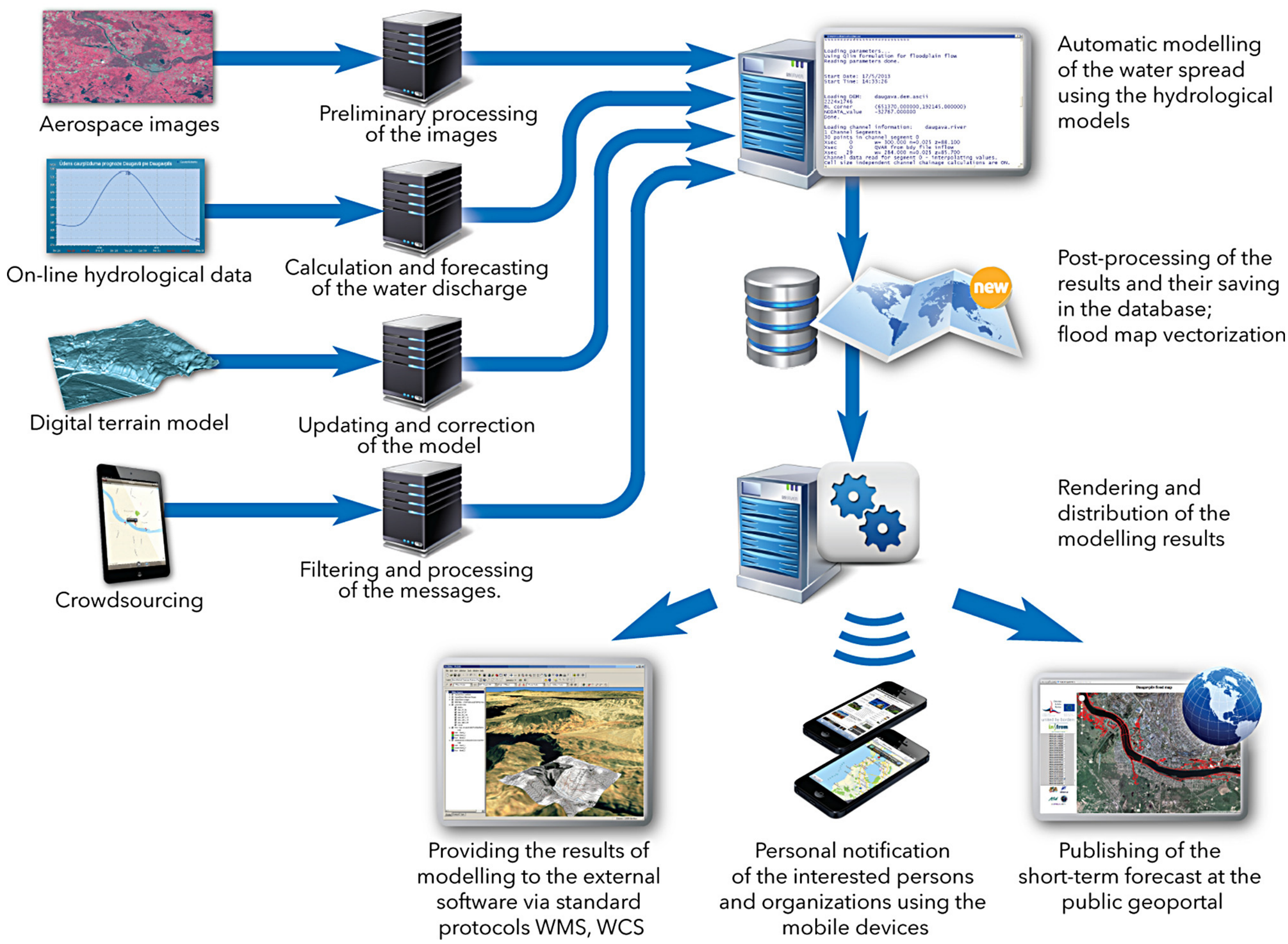


Fig. 2. Flood monitoring and forecasting system.

mobile devices. The system contains the following main components (Fig. 2):

(1) ***Input data collection and pre-processing*** component provides input data collection (e.g., aerospace images, on-line hydrological data from meteorological station; a digital terrain model obtained by the airborne Lidar technology) and pre-processing (i.e., primarily image processing, information filtering and information fusion).
(2) ***Modelling and forecasting*** component allows forecasting of water level, calculation and forecasting of the water discharge as well as automatic modelling of the water spread using hydrological models.
(3) ***Post-processing and visualisation*** component provides post-processing of modelling results, output data storage in a database, flood map vectorisation and visualisation of inundation areas.
(4) ***Information distribution*** component provides distribution of the modelling results to the external software, publishing short-term forecasts at the public GeoPortal and automatic notification of the local citizens and organisations (e.g., emergency rescue services, local municipalities) using web service and mobile applications.

The input data collection and pre-processing component aims to effectively integrate all the available data from various geographically distributed data sources with analytical capabilities to enhance the reliability of the monitoring information and the speed at which it becomes available to decision makers. Another important aspect is to provide the user with the most accurate spatial and temporal resolutions of data, models and tools according to the actual tasks to be solved. Consequently, assessment at different geographic scales should take advantage of different data sources. The component implements automated data fusion allowing essential measurements and information to be combined to provide knowledge of sufficient richness and integrity that decision may be formulated and executed autonomously. The architecture and functionality of the system is universal regarding the input data type diversity, density and speed.

The proposed system operates automatically and provides flood forecasts over 48 h ahead with hourly outlines of the potential flooded zones and objects and a water depth map, both available via standard protocols WMS, WCS. A high-resolution digital elevation model is required to provide a high accuracy of flood forecasts. Visualisation of the modelling results in 2D and 3D modes is performed. The flood forecasting results are provided as a web service on a remote basis. The modelling and forecasting results are automatically presented at the GeoPortal where data and information are continuously updated and available on-line for the end users. The users of the system are not required specific knowledge in modelling and simulation or programming skills.

5. Short-term flood forecasting algorithm and models

5.1. Short-term forecasting algorithm

A short-term flood forecasting algorithm includes the following main steps (Fig. 3): (1) on-line hydrological data on the river water

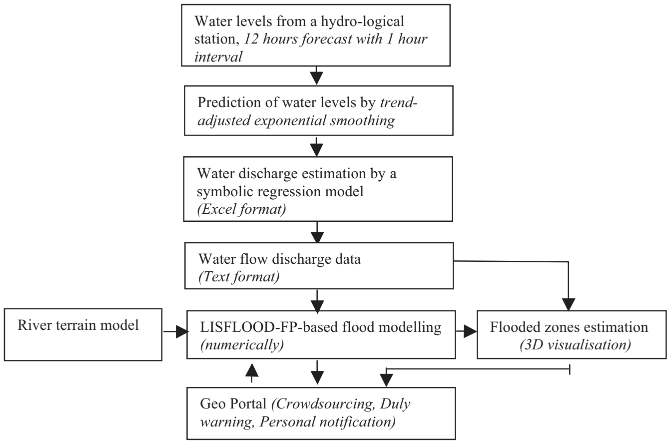


Fig. 3. Short-term flood forecasting algorithm.

levels are obtained from a hydrological station; (2) the observed data are processed by their smoothing with trend extraction in order to predict the river water levels in a short-term; (3) a symbolic regression-based forecasting model is built which provides water flow discharge forecasts; (4) water flow discharge data, accompanied by the river terrain information, are processed by an adaptive hydrological model, which simulates water floating routes and thus provides forecasts on water covered territories in the river basin; (5) visualisation software is used for geo-presentation of the river simulation results on water flows and inundation areas; and (6) archival data and images, satellite images of the current situation and data crowd sourcing through a Geo-Portal are used to validate and calibrate the hydrological model. Below, a description of three main models, i.e., a water level forecasting model, a water discharge estimation model and the LISFLOOD – FP-based hydrological model is provided.

5.2. Water level forecasting model

A trend-adjusted exponential smoothing is applied to predict water levels. The model is appropriate when data vary around an average data and have gradual changes and are often used for flood forecasting [24].

The trend-adjusted forecast F_{t+1} is composed of two elements – a smoothed error and a trend factor, that is:

$$F_{t+1} = S_t + T_t, \tag{1}$$

where S_t denotes a previous forecast plus smoothed error, T_t presents a current trend estimate. These elements are calculated as follows:

$$S_t = \alpha F_t + (1-\alpha)(S_{t-1} + T_{t-1}), \tag{2}$$

$$T_t = \beta(S_t - S_{t-1}) + (1-\beta)T_{t-1}, \tag{3}$$

where α and β denote smoothing constants for average and for trend, correspondingly. Values of α and β which minimise the average of the squared forecast errors for historical data are selected. In the model, smoothing constants are defined as $\alpha = 0.2$, $\beta = 0.05$. A trend adjusted forecast value for water levels is calculated in Ms Excel [16].

5.3. Water flow discharge estimation model

To predict water flow discharge values based on the dataset of the water level in the river, a symbolic regression model is used [3].

The initial dataset includes data on the following explanatory variables: the current water level *h0* in the river at time when the water flow is measured; water levels *h3*, *h6*, *h12*, *h18* in the river which measured in 3, 6, 12 and 18 h before the flow is measured, and water levels *d1*, *d2*, *d3* and *d7* which measured 24 h, 2 and 3 days, and 1 week before the current flow is measured.

To find symbolic expressions for flow value that fit the dataset on the water levels, genetic programming based symbolic regression in HeuristicLab optimisation [1] is used. The following model for the flow discharge estimation is found:

$$\begin{aligned} flow \approx\ & 216.678 - 0.202 \cdot (0.645 \cdot h0 - 0.666 \cdot h12 + 0.361 \cdot h18 \\ & - 0.066 \cdot d3) \cdot (-0.361 \cdot h18 + 0.290 \cdot h12 - 24.078), \end{aligned} \tag{4}$$

where *flow* defines the river water discharge in m^3/s. The main factors that affect the water flow discharge are attributes *h12* and *h18* that define the water levels 12 h and 18 h before, correspondingly. Additionally, *d1* denotes the water level measured 24 h before.

The model fitted data with coefficient $R_2 = 0.963$ for the training set and $R_2 = 0.953$ for the test set. In case when the current water level *h0* in the river is not known, the following model is used:

$$\begin{aligned} flow \approx\ & 208.214 - 0.011 \cdot h12 + 0.014 \cdot (-0.415 \cdot h3 + 1.123 \cdot h6 \\ & - 1.262 \cdot h12 + 1.503 \cdot h18) \cdot (1.123 \cdot h6 - 0.814 \cdot h12 \\ & + 98.845). \end{aligned} \tag{5}$$

More details on the water discharge estimation model, as well as parameters of a genetic algorithm applied to found this model and software used are given in [3].

5.4. The LISFLOOD hydrological model

The model structure includes two main components [2,17]: 1D model for simulating a channel flow by capturing the downstream propagation of a flood wave and the response of flow to free surface slope; and 2D floodplain model which represents 2D dynamic flows on the floodplain or water transfer from the channel to the overlying floodplain grid when bank full depth is exceeded. Both models are described in terms of continuity and momentum equations and discretized using finite differences.

A case study on flood forecasting for the Daugava River in Latvia that demonstrates the applicability of the proposed forecasting algorithm and models is described below.

6. Case study

A case study was developed for a short-term flooding forecast for the Daugava River near the city of Daugavpils in Latvia, in spring 2013 when unexpected intensive flooding was observed, exceeding the previous highest water level in spring 2010 – 7.7 m. The main

Fig. 4. Flooding research area.

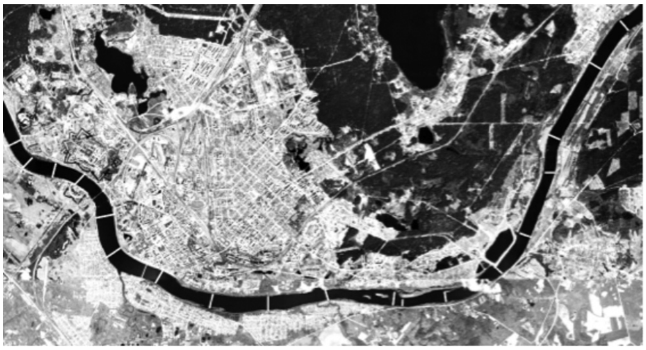
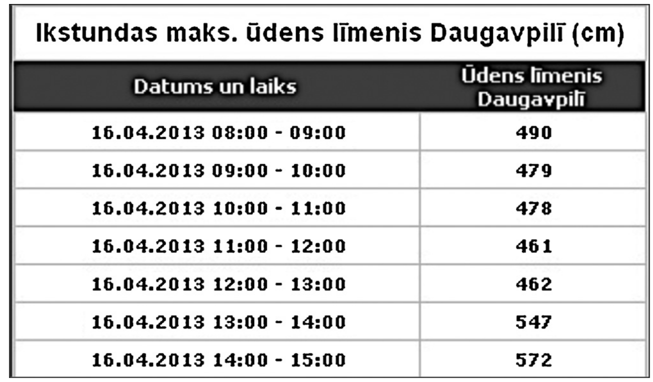


Fig. 5. Estimation of the river hydrological characteristics.



Ikstundas maks. ūdens līmenis Daugavpilī (cm)

Datums un laiks	Ūdens līmenis Daugavpilī
16.04.2013 08:00 - 09:00	490
16.04.2013 09:00 - 10:00	479
16.04.2013 10:00 - 11:00	478
16.04.2013 11:00 - 12:00	461
16.04.2013 12:00 - 13:00	462
16.04.2013 13:00 - 14:00	547
16.04.2013 14:00 - 15:00	572

Fig. 6. Operational data from a hydrological station.

reasons for spring floods in Daugavpils are considered as river ice jams arising from ice melting and rapid rise in the river water level.

6.1. Input data collection and pre-processing

The research area covers the territory along the river at a length of about 20 km (Fig. 4). It is specified based on historical data from flood risk assessments for the period April 1–26, 2010 with the probability of floods increased by 10%. The critical water level in the Daugava River near Daugavpils city is 7.5 m.

A digital elevation model of the research area was obtained by means of airborne laser scanning performed by a specialised company with a horizontal resolution of 5 m and a vertical resolution of 0.25 m. To define hydrological characteristics of the river required for modelling water flows of the river channel network, a simplified model of the river channel on the selected section of the river was built. The width data of the river channel were determined based on the archival optical range space image for the period of low water levels in the river (Fig. 5). Absolute heights of the river bottom channel were calculated using a digital elevation model.

The flood forecast horizon is defined by a period up to 12 h, with 1 hr interval. There is only one hydrological station on the selected section of the Daugava River which can provide hydrological data on water levels, heights of waves, a flow direction, etc. These data become available on web site of the Meteorological Centre with a 10-h delay. Moreover, for hydrological modelling the water flow data are required which actually are measured only twice a month. Thus, to get operational data on the water levels in the river on-line web service has been created. The resulting dataset included time series of water hourly levels observed in the river (Fig. 6).

6.2. Forecasting and modelling

To predict the river water levels for the upcoming period of 12 h on a daily base, a trend-adjusted exponential smoothing model is applied to observed water hourly level time series. By application of a symbolic regression method, a model for converting the water level into the water flow discharge in m^3/s was created.

To determine the functional dependency between the water flow discharge in the river and its water level within the forecasting horizon, several modelling scenarios such as linear, nonlinear regression models and a symbolic regression were experimentally tested [3]. Finally, a symbolic regression-based method implemented in HeuristicLab optimisation framework [1] has been selected. In order to train the model, historical data on water level forecasts for the previous intensive flooding period in March–April 2010 were used. A web service for recalculation of the river water level into the water flow discharge was created providing hourly receipt of the water discharge in the river. In fact, forecasts of the water levels are transformed into forecasts for the water discharge values. The forecasting accuracy of the river water flow discharge was within 95% confidence interval (Fig. 7).

A LISFLOOD hydrological model is developed to simulate water flows in the Daugava river bed and within the channel network by integrating the digital map of the relief of the specified area and

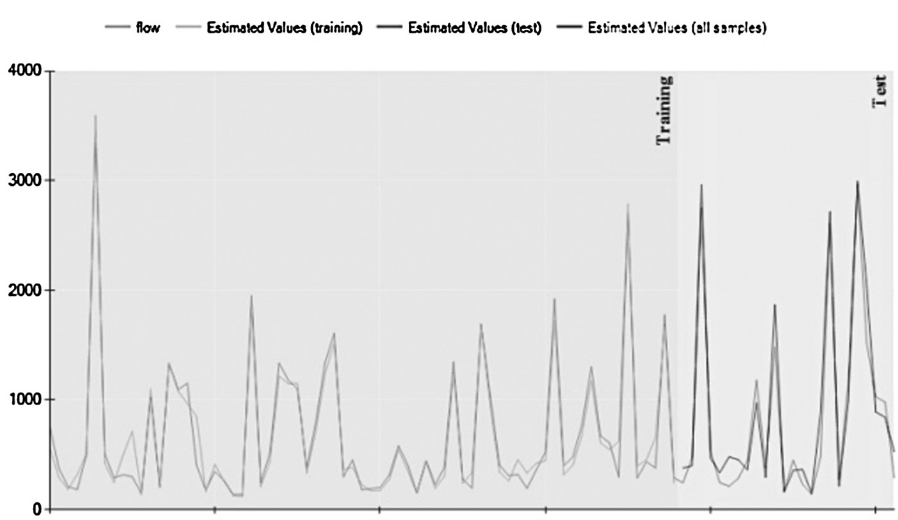


Fig. 7. Empirical data versus model-based forecasting results.

obtained hydrological characteristics of the river. To increase an accuracy of flood forecasts, 3D elevation model data with low vertical resolution that does not exceed 1 metre is used. Consequently, based on the water flow discharge data and a digital elevation model, LISFLOOD-based hydrological model is built, which allows forecasting inundation territories along the river basin.

To test and validate the model, the flood simulation results have been compared with available historical data on the flooded zones in the research area in March–April, 2010 (Fig. 8). The bounds of the inundation area from simulation experiments are close to historical data, and a forecast error is less than 10%.

Then calibration of the model has been performed in two steps: by using the image received from the satellite RADARSAT-1 to precise the current state of the river channel and by using data crowdsourcing technology – photos and video materials downloaded by socially active residents of the Daugavpils district through a created web service http://daugava.crowdmap.com based on open-source platform *Ushahidi*. The implemented solution combines real-time automated image and location data processing with human validation of flood forecasting results. Shooting has been conducted by synthetic aperture radar in the Fine mode with an image-swath width of 50 km and spatial resolution of approximately 8 m. The synchronisation of used heterogeneous data was performed along the timeline. The model calibration was done manually.

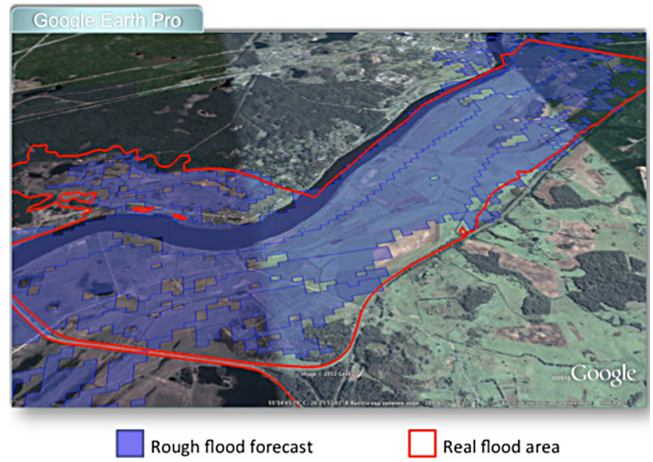


Fig. 8. Matching between simulation results and historical data from year 2010.

The performed real-time experiments with the developed model allowed achieving about 90% confidence in flood forecasts

Fig. 9. Crowdsourcing: sample experimental results.

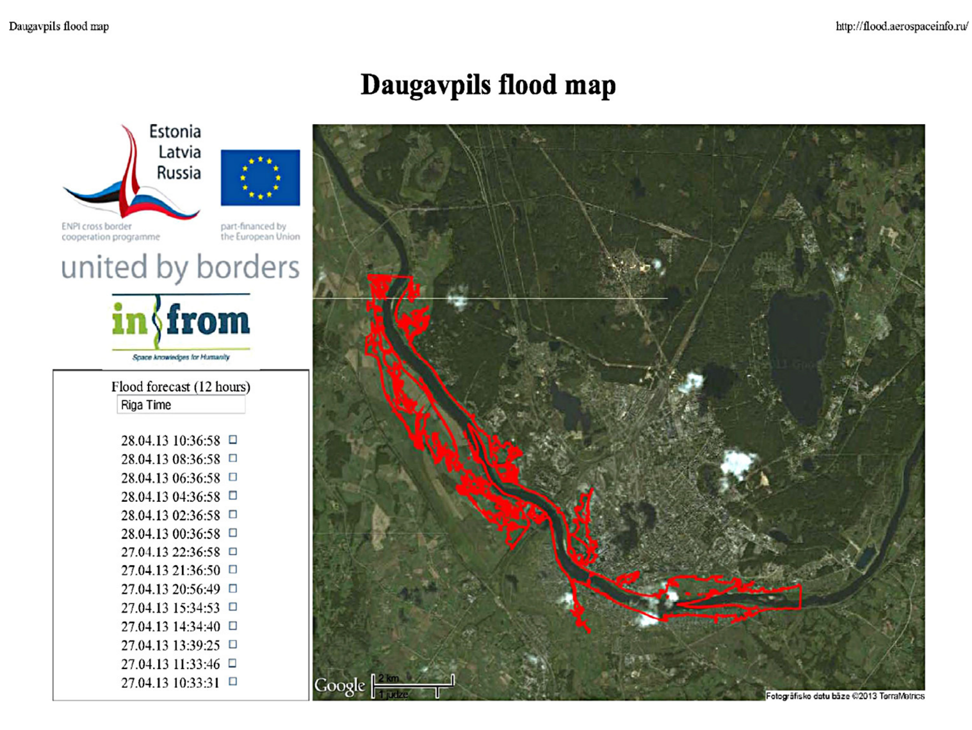


Fig. 10. Sample flooding forecast in Daugavpils: 26.04.2013, 20:30.

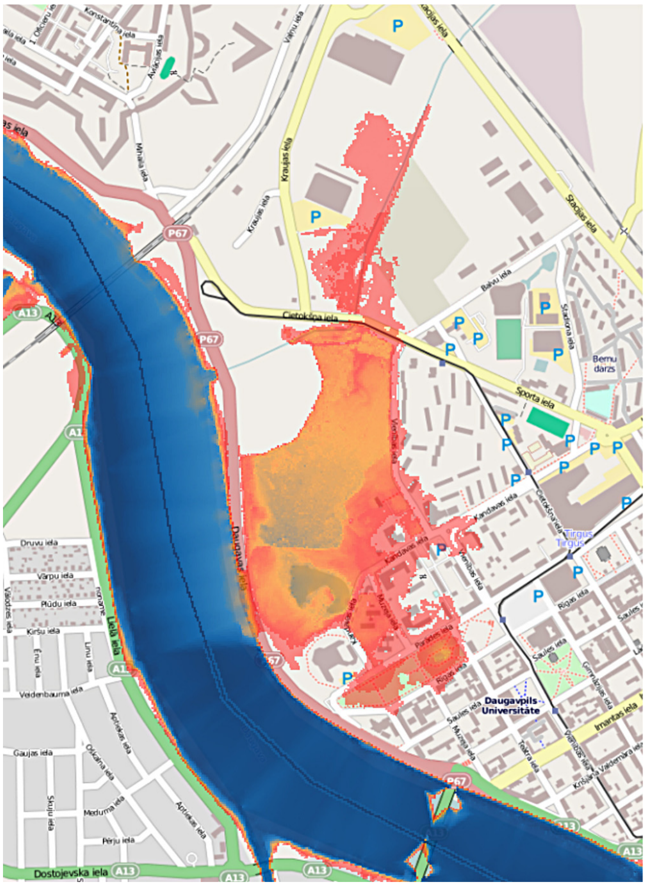


Fig. 11. Raster map of flooded territory.

regarding significant objects which were actually inundated later on (Fig. 9). The high forecast precision is achieved through continuous updating of input parameters and arising out short-term forecasts.

6.3. Post-processing and visualisation of modelling results

The LISFLOOD-HP hydrological model generates 12-h forecasts of inundation zones hourly (Fig. 10). The results of flood simulation are presented as a raster map (Fig. 11) with information about the depth of water in the flooded territory which automatically vectorised to provide compatibility with the external GIS software and storing in the data base archival information about flood dynamics.

Flood forecasting results are automatically published at the Google maps based Geo-Portal for prior notification about emergency situations. The web service provides possibilities of viewing layers with flood contours from the beginning of the modelling process up to 12-h forecast.

7. Conclusions

The review of the state-of-the-art in river flood flow forecasting and simulation allows defining the most efficient models and tools for water flow forecasting and river simulation. The river flood integrated monitoring, modelling and forecasting approach enables one to advance the traditional approach based on modelling river physical processes by integration of different types of models and technologies for advancing risk analysis of river floods. These models and technologies provide input data clustering and filtering, using of digital maps of a relief and river terrain, data crowdsourcing, different hydrological models for time scale modelling water flows and geo-simulation, visualisation of the modelling results as well as duly warning and personal notification on the flood status. The advanced approach is based on processing and integrated use of heterogeneous data from both space and ground-based information sources. The experimental results showed a high forecasting accuracy. The flood monitoring and forecasting system allows one to significantly improve the social security and decrease economic damage caused by floods.

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