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Discussions

Brief communication: On-site data collection of damage caused by flash floods: Experiences from Braunsbach, Germany, in May/June 2016

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Abstract. Flash floods are caused by intense rainfall events and represent an insufficiently understood phenomenon in Germany. The understanding of damage caused by flash floods requires ex-post collection of relevant but yet sparsely available information for further research. Thus, on-site data collection was carried out after the flash flood event on 29 May 2016 in Braunsbach, Germany, using open source software as helpful and efficient tool for data acquisition and evaluation. The post-hoc analysis links process intensities to damage and reveals differences in damage driving factors of flash floods compared to riverine floods, indicating that also risk patterns vary among different flood types.

1 Introduction

At the end of May and beginning of June 2016, intense rainfall events in Central Europe led to severe surface water flooding and flash floods, which were partly accompanied by mud and debris flows, hitting several municipalities mainly in the south of Germany. Eleven people lost their life; infrastructure and buildings were heavily damaged. Overall, the insured losses of these events amounted to EUR 1.2 billion (GDV, 2016), an unprecedented monetary loss caused by flash floods in Germany. Especially the strong and unexpected flash flood in Braunsbach (Baden Wurttemberg) on May 29th attracted media and policymakers due to its devastating character. Braunsbach is a small village counting about 1,000 residents, located within the administrative district of Schwäbisch Hall, a region with a population count of roughly 190,000. The monetary losses for the municipality of Braunsbach were estimated to EUR 104 million, which is more than 90% of the estimated EUR 112 million of total damage in its administrative district (Landkreis Schwäbisch Hall, 2016). The catchment of the creek primarily responsible for the inundation in May 2016, the “Orlacher Bach”, is only about 6 km² and characterized by steep slopes. Heavy rainfalls in the catchment area between 18:45 and 20:00 of May 29th resulted in an estimated accumulated precipitation of 100 mm (Ziese et al., 2016) - which was revised to estimates of up to 140 mm using the method of Jacobi and Heistermann (2016) (Bronstert et al., 2016) - eventually leading to the severe flash flood and debris flow in Braunsbach. Streets along the main runoff channel were blocked by layers of debris, up to a thickness of two to three meters while

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numerous houses in the area showed severe structural damage. Given the relation of town size, event duration and catchment area, the losses were extremely high which indicates essential differences in the damaging processes of flash floods and debris flows compared to riverine floods. Due to recent severe riverine flooding in Germany, particularly in August 2002 and June 2013, the flood risk management system in Germany and the relevant legislation have been considerably improved, among others, due to the European Floods Directive (2007/60/EC) and its implementation in the Federal Water Act of 2009 (e.g. Thieken et al., 2016). However, when implementing the Floods Directive in Germany, surface water flooding and flash floods were not considered as risks of national importance and thus neglected. Yet, this assessment is currently questioned, since the destructive events of May and June 2016 have shown that research on and management of surface water flooding and flash floods need to catch up.

To obtain a better understanding of the damage processes of flash floods as well as of effective mitigation options a comprehensive damage data base that links process dynamics and intensities with damage and loss is needed, but currently not available. Therefore, an on-site damage assessment was carried out in Braunsbach between June 6th and June 9th, 2016. The data collection was done with tablet computers using an up to date, self-explaining and network based open source software called "KoBoCollect", which was developed by the Harvard Humanitarian Initiative together with the Birmingham and Women's Hospital in 2014 (kobotoolbox.org, 2016). The software is designed for quick and reliable information collection after natural disasters or in humanitarian crises. Open source software, as a method for data collection and gaining of knowledge, increasingly gains importance within the field of natural hazards (Eckle et al., 2016; Klonner et al., 2016). For instance, OpenStreetMap (OSM) and other volunteered geographic information helps to create comprehensive databases of up to date geospatial data which also can be used for natural risk assessment (Schelhorn et al., 2014; Vaz and Arsanjani, 2015; Yang et al., 2016).

The aim of this brief communication is twofold. Using the flash flood in Braunsbach as a case study, it is aimed at identifying factors that govern damage caused by flash floods. Therefore, the methods used for the ex-post damage data collection in Braunsbach and the analysis of this recently created and novel database are presented and discussed. Since "KoBoCollect" turned out to provide major advantages with regard to the duration of data acquisition, simplicity, effectiveness and in-field handling, this brief communication also aims to discuss the benefits as well as important issues of open source software and its potential for the collection and analysis of damage data collected in the field.

2 Methods

Collecting and analyzing data of structural and nonstructural damage to buildings is valuable for designing and assessing effective mitigation measures and creating damage models, which can be used to estimate potential monetary losses ex-ante. Thus, a digital survey was designed and conducted on site by a team of five researchers who investigated all buildings in Braunsbach affected by water and debris flows. The gathered information includes an estimation of a damage class ranging from D1 (no structural damage, slight nonstructural damage) to D5 (very heavy structural damage, very heavy nonstructural damage). For this classification, the scheme developed by Schwarz and Maiwald (2007) was adopted to obtain a consistent database. Further information included the address, the inundation depth at the building, visible damage caused by debris, visible contamination, the building substance and type, specific precaution measures per building, the building usage (residential, commercial, public etc.), the number of storeys and types of outbuildings, the estimated year of construction, the perceived condition of the building before the event, existing shop windows on the ground floor, a detectable cellar, the exposition (of the building) in flow direction as well as the sealing degree of the near surrounding.

The exposition in flow direction describes the exposition of building walls, corners or parts to the direction and area of the main runoff channel. In this case, a high exposition means that at least one side of the building was fully exposed to water and debris flows. A medium exposition was assumed when parts of the building were exposed, sheltered buildings are characterized by a low exposition. All variables except for the address, inundation depth, storeys and the estimated year of construction were pre-coded with the option to record open answers or NA values, resulting in a nominal-, ordinal- as well as interval-scaled data structure. All answer options are summarized in Table 1.

The survey was implemented on tablet computers with an integrated GPS function, applying the open source software "KoBoCollect" which provides a fast, systematical and standardized approach to acquire data. Further, a thermographic camera (model Testo 876, 160x120 pixels) was used to verify the estimated inundation depth through the remaining moisture in the building walls and to detect differing building materials which may be covered externally.

The data analysis was done with R 3.3.1 and QGIS 2.14.3. The preprocessed data were further used to construct a Random Forest model (RF) and a Random Generalized Linear Model (RGLM) (Breiman, 2001; Song et al., 2013), to obtain the impact of potential damage driving factors on the dependent variable "damage class". The following variables are used as predictor variables in both models: water depth, exposition in flow direction, near surrounding sealed, storeys, building substance - masonry, building substance - wood, building substance - half-timbered, shop window on ground level, building condition before event, no structural precaution, structural precaution - higher ground floor, structural precaution - different building materials and contamination visible. Additionally, the identified feature importance, that describes the impact of each predictor variable on the depending variable, was compared to the results from a Spearman's rank correlation matrix.

3 Results and discussion

The in-field work load can be estimated to roughly 10 hours in which a team of five researchers was able to survey 96 buildings in Braunsbach, for each specifying 21 variables and taking a picture. The survey is shown in table 1, providing an overview of the data types and frequency distributions.

Overall, the in-field data collection was greatly facilitated by the use of "KoBoCollect" in terms of speed, handling of the gathered data and efficiency of data processing and analysis. However, to create a uniform, unbiased database and to maintain consistency among the different team members throughout the data collection process, objective criteria for items such as the structural damage had to be defined. Therefore, careful preparations and agreements were carried out prior to the

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field trip off site as well as on site. Still, an estimation to which degree the data is biased by subjective perception is difficult, but is expected to have a minor impact. Yet, a good consistency in data collection is assumed which is explained below.

Table 1 shows the survey extent with variable names, variable characteristics and the number of recorded characteristics for all 96 buildings. Looking at the damage class, the most frequent classes are D1 and D2 with 40 and 35 cases, respectively. The post-hoc data analysis revealed that the RF and RGLM give both the highest feature importance for the damage class to "inundation depth" and "exposition (of the building) in flow direction". Here, the Mean Decrease Gini - which describes the loss in model performance when permuting the feature values - for the RF was 12.38 and 7.86, whereas the RGLM feature selection count in 100 iterations was 99 and 90, respectively. To gain more insights into variable correlations and coherences with the damage class, a Spearman's rank correlation matrix (Figure 1) was calculated. Additionally and for better interpretation, the p-values of the correlations based on t-tests for each correlation are given.

3.1 Correlation tests

The highest positive (and significant) correlations can be seen between the damage class and the exposition of the building in flow direction as well as the damage class and inundation depth with a value of both 0.64, which strongly confirm the results of the RF and RGLM. This points out that both, the exposition of the building in flow direction and the inundation depth, are strongly positively linked to the damage, what makes sense given the nature of the event and the mass of debris, water and mud flowing down the main channels within the village of Braunsbach. Further, a positive and significant correlation can be observed between the damage class and a shop window on ground level with a value of 0.22 and a p-value of 0.05. Here, a trend towards higher damage classes caused by shop windows on ground level which - in case of breaking - open debris and water paths to the inside of the building can be assumed. Yet, the results might also be affected by the fact that buildings with shop windows mainly occur along the main street and city center and are therefore located inside the main flow channels. No (obvious) precaution indicates a slightly higher probability for higher damage as well by displaying a positive correlation of 0.14 with the damage class, although the significance is relatively low (p-value 0.21). This this is in line with the negative correlation between the damage class and the "precaution measure - different building materials" of -0.18 which in fact shows a low significance (p-value 0.11) but still allows for meaningful assumptions. The building substance masonry seems to have a damage reducing effect by displaying a negative correlation of -0.11 (p-value 0.31) with the damage class whereas the building substances half-timbered and wood show slightly positive correlations with the damage, although it is not significant. Again this could be a bias in a way described above, i.e. that old half-timbered and wooden houses are mainly located in the town center where the event intensity was stronger.

However, when performing detailed analyses and correlation tests it has to be considered that the database with 96 data points is rather small and assumingly insufficient for creating representative and universal results. This fact could also explain the low significances in some of the cases discussed above. Nonetheless, it is important to point out the strong correlations in many cases of up to 0.64 (damage class and inundation depth) revealing obvious damage driving factors and showing that the data collection within the team of different researchers was consistent.

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3.2 Process intensity

Based on RF, RGLM and the correlation analysis, the two most important factors that govern the damage class, i.e. "inundation depth" and "exposition of the building in flow direction", were used to derive a so called process intensity. The computation of the process intensity was performed in a way that inundation depth and exposition in flow direction contribute equally to the resulting values. This was done by first obtaining the mean values for the lower, middle and upper 30 % percentile of the inundation depth, which ranges from 2 cm to 360 cm. In a next step, the three exposition classes (formerly coded "low", "middle" and "high") were replaced with these mean values to ensure an equal relation of values among the two variables. This enables the summation of the inundation depth and the transformed exposition value leading to the derived process intensity. Furthermore, for visualization and comparison to the spatial distribution of the damage classes a "process intensity"-map was created in QGIS (Figure 2) by applying a linear inverse distance interpolation (IDW) to the geocoded data points and only displaying the area with affected houses.

The process intensity map reveals that highly damaged buildings and strong process intensities occur along the main runoff channels of water and debris during the event. Higher damage classes were also recorded in the lower-lying town regions, where the tributaries "Orlacher Bach" and "Schlossbach" flow into the river "Kocher", since debris and water accumulated in these areas and caused severe structural damage. Most of the higher damage classes are located in high process intensity areas. Yet, especially in those areas the degree of damage differs strongly, highlighting the complexity of damage driving processes that cannot be explained by the process intensity alone. However, it becomes obvious that buildings with a high exposition in flow direction are more susceptible to severe structural damage, since the probability of heavy and large debris colliding with building walls is much higher. Yet, some neighbouring buildings can hereby benefit from shadowing effects of buildings. This means, that most of the debris can be retrained by the building with the slightly higher exposition in flow direction, thus the probability that neighbouring buildings suffer damage from debris is lowered. Further, although it is not captured by the correlation and the RF and RGLM analysis, it can be assumed that if being hit by debris, half-timbered houses are even more susceptible to structural damage than houses made of masonry and concrete due to their lower structural stability.

Hence, it is revealed that not only the water depth, which is often considered as only damage driving factor in riverine flood loss modelling (see Merz et al., 2010), but also the exposition of a building to the flow direction and susceptible building parts like e.g. shop windows seem to be risk factors in flash-flood prone regions. This result considerably differs from investigations on damage caused by riverine floods (Kreibich et al., 2009). Although no significant correlations were found, the analyses indicate that also building material (i.e. half-timbered or masonry) and structural precaution could play a role on the extent of damage and therefore offers options of damage mitigation.

4 Conclusion

The data analysis in this study resulted in important information about the impacts (damage to buildings) of the flash flood event in Braunsbach and possible damage driving factors like e.g. the exposition of the buildings, as well as options for mitigation. Besides, knowing processes of flash floods and their impacts can help to create awareness for future events and support strategic planning with regard to similar emergencies. It became clear that the damage driving as well as damage reducing factors are complex, contingent upon the surrounding and remarkably different from riverine floods. However, further investigations are needed in order to verify the results and to obtain larger databases.

To facilitate data collection in the future, the case further demonstrates the potential of mobile devices and open-source applications. In the field, the simplicity, speed, quality and handling of information using the open source application “KoBoCollect” particularly stood out as a great advantage. Even in a short time and with a small team of researchers it was possible to gather a fair amount of useful information that could be further processed and analyzed. The public availability of the software makes it a fast and ad-hoc tool for assessing different kind of questions, usable in various research fields and not only for scientific but also for private uses. However, creating consistent data given the subjective nature of estimations for variables, particularly the classification of structural damage, was a challenging task. Thus, the question should be raised whether the quality of crowdsourced information is good enough for scientific investigations and how to approach and deal with possible limitations and uncertainties. Other aspects to consider when using open source software and online storage are data security, copyright issues and accessibility. Since “KoBoCollect” by default requires an upload of collected data to a company-owned server, the data purpose and relevance should be considered beforehand to avoid potential disputes over data-ownership, rights and data-access especially with regard to sensitive information. Yet, the use of private servers is also feasible which allows for a solution to these issues.

Overall, it can be concluded that open source data collection software for mobile use has great potential as a scientific tool to generate extensive valuable data under challenging conditions. It should be especially considered in time critical research applications such as ex-post-disaster analyses, as was demonstrated by the presented case of Braunsbach.

Competing interests

The authors declare that they have no conflict of interest.

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Online resources

KoBoToolbox: http://www.kobotoolbox.org/, last access: 15 November 2016.

Unwetter-Schadensliste Landkreis Schwäbisch Hall: http://www.lrasha.de/index.php?id=302?&id=302?&no_cache=1&publish[id]=457120&publish[start]=, last access: 16 August 2016.

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Table 1: Features of 96 buildings affected by flooding in Braunsbach, Germany, recorded between 6th and 9th June 2016, and their frequency of occurrence.

Variable	Characteristics	n
Damage class	D1 (no structural damage, slight nonstructural damage)	40
	D2 (no to slight structural damage, moderate nonstructural damage)	35
	D3 (moderate structural damage, heavy nonstructural damage)	5
	D4 (heavy structural damage, very heavy nonstructural damage)	6
	D5 (very heavy structural damage, very heavy nonstructural damage)	5
	No damage	5
	NA	0
Inundation depth	"Integer value"	90
	NA	6
House type	Single-family house	47
	Apartment building	25
	Semi-detached house	3
	Terraced house	0
	NA	21
Building substance	Masonry	57
	Half-timbered	26
	Wood	9
	Concrete	2
	Steel	0
	Rubber	0
	NA	2
Building usage	Residential	59
	Commercial	8
	Combined/Mixed	21
	Public services	7
	NA	1
Near surrounding sealed	Yes	66
	Mainly yes	21
	Mainly no	8
	No	0
	NA	1
Exposition in flow direction	High	34
	Medium	35
	Low	27
	NA	0
Damage caused by debris flows	Yes	56
	No	38

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Natural Hazards and Earth System Sciences
Open Access
Discussions

	NA	2
Building condition before event	Good	45
	Medium	48
	Bad	1
	NA	2
Outbuildings present	Yes	32
	No	0
	NA	64
Type of outbuilding	Garage	11
	Carport	1
	Barn	9
	Shelter	7
	Summerhouse	1
	Greenhouse	0
	Conservatory	0
	Other	6
Number of storeys	"Integer value"	96
	NA	0
Cellar	Yes	30
	No	58
	NA	8
Estimated construction year	"Integer value"	90
	NA	6
Structural precaution	Higher ground floor	17
	Different building materials of cellar and ground floor	12
	Protection of cellar duct	3
	Other	6
	No precaution	59
	NA	4
Visible contamination	Yes	79
	No	15
	NA	2
Contamination type	Oil	4
	Chemicals	0
	Sewage	0
	Mud	79
	Other	0

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Open Access
Discussions

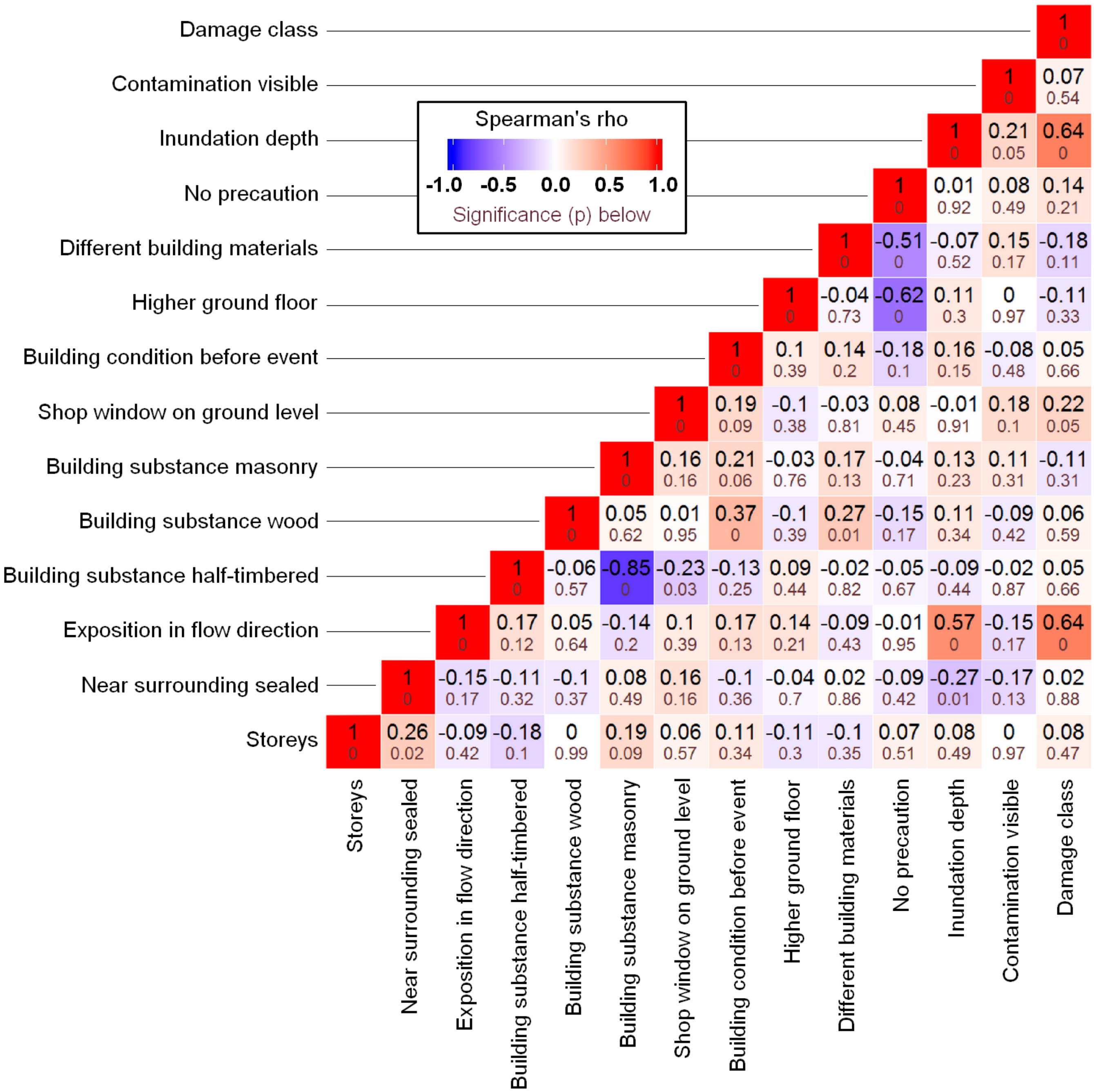

Figure 1: Spearman's rank correlation matrix and correlation significances of relevant variables (see Table 1 for a description of the variables).

5

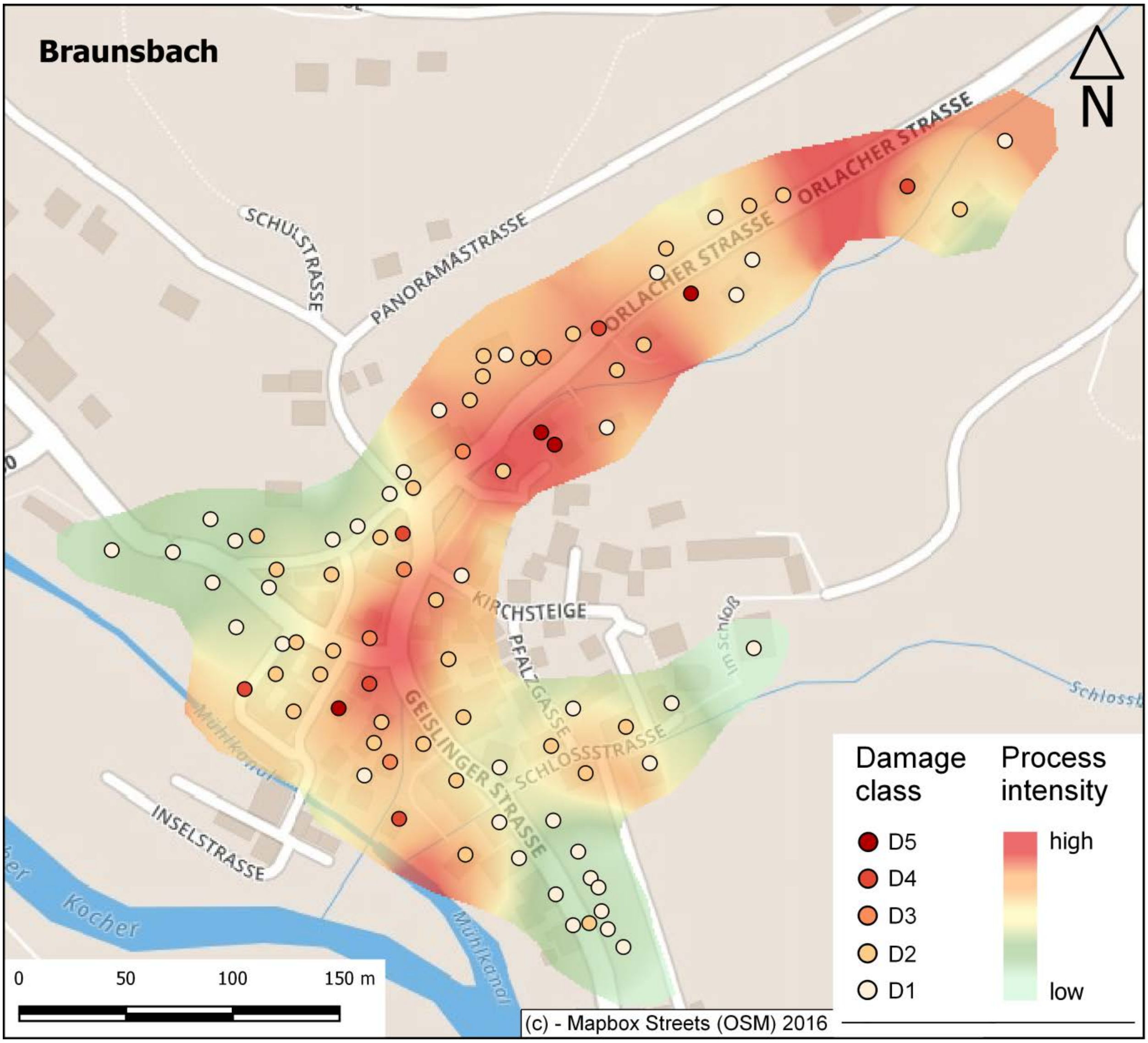

Figure 2: Map of the study area with the process intensity, which is a combination of the inundation depth at the buildings and its exposition to the flow direction (see text for further details) and the damage classes as recorded on site using the classification scheme of Schwarz and Maiwald (2007); see Table 1 for a verbal description of the damage classes.