GeoDPA'24
23.-25. April 2024
in Oldenburg
International Conference on Geoinformation Data, Processing and Applications

A new Approach to Hazard Analysis of Heavy Rainfall Events based on the Catchment Area of the Ahr River

Thomas Krauß, Veronika Gstaiger
German Aerospace Center (DLR), Earth Observation Center (EOC), Münchener Str. 20, 82234 Oberpfaffenhofen, Germany

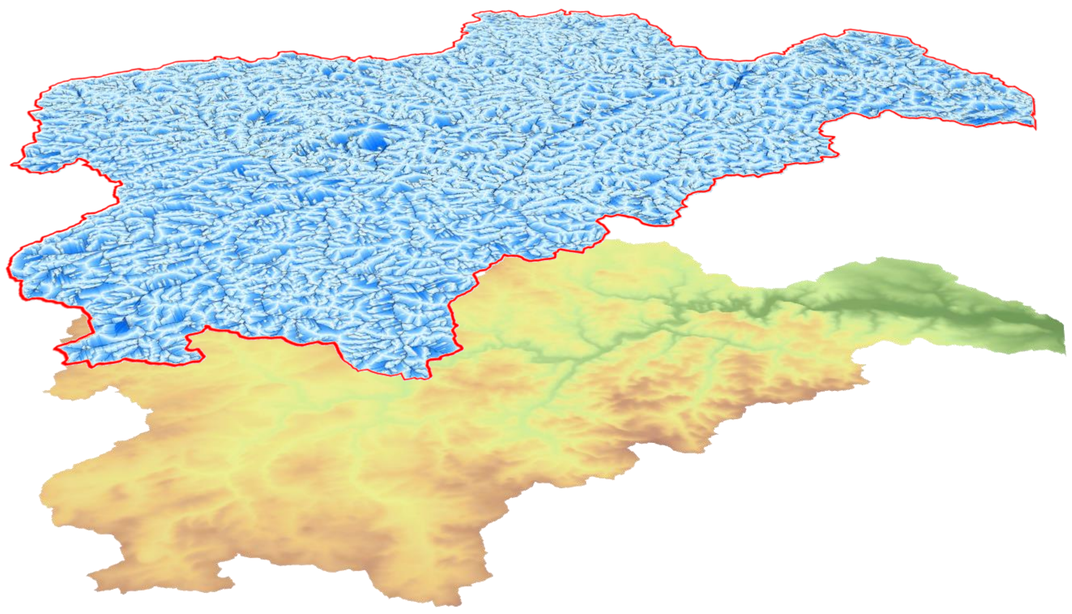
Introduction

In the summer of 2021, heavy rainfall over North Rhine-Westphalia and Rhineland-Palatinate led to catastrophic flooding, especially in the Ahr valley. This study presents the results of a method calculating the extent of a possible flood with a small amount of input data. The results are finally compared with aerial photographs and a flood line reconstructed from them. The method was developed to be as transferable as possible – especially to regions with insufficient data for detailed modelling and compared with the reference data of this flood event as an example.

Damages along the river Ahr from 16 July 2021

Method

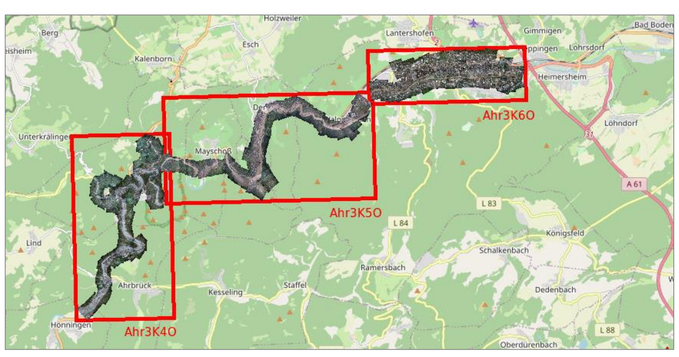
The method is based only on a digital elevation model (DEM) that contains the entire catchment of an area to be processed. In a first step, local depressions are filled in the DEM to calculate runoff directions. Based on the runoff direction map, an initial rainfall amount is iteratively distributed according to these directions and cumulated. The result is a runoff map containing the amount of water flowing through each pixel. For the positions of every 10th volume value in this runoff map, the cross-section in the DEM across the flow direction is derived and filled with the volume at that position. The result is a filled profile with water extent and water level height. If one connects and fills all these derived flood profiles to a flood level DEM and intersects this with the DEM, one obtains the flooded areas together with the estimated water levels of the flood.



Catchment area of the river Ahr with runoff map and SRTM DEM

Reference Data

For calibration and validation a flood mask generated by the ZKI (Center for Satellite Based Crisis Information) of DLR was used. This mask shows a semi-automatically derived flood extend that is based on aerial imagery acquired on July 16, 2021 by the 4k camera system of DLR.

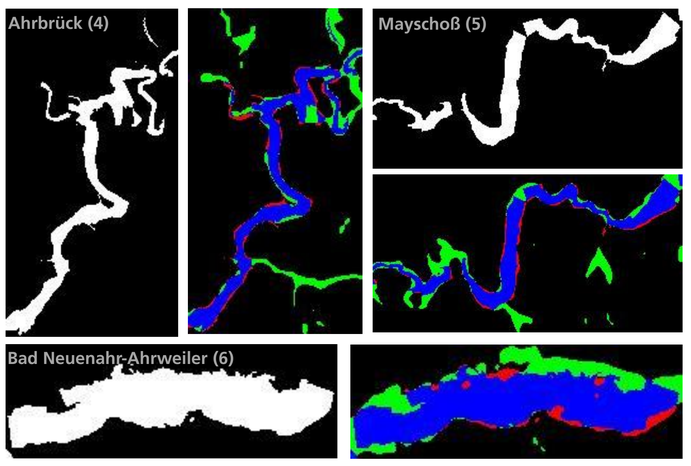


Test areas:
- Ahrbrück (Ahr3K4O)
- Mayschoß (Ahr3K5O) and
- Bad Neuenahr-Ahrweiler (Ahr3K6O)

Calibration and Validation

To calibrate the described method we simulated flood maps for rain amounts of 0.001 to 1.0 mm/m² and calculated the IoU (intersection over union) of these maps with the manually derived ZKI flood map for three test-regions.
During the heavy rain event of 13/14 July 2021, rainfall amounts of 100 to 150 mm/m² were measured in the catchment area of the Ahr. We can therefore calibrate our undrained simulation value of 0.05 mm/m² to a mean value of 125 mm/m² measured in real terms. The input rainfall value for the simulation is thus calibrated to

$$R_{sim} = 0.05/125 * R_{real} = 0.0004 * R_{real}$$



Final flood masks (Rsim=0.05 mm/m²), white: manually derived flood-mask, colored: overlay of manual mask (red), simulated flood mask (green), intersection (blue), test areas: left: Ahrbrück, right: Mayschoß, bottom: Bad Neuenahr-Ahrweiler

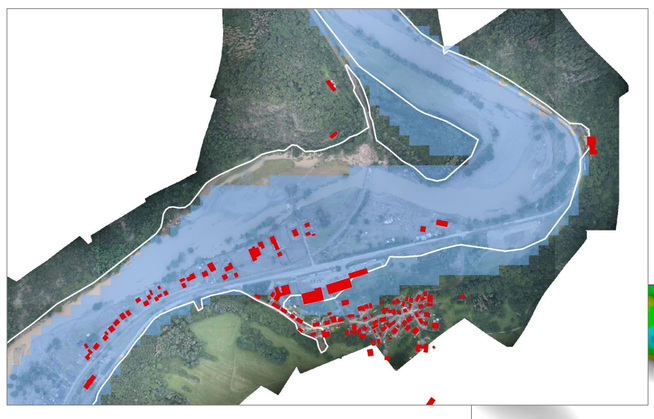
Area	mm_rain	ZKI	SimFlood	InterSec	Union	IoU
4	0,001	3822	3035	1431	5426	0,264
4	0,002	3822	3353	1650	5525	0,299
4	0,005	3822	2794	1993	4623	0,431
4	0,01	3822	3194	2330	4686	0,497
4	0,02	3822	4345	2786	5381	0,518
4	0,05	3822	5326	3288	5860	0,561
4	0,1	3822	6245	3573	6494	0,550
4	0,2	3822	7550	3737	7635	0,489
4	0,5	3822	9872	3806	9888	0,385
4	1.0	3822	13498	3820	13500	0,283
5	0,001	4629	3147	2454	5322	0,461
5	0,002	4629	2891	2431	5089	0,478
5	0,005	4629	3351	2758	5222	0,528
5	0,01	4629	3896	3218	5307	0,606
5	0,02	4629	5368	3645	6352	0,574
5	0,05	4629	6378	4143	6864	0,604
5	0,1	4629	7291	4442	7478	0,594
5	0,2	4629	8760	4585	8804	0,521
5	0,5	4629	12576	4629	12576	0,368
5	1.0	4629	16281	4629	16281	0,284
6	0,001	6374	1590	1433	6531	0,219
6	0,002	6374	1915	1781	6508	0,274
6	0,005	6374	2411	2272	6513	0,349
6	0,01	6374	3718	3406	6686	0,509
6	0,02	6374	5385	4578	7181	0,638
6	0,05	6374	7707	5838	8243	0,708
6	0,1	6374	8775	6209	8940	0,695
6	0,2	6374	9609	6313	9670	0,653
6	0,5	6374	10972	6374	10972	0,581
6	1.0	6374	12427	6374	12427	0,513

Results of calculated IoU for simulated rain amounts and test-areas

Results

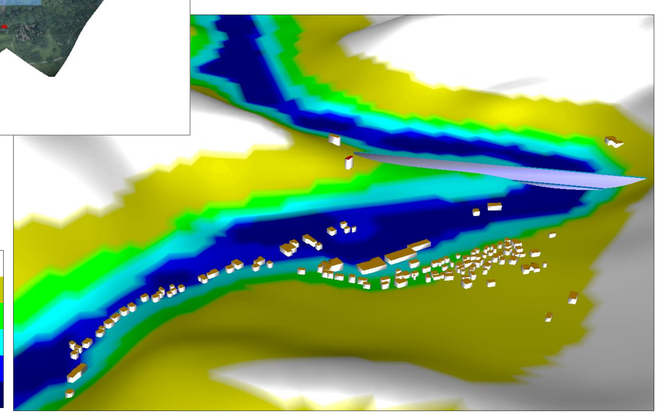
The comparison of the resulting simulated inundation masks with an assumed R_{sim} of 0.05 mm/m² to the manually extracted inundation masks show a good correlation. The IoU values are 0.56, 0.6 and 0.7 for the three test areas respectively.

A closer look at the erroneous IoU areas (green or red in the previous figure) shows missing areas in the manual reference in green (tributary streams and/or not covered by the aerial image) and DEM inaccuracies due to the 25 m SRTM DEM used for the simulation.



Aerial imagery of Ahrbrück with simulated flood mask (blue), derived flood mask by ZKI (white) and buildings (red)

3D view of derived risk map for Ahrbrück, blue walls: simulated flood levels for rainfall of 1250 and 125 mm/m²



Risk map:
For a predicted rainfall over the upstream catchment the colors represent areas covered by 10 cm or more water – for risk assessment of small rain values a more detailed DEM should be used

Conclusion

This work presents a method for rapid estimation of hazard due to heavy rainfall in areas with runoff from higher ground. Calibration of the method with a derived ground truth of the flood event in the Ahr valley in 2021 yields the input rainfall value of the simulation as 0.0004 times the estimated precipitation over the catchment in mm/m². The analysis of the resulting flood masks shows a quite good correlation with the ground truth and a good prediction of the flood hazard for most of the affected areas.