

Fluvial flood inundation mapping: hydraulic versus GIS-based Height Above the Nearest Drainage model

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Abstract:

Fluvial flooding happens at such situations when the water level in a river rises and exceeds the capacity of its banks, which causes that the water is split over onto the adjacent floodplain. Fluvial floods can be divided into riverine and flash floods. Main difference between them is that riverine floods are usually caused by long-term rainfall or snowmelt and affect larger areas while flash floods are caused by short and intense rainfall, which quickly increases the volume of water in watercourses affecting spatially smaller areas. In the past decades, the negative effects of climate and land cover changes have amplified the flood hazard, in particular, by changing the magnitude and frequency of floods. Therefore, finding a reliable, cost-effective, and detailed modeling procedure for fluvial flood inundation mapping is required. There are different approaches that can be used for flood inundation modeling purposes. One of the most common is the hydrologic-hydraulic approach. Hydrologic/rainfall-runoff part aims at determining the design discharges while the hydraulic part is used for computing the flood extents, flow depths or velocities. On the other hand, a representative of GIS-based methods is the Height Above the Nearest Drainage (HAND) model. The primary input for the HAND model is the digital elevation model (DEM) based on which it computes the relative height of any land surface cell with respect to the watercourse bottom cell that it drains into (Nobre et al., 2011). The HAND model is then used to generate the flow depths. The aim of this study is to compare the performance of hydraulic and HAND modeling approaches for generating the flood extents and flow depths. The study area was represented by a 3.1 km river section of the Gidra River, which is located in the upper part of the Gidra River Basin (western Slovakia). The modeled river section has a bed slope of 0.0186 m/m and is without any tributary.

As for the hydrologic modeling procedure, we first applied the STORAGE rainfall generator (De Luca and Petroselli, 2021) to synthetically generate rainfall timeseries using the annual maxima of daily rainfall (1990-2020) measured at the Častá rainfall station. Then, the COSMO4SUB hydrological model (Grimaldi et al., 2021) was used to determine the design peak discharges for return periods of 100-years and 1000-years. These flood discharges were calculated for the starting cross section of the hydraulic simulation. Regarding the hydraulic modeling approach, we performed the 1D steady-state flow using the MIKE+ model from DHI. The 1D model was chosen because it is less time-consuming and demanding for input data, thus more comparable with the HAND model. Necessary input data were created for hydraulic modeling, such as cross sections with average distance of 73 m and land use/land cover map with the Manning's *n* roughness coefficients assigned based on Chow (1959). Basic source data for their processing were the orthophotos with 15 cm resolution and the Light Detection and Ranging (LiDAR) DEM with 1 m resolution, which can be freely downloaded from the websites of the Geodetic and Cartographic Institute, Bratislava. The HAND model procedure required basically two primary inputs: LiDAR DEM and a raster of modeled river. The modeled river centerline had to be manually modified to fit the channel in the LiDAR DEM. The HAND tool (Topography Tools toolbox) in ArcGIS 10.2.2, which also performs the flow direction and flow accumulation analysis, was used for creating the HAND model. The flow depths from the HAND model were calculated using the raster calculator, where the maximum flow depths obtained from the hydraulically modeled Q_{100} and Q_{1000} flood scenarios were set as the maximum flow depths also in the respective HAND models.

Based on the results of hydrologic modeling, the estimated flood discharges of Q_{100} and Q_{1000} were 70.2 m³/s and 135.0 m³/s, respectively. The flood extent of the MIKE-based model for Q_{100} was 110,142 m² while for the HAND-based model, it was 95,961 m². Regarding the Q_{1000} flood scenario, the flood extents for the MIKE-based model and HAND-based model were 159,333 m² and 133,827 m², respectively. The flood extent for Q_{100} modeled by the HAND model was smaller by 12.9% than that of the hydraulic model while for Q_{1000} flood scenario, it was smaller by 16.0%.

Differences in flow depths ranged from -2.15 to 1.46 m in case of the Q_{100} flood scenario while for the Q_{1000} flood scenario, the range of flow depths was from -2.75 to 1.90 m. Spatial distribution of modeled flow depths for the studied flood scenarios with the use of MIKE+ and HAND models is shown in Figure 1.

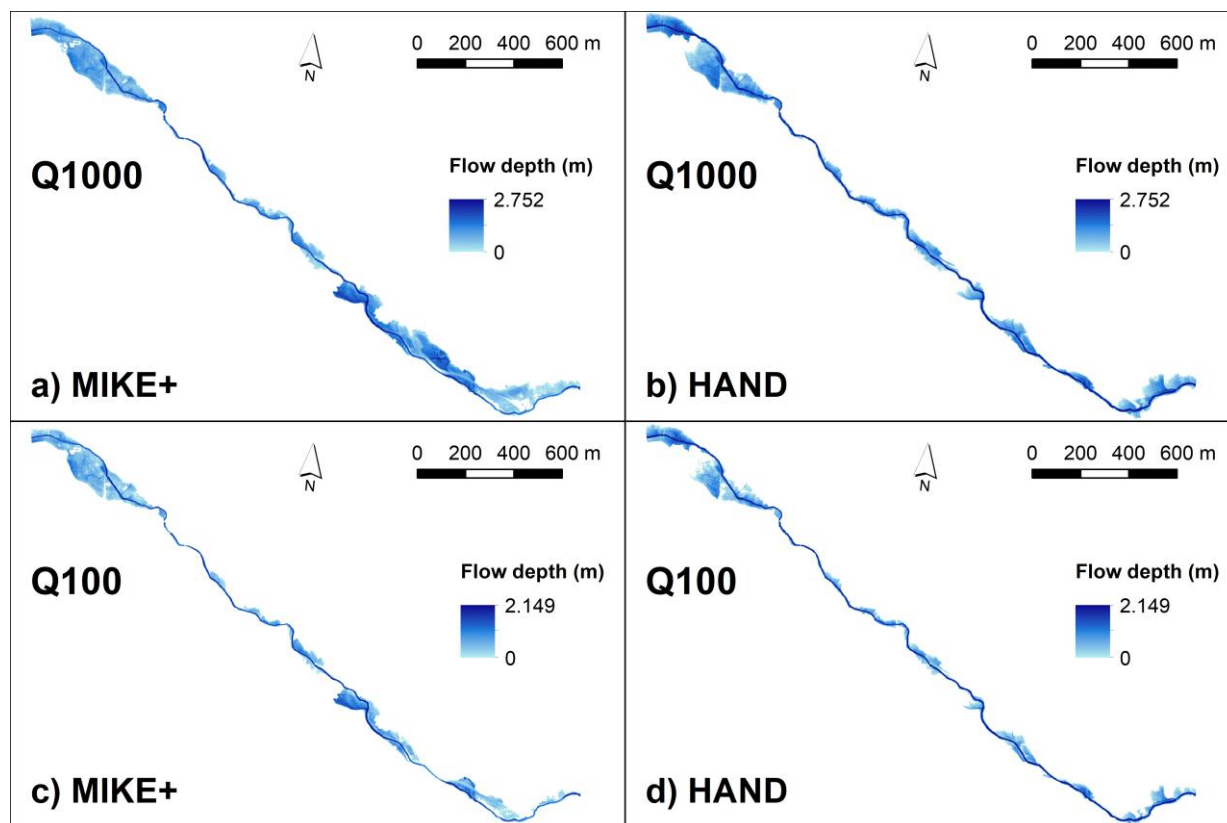


Figure 1. Comparison of modeled flow depths for the studied Gidra river section by: a) MIKE+ model for Q_{1000} flood scenario, b) HAND model for Q_{1000} flood scenario, c) MIKE+ model for Q_{100} flood scenario, and d) HAND model for Q_{100} flood scenario.

Following the calculated Bias values of 0.871 and 0.840 for the Q_{100} and Q_{1000} flood scenarios respectively, we can state that the flood extents of HAND models underestimated the hydraulically modelled flood extents by 1D model. The Recall metric of HAND-derived flood extents resulted in values of 0.702 and 0.714 for the Q_{100} and Q_{1000} flood scenarios, respectively. In case of the Q_{100} flood scenario, the Overall Accuracy had the value of 0.944 while in case of the Q_{1000} flood scenario, it had the value of 0.929. The calculation of quantitative metrics for the accuracy assessment of the modeled flow depths suggests in this case that the quality of HAND-based models is comparable to the quality of 1D hydraulic models, which makes them suitable for flood inundation analysis. Due to lower data and computational demands, the usefulness of the HAND model is seen mainly in operational practice when rapid and preliminary flood inundation mapping is needed. Future research can be directed to the application of the HAND model to other types of terrain, than the valley type used in this study, to further investigate the usefulness of the HAND model, for example, in flat terrains where the drainage points might be more difficult to determine even with high-resolution DEM.

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