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Assessing flood risk for urban areas in the Lower Don River using GIS and Remote Sensing

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ABSTRACT:

Increasing urbanization rates and related colonization of traditionally unoccupied and potentially unsafe territories may result in great economic and human losses. In order to ensure resilience of growing and expanding communities, it is necessary to understand both existing risks and potential threats coming from natural and anthropogenic factors. The expansion of urban areas into the Lower Don River floodplain (Rostov Oblast, Russia) is a good example of such processes. Flood events were common for the region, and even after the construction of the Don Dam complex and significant regulation of the river discharge, the risk of inundation still exists. Historically, regular flooding was not considered as a disaster by local communities. However, ongoing floodplain urbanization changes the perception of floods and requires assessing its risks for settlements and economic activities.

Assessment of the flood risk was conducted for the region using remote sensing data and GIS. The aim was also to explore the scale and dynamics of floodplain urbanization. In order to evaluate the land cover changes and urbanization rates, Landsat satellite imagery was collected, processed and analyzed for two years 1985 (Landsat 5) and 2013 (Landsat 8). The obtained results have been compared to regional statistical data. Urban growth has been identified in the study area despite the decrease in the total population of the Rostov Oblast. Assessment of flooding risk for urban areas was carried out using the FLO-2D flood routing model (FLO-2D Software, Inc.) and verified using the records of the recent floods. Five flooding scenarios including natural 100-year flood were formulated and tested. The settlements potentially threatened were identified for each of these scenarios.

Keywords: Flood, Floodplain urbanization, GIS, Remote Sensing, Modelling

1. INTRODUCTION

Statistical data show that number of reported natural disasters has clearly grown in the last decades, and this trend cannot be explained only by improved reporting (EM-DAT 2016). The increased frequency of extreme events and uncertainty in weather patterns, accompanied by growth of urban population, related urbanization and corresponding increase in disaster exposure, contribute to rising numbers of affected people and economic losses from natural disasters. Apart from climate, the latest development patterns, such as urban sprawl and floodplain urbanization, are increasing exposure of communities (people, property, infrastructure) to natural hazards, like floods (EU 2007). In addition, floods stand out as one of the most common hazards, which can affect the population and assets on a great territory (EM-DAT 2016).

This research was focused on assessment of changes in flood risk caused by expansion of urban areas to flood-prone territories. The Lower Don River floodplain (Rostov Oblast, Russia) was selected for analysis, since this region is both rapidly developing and historically was considered to be a flood-prone area (Lagutov and Lagutov 2011). Moreover, the Don River floodplain from the Tsimlyansk dam to the river delta at the Sea of Azov is a good example of changing perception of flood events and related risks.

The historical development of the Lower Don and its ecosystem functioning can be divided into two main periods by the construction of the high pressure Tsimlyansk dam in 1952, which has drastically changed the river hydrological regime, communities life style and minimized floods frequency and duration. In the present day, the regime of the Lower Don water discharge is defined by many factors such as navigation needs, electricity production, drawdown in the Tsimlyansk reservoir, water losses for irrigation, water supply, evaporation from water mirror (Lagutov and Lagutov 2011). The reservoir creation and maintenance has resulted in the redistribution of the snow-fed Don River runoff through the year, minimizing the volume and frequency of spring floods and increasing summer time discharge. This change has a significant impact on the river ecosystem and biodiversity, but at the same time the reservoir allows flood risk reduction and control. Nevertheless, the reservoir can decrease flood risk and alleviate consequences only to a certain extent. For example, after the reservoir construction the Lower Don floodplain still was submerged in some years (completely in 1963, 1979, 1981, and 1994) (Rosvodresursy 2013), causing economic losses and threatening population wellbeing.

Changing climate, weather extremes, technological security and terrorism threats require an elaborate disaster risk assessment, preparedness and management plan for the region. Identifying the areas vulnerable to severe floods can help to increase awareness of the risks among local government and population as well as "shift towards managing risks rather than emergencies" (Brecht *et al.* 2013).

2. METHODOLOGY

The main aim of the research was to assess the urbanization of the Lower Don River floodplain and the related flood risk to urban areas. A combination of set of various methods and tools were employed to achieve these objectives. Collected historical statistical data, Remote Sensing (RS), Geographic Information System (GIS), and Modelling were used to study floodplain urbanization. The urban area flood risks were identified through a 2-step process: identifying urbanized areas in the floodplain and simulating potential severe flood events.

2.1 Remote Sensing and GIS

Satellite imagery was used to identify changes in land cover, particularly expansion of urbanized areas in the floodplain from 1985 to 2013. Landsat 5 and Landsat 8 data were used for years 1985 and 2013, correspondingly. The recorded regional severe flood events were identified using historical statistical data and used for the further described flood model verification and assessment of the historically affected area. Such severe floods were recorded in 1978, 1979, 1981, characterized as high-water years when the Lower Don floodplain was inundated completely (Rosvodresursy 2013). Satellite images for the spring months of these years were acquired and processed using Esri ArcGIS 10.

2.2 Simulation

The potential flood extent and propagation were assessed using the combination of remote sensing and modelling tools. Flood simulation using modelling package can allow identify territories that are at the most risk, flood wave speed, time required to reach a particular settlement and other flood characteristics. The hydrological model for the Lowere Don River was developed using FLO-2D cellular automata-based model (FLO-2D 2016). Five alternative flood scenarios were formulated based on recorded floods statistics and tested using the developed model (Rosvodresursy 2013).

3. RESULTS

3.1 Urbanization of the Lower Don River Floodplain

The urbanized areas in the Don floodplain were identified using supervised classification of Landsat satellite imagery. As the first step, two land cover maps for 1985 and 2013 were developed. According to the focus of the research on urbanization changes, the revealed vegetation change patterns were not indicated on the final maps. Although the total population of the Rostov Oblast in the considered time period slightly decreased (ROSSTAT 2014), the population within the study area, especially in the large and economically important cities, grew following the global urbanization trend. The regional urbanization patterns revealed through remote sensing techniques can be clearly seen from combining urbanized areas in 1985 and 2013 (Fig. 1).

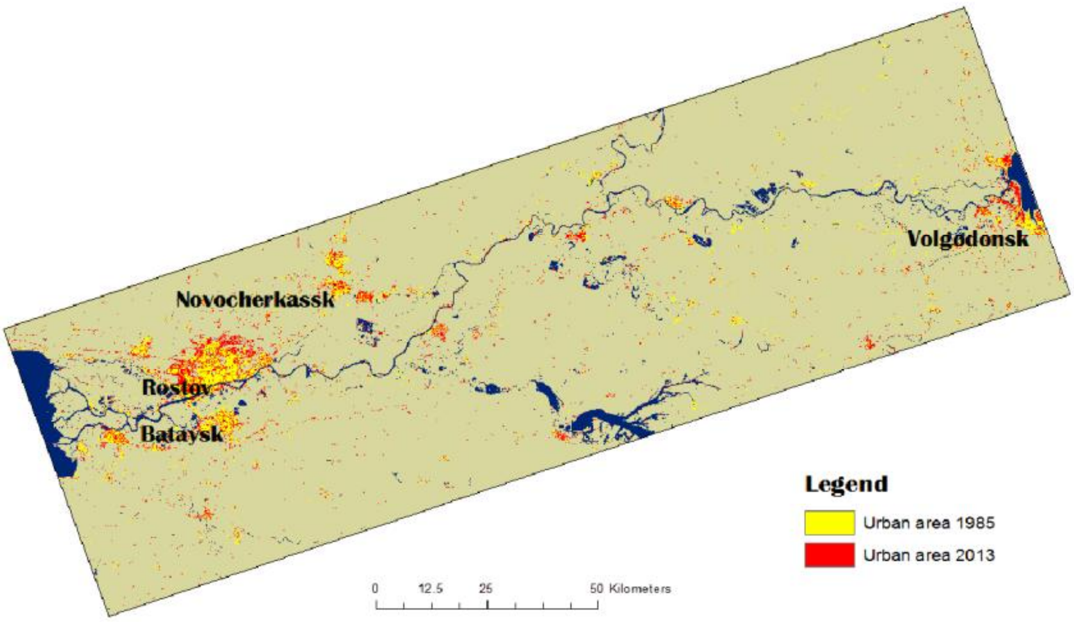

Fig. 1: Comparison of extent of urbanized areas of the Lower Don River in 1985 and 2013

The total built up area within the considered region (Fig. 1) increased by the 171 km2 from 1985 to 2013. The analysis confirmed that the urbanized areas of the large settlements (e.g. Rostov-on-Don, Bataysk, Novocherkassk, Volgodonsk) had increased significantly. It should be noted, however, that according to the regional statistical data, the population of some of the very same settlements (for instance, Volgodonsk's) has decreased (ROSSTAT 2014). The situation with small communities is different and needs more detailed analysis. The current scoping analysis shows that some small settlements became larger, while others did not change or even decreased slightly.

3.2 Flood simulation and flood-prone areas delineation

A flood routing model FLO-2D was used to define flow characteristics, delineate flood threatened areas and assess the risks. Most of the data for the model functioning and scenarios development were acquired from the "Regulations of the Tsimlyansk Reservoir Water Resources" (Rosvodresursy 2013). Detailed historical data on the Don River discharge and the rules of dam management were essential to formulate scenarios of flood events and test them. For example, based on available data a separate scenario was formulated for the 1917 flood, which one of the most severe flood events within the recorded high spring floods. Hydrograph for the 1979 flood was chosen for the verification of the developed Flo-2D model. As a result the following five scenarios were formulated for flood simulation:

1) 1917 flood (based on historical records);
2) 1979 flood (based on historical records);
3) 20-year flood (5% probability);
4) 100-year flood (1% probability);
5) 1000-year flood (0,1% probability).

Flood hazard maps were created using Mapper post-processing program, a part of the FLO-2D modeling package. One of the calculated parameters, flood intensity was selected as an indicator of flood hazard. Flood intensity is determined by maximum flow depth and maximum flow velocity (O'Brien 2010). Three flood intensity zones (high, medium, low) were differentiated to indicate flood risk. Taking the 1979 flood simulation as an example, we can see how areas with different flood intensity are distributed within the floodplain (Fig. 2).

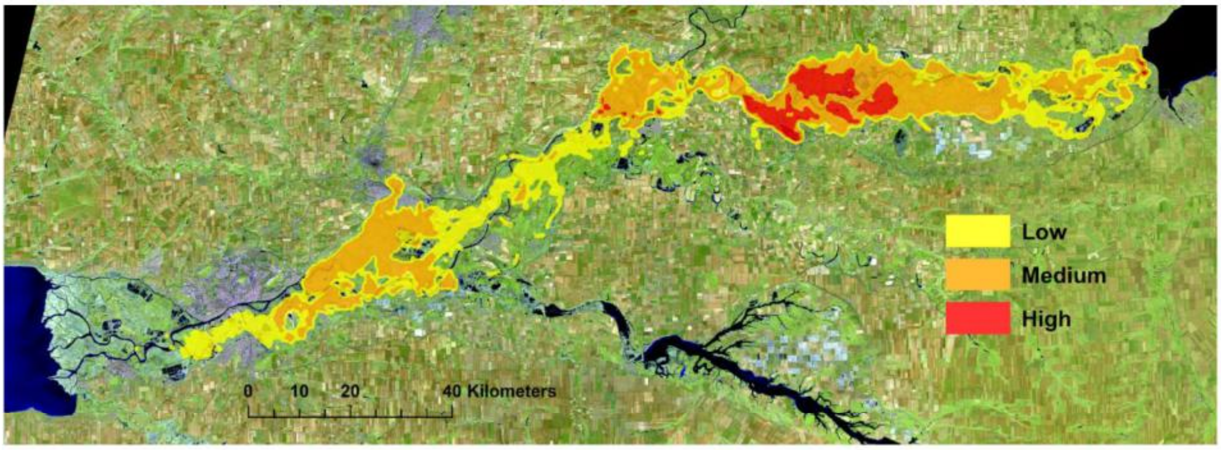

Fig. 2: 1979 flood intensity map

3.3. Flood-prone urban areas

The developed flood risk maps for the five simulated scenarios were combined with the urbanized areas identified through remote sensing for both considered years. As a result flood-prone urbanized territories for each scenario were acquired. The following Table assembles the acquired information about the urbanization growth on the floodplain for all five scenarios. The data is presented both for the totally affected area and for each flood intensity level (Table 1). The territory of the flood-prone built up areas increased from 1985 to 2013 for each scenario. Almost no urban growth within affected territory was noticed for the 1979 flood simulation, and consequently the least flood risk for the urbanized areas was observed for this the most mild scenario.

The most endangered settlements on the floodplain were identified. One of the most risky area is the floodplain to the East from Rostov-on-Don. Though no large settlements located there, many existing newly constructed villages will be submerged in all scenarios. Simulations showed that no historical large settlements are endangered, since they are located on uplands, outside the floodplain (e.g. Rostov-on-Don, Novocherkassk). However, the existing development strategy and plans of the Rostov-on-Don agglomeration suggest city expansion to the floodplain area (Lagutov and Lagutov 2011). Moreover, some of the medium size settlements which were actively developed after the construction of the Tsimlayansk dam, like Bataysk or Volgodonsk, can be characterized as unsafe areas. The territories directly downstream the Tsimlyansk dam were identified as the most risky.

Table 1: Urbanization on the flood-prone areas

Scenarios	Year	Total affected area, km^2	Flood intensity, km^2		
			Low	Medium	High
1917 flood	1985	88,92	10,22	45,07	33,63
	2013	121,17	16,38	62,43	42,36
1979 flood	1985	18,81	7,02	10,76	1,03
	2013	19,04	7,85	10,18	1,01
20-year flood	1985	64,15	14,58	38,27	11,30
	2013	84,59	22,50	51,85	10,24
100-year flood	1985	80,28	11,46	44,71	24,11
	2013	107,74	15,82	63,45	28,47
1000-year flood	1985	92,42	9,26	42,11	41,05
	2013	126,48	14,42	59,98	52,08

4. ADDED VALUE FOR INTEGRATIVE RISK MANAGEMENT AND URBAN RESILIENCE

The Hyogo Framework for Action encourages more pro-active, holistic approach in disaster management. The present research is supporting implementation of various actions during pre-disaster phase by defining potentially flood-prone areas in areas of active infrastructure development. Better understanding of communities' risks, vulnerabilities, and recovery capacities must get more attention by local governments, developers, various organizations and population. It is widely recognized that investments in pre-disaster activities, instead of the post-disaster recovery phase, can pay off in the future, because of reduced risk exposure, and local communities' preparedness and minimizing potential damages. However, the Hyogo Framework for Action also stresses the lack of financial support for disaster risk reduction. The presented research might help to address this issue by demonstrating potential use of various freely available resources and tools. All remotely sensed data was acquired through the U.S. Geological Survey website, in particular EarthExplorer and USGS Global Visualization Viewer (GloVis) online tools. The flood modelling was also conducted using the free modelling package FLO-2D. Abundance of available disaster-focused innovative tools should be demonstrated to relevant users and communities in need. The application of relevant geospatial and information and communication technologies, especially free and easily accessible, while being useful at all stages of disaster management cycle, can potentially play a particularly important role during the risk reduction and preparation phases.

5. CONCLUSIONS

The urban expansion to the historically inhabited floodplain areas became possible due to the construction of the high-pressure Tsimlyansk dam, however, the dam cannot guarantee safety of the newly developed infrastructure downstream and communities must be aware of the risks. The most hazardous urbanized areas within in the Lower Don floodplain with highest flood hazard risk were defined, by simulating flood intensity (based on the flow depth and the flow velocity) for five scenarios. It was found that generally small villages on the river bank within the wide part of the floodplain would experience the most intense flood, together with the territory right under the dam. Currently most of the large historical cities lie within the safe uplands, however, some newly built settlements are situated at the of the low left bank as well as planned city district of Rostov-on-Don, which might be submerged in case of severe flood. The results acquired through this research might be of interest not only to local stakeholders (urban planners, local population), but also to a broader research community. Information about the flood-prone areas of the Lower Don River floodplain can be used for better regional planning and urban development as well as improving regional early warning systems.

6. REFERENCES

Brecht, H., Deichmann, U. and Wang, H.G. (2013). *A global urban risk index*, World Bank.

EM-DAT: Emergency Events Database (2016). *International Disaster Database,* Brussels, Belgium: Universite Catholique de Louvain. Accessed June 25, 2016. URL: http://www.emdat.be/

EU (2007). *Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (Text with EEA relevance,.* Official Journal of the European Union.

FLO-2D (2016). *Flood routing model.* Accessed June 25, 2016. URL: http://www.flo-2d.com/

Lagutov, V. and Lagutov, V. (2011). The Azov ecosystem: resources and threats. In Lagutov, V. (Ed.), *Environmental Security in Watersheds: The Sea of Azov,* pp. 3-62, Springer, Netherlands.

O'Brien, J. (2010). *Guidelines for applying the FLO-2D model to the Central Valley floodplain evaluation delineation program,* Nutrioso, AZ. FLO-2D/Riada Engineering, Inc.

ROSSTAT (2014). *Численность населения Ростовской области на 1 января 2014 года* [The population of the Rostov region on January 1, 2014]. Territorial authority Federal State Statistics Service of the Rostov region.

Rosvodresursy (2013). *Правила использования водных ресурсов Цимлянского водохранилища* [Regulations of the Tsimlyansk Reservoir Water Resources].