Planning of mitigation measures for climate resilient urban drainage systems

Janet Roosimägi[1], Ivar Annus[1], Nils Kändler[1], Murel Truu[1], Anatoli Vassiljev[1], Katrin Kaur[1]

[1] *Department of Civil Engineering and Architecture, Tallinn University of Technology, Ehitajate tee 5 19086 Tallinn, Estonia*

**Corresponding author email: janet.roosimagi@taltech.ee*

Highlights

- An integrated planning ensures higher resilience of the cities to face extreme weather events
- Resilience analysis needs to take into account conflicts of land use interest in urban areas
- EWL enables the urban planner to analyse flood risk areas and plan for mitigation measures

Introduction

Awareness of the negative impacts of extreme weather events in cities has exponentially increased over the last decades as reflected by the exponential growth in the number of scientific articles published about urban resilience and resilient cities (Meerow and Newell, 2019). The trend is similar to the changes where people live – nearly three quarters of Europeans already live in urban settlements (Eurostat, 2021) and by 2050 the number is expected to raise to 80% (Eurostat, 2020). As most of the population, assets and economic activities are concentrated to urban areas, it is crucial to find climate change adaption and mitigation strategies for the cities and towns (European Environment Agency, 2020). European countries have started to tackle the challenge by assessing fluvial flood risks. Such flood risk maps derived for different scenarios are publicly available and widely applied in planning processes. On the other hand much higher number of cities around Europe are affected by the pluvial flood risks (Tapia et al, 2017; Guerreiro et al, 2018). Therefore, there is a severe need to analyse the pluvial flooding related risks and support the planning of the mitigation measures. These tasks can be addressed through planning support systems (PSS) that help to improve the resilience of urban areas and water systems through simplifying the visualization and analyses of the spatial data about the flood prone areas and related spatial, technical and social factors. Over the years several PSS have been developed concentrating for example on integration of nature based solutions (NBS) (Bush & Doyon, 2019; La Rosa & Pappalardo, 2020; Simperler et al., 2020) and urban storm water management (Bach et al., 2020; Zeng et al., 2021).

A novel PSS called Extreme Weather Layer (EWL) has been developed in the Interreg BSR NOAH project (https://sub.samk.fi/projects/noah/) that connects the storm water system hydraulic model with urban planning. The tool allows to firstly visualize the areas and properties contributing in the urban runoff, secondly present the most flood sensitive districts and thirdly rank the contributing areas on the basis of the flood volume and duration. The objective of the present study is to propose an upgraded version of EWL which enables to plan flood mitigation measures. The developed methodology encounters hydraulics, flood risks, land use and ownership and is tested in a pilot site in Haapsalu, Estonia.

Methodology

The methodology presented in Figure 1 is based on the EWL planning tool that combines the UDS digital twin with the GIS system, enabling one to analyse the urban areas causing and suffering flood risk. The areas are presented in a traffic light manner (i.e. green indicates low flood risk, yellow moderate flood risk and red severe flood risk).

Urban planning is always related to finding the optimal solution between property owners' or developers' ambitions. In terms of pluvial flood mitigation, the planning is expected to look beyond which technical solution provides the best flood risk reduction – it is also necessary to consider the property ownership, land use and other constraints. One way to find the optimal places for the flood risk mitigation is to analyse the system performance while changing the settings in the hydraulic model one catchment at a time. This procedure is time consuming and more importantly the results are not always applicable because of the availability of free urban space and its ownership. Therefore, in this study a concept how to analyse nearby areas related to the flooding and to detect the factors that increase and locations that can be used to decrease the flooding risk was analysed. USEPA SWMM modelling software was used to detect the conduits that are 90-100% filled during the rainfall event. In addition, information on cadastral units was added to the flood risk maps, which can be used to assess the location of potential mitigation measures as well as the construction of new buildings.

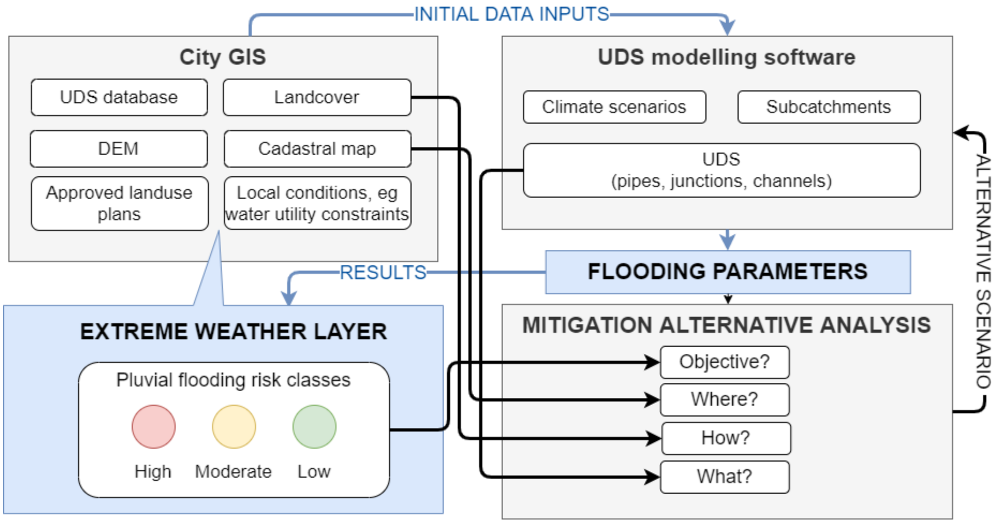

Figure 1. Flow chart of the proposed methodology to analyse the flood mitigation measures in urban areas.

The results of the EWL are used to detect the areas that are under flooding risk. Information from the cadastral maps is used to define the ownership of different properties. The municipality or state owns usually just a small fracture of the urban area. This limits the potential areas where to apply flood mitigation measures being grey, green, blue or combined solutions. Land use maps indicate how and what kind of measures can be implemented. After the primary selection the UDS modelling software can be used to analyse the impact of the proposed mitigation measures during different rainfall events.

Results and discussion

The results presented in this study are obtained by applying the methodology to a real catchment located in Haapsalu, Estonia. The length of the coastline, moderate ground elevation, ageing drainage systems, bottlenecks in pipelines, ditches with adverse slopes all contribute to pluvial flooding. The area of the sub-catchments is 13.5 ha, of which approximately 55.6% (7.5 ha) is impermeable. Almost 81% of the pilot area is privately owned, municipality owns 7% and state 11% of the land.

Figure 2 presents the EWL static flooding maps in case of future climate scenario RCP8.5. Flooding areas with 90-100% filled conduits and cadastral information enable to specify and analyse different mitigation measures. It is evident that the flooding event presented in Figure 2 is caused by the insufficient capacity of the pipeline upstream of the pilot area. The peak flow in case of the extreme weather event is too large and will cause severe flooding risk in the surrounding area (indicted with red in Figure 2). Flooding will affect surrounding buildings and therefore pose additional risk to properties and public health. In order to cut the peak flow it is necessary to implement on-ground (e.g. Kändler et al, 2019) or underground (e.g. Kändler et al, 2020) solutions dependent on the land use, available space and ownership.

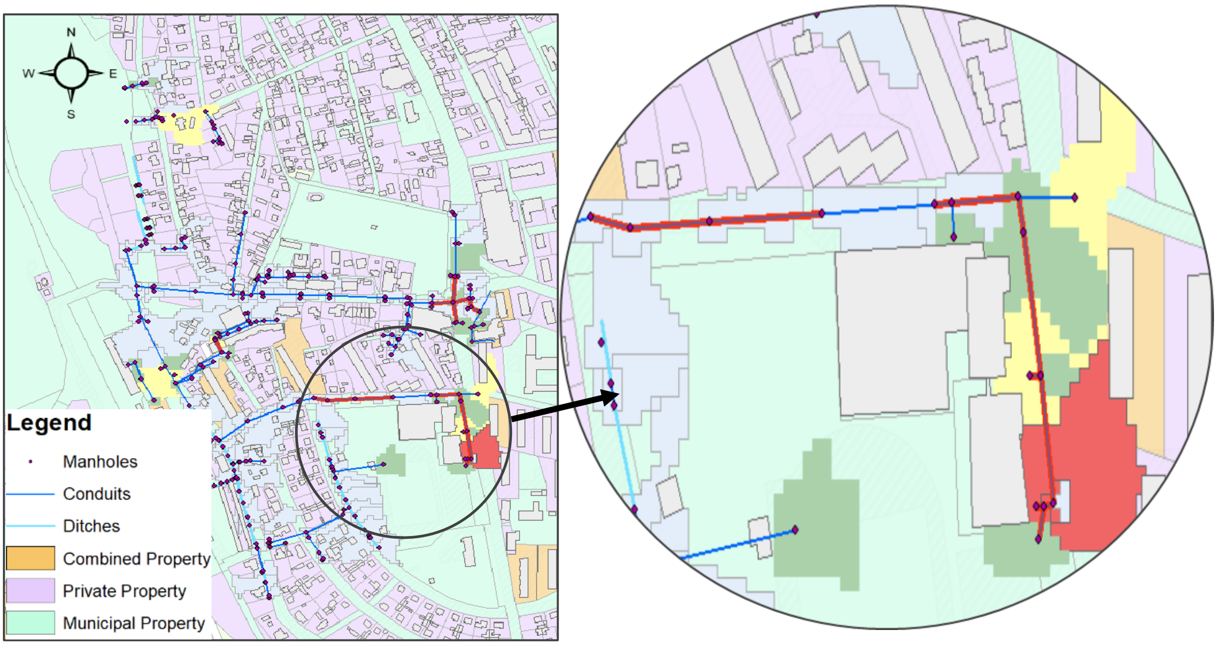

Figure 2. Flooding risk areas and 90-100% filled pipes. The colours of the sub-catchments indicate the risk levels: green – low risk level; yellow – moderate risk level; red – high risk level; light blue – no risk.

Conclusions and future work

The methodology presented in this study aims to identify how and where to plan mitigation measures, taking into account the pluvial flood maps generated by EWL, including information on hydraulics, flood risks, land use and ownership. In the future work the planning tool will be coupled with UDS development strategies to find feasible mitigation measures to reduce pluvial flooding. In addition, the tool will be used to analyse the impact of different technical solutions to the reduction of pluvial flood risks in case of different extreme weather events.

References

Bach, P. M., Kuller, M., McCarthy, D. T., and Deletic, A. (2020). A spatial planning-support system for generating decentralised urban stormwater management schemes. Science of the Total Environment, 726, 138282. https://doi.org/10.1016/j.scitotenv.2020.138282.

Bush, J., and Doyon, A. (2019). Building urban resilience with nature-based solutions: How can urban planning contribute? Cities, 95, 102483. https://doi.org/10.1016/j.cities.2019.102483.

European Environment Agency. (2020). "Urban Adaptation in Europe: How Cities and Towns Respond to Climate Change." Publication 12/2020. European Environment Agency. https://www.eea.europa.eu/publications/urban-adaptation-in-europe.

Eurostat. (2020). Sustainable Development in the European Union — Monitoring Report on Progress towards the SDGs in an EU Context — 2020 Edition. https://ec.europa.eu/eurostat/web/products-statistical-books/-/ks-02-20-202.

Eurostat. (2021). "Distribution of Population by Degree of Urbanisation, Dwelling Type and Income Group." 2021. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ilc_lvho01&lang=en.

Guerreiro, S.B., Dawson, R.J., Kilsby, C., Lewis, E., Ford, A. (2018). Future Heat-Waves, Droughts and Floods in 571 European Cities. Environmental Research Letters 13 (3). https://doi.org/10.1088/1748-9326/aaaad3.

Kändler, N., Annus, I., Vassiljev, A., Puust, R. (2019). Peak flow reduction from small catchments using smart inlets. Urban Water Journal, 17(7), 577-586. https://doi.org/10.1080/1573062X.2019.1611888

Kändler, N.; Annus, I.; Vassiljev, A.; Puust, R. (2020). Real time controlled sustainable urban drainage systems in dense urban areas. Journal of Water Supply Research and Technology—AQUA, 69 (3), 238−247. 10.2166/aqua.2019.083

La Rosa, D. & Pappalardo, V. (2020). Planning for spatial equity - A performance based approach for sustainable urban drainage systems. Sustainable Cities and Society, 53, 101885. https://doi.org/10.1016/j.scs.2019.101885.

Meerow, S. and Newell, J.P. (2019). Urban resilience for whom, what, when, where, and why? Urban Geography, 40(3), 309–329. https://doi.org/10.1080/02723638.2016.1206395.

Simperler, L., Himmelbauer, P., Ertl, T., and Stoeglehner, G. (2020). Prioritization of stormwater management sites in urban areas. Journal of Environmental Management, 265, 110507. https://doi.org/10.1016/j.jenvman.2020.110507.

Tapia et al. (2017). Profiling urban vulnerabilities to climate change: An indicator-based vulnerability assessment for European cities. Ecological Indicators, 78, 142-155.

Zeng, Z., Yuan, X., Liang, J., and Li, Y. (2021). Designing and implementing an SWMM-based web service framework to provide decision support for real-time urban stormwater management. Environmental Modelling and Software, 135, 104887. https://doi.org/10.1016/j.envsoft.2020.104887.