

# Critical infrastructure cascading effects. Disaster resilience assessment for floods affecting city of Cologne and Rhein-Erft-Kreis

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## Abstract

At the case study of the city of Cologne and the neighbouring Rhein-Erft-Kreis (a county), selected resilience aspects of critical infrastructure (CI) and cascading effects are analysed concerning major river floods. Using a Geographic Information System, the applicability of the approach is demonstrated using open source software and data, augmented by manual entries. This study demonstrates the feasibility and limitations of analysing lifeline features of interest for disaster risk and emergency management such as roads, bridges and electricity supply. By highlighting interdependencies of emergency services with CI such as roads, cascading effects of interconnected paths are shown. The findings indicate that in an extreme event flood scenario over 2,000 km of roads and eight bridges will be exposed to floods in the area of the rivers Rhine and Erft. This places huge demands on disaster and emergency management institutions and people affected and limits their resiliency.

## KEYWORDS

civil contingency planning, disaster management, disaster risk, mapping of hazard and risk, reduction

## 1 | INTRODUCTION

Flood damages are increasing (Barredo, 2007; Hettiarachchi, Wasko, & Sharma, 2018; Kron, 2005; Plate, 2002; Winsemius et al., 2016), despite years of research (White, 1945), investments into flood protection and damage mitigation (in den Bäumen, Többen, & Lenzen, 2015; Thielen et al., 2016), knowledge created (Weichselgartner & Kasperson, 2010; White, Kates, & Burton, 2001) and an increasing international awareness of the importance of disaster risk reduction (United Nations, 2015). Critical infrastructure (CI) is an emerging topic of importance not only in the traditional sense of

economic damages or flood losses (in den Bäumen et al., 2015; Thielen et al., 2016). It is still underresearched (Merz, Kreibich, Schwarze, & Thielen, 2010), but important because of wide-ranging second-order (“cascading”) effects and interdependencies between water, energy, information, transport, or cyber infrastructure (Rinaldi, Peerenboom, & Kelly, 2001). At the international stage, local flood risk assessments are demanded (UN/ISDR, 2004; UNISDR, 2017a, 2017b). The concept and perspectives of resilience should be integrated into existing flood protection and flood risk management approaches (Di Baldassarre, Kemerink, Kooy, & Brandimarte, 2014). It is important therefore to analyse local risks and

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resilience traits and operationalise resilience by making CI cascading effects explicit. Spatial resilience assessment offers the tools for local and explicit place-based assessments (Cutter et al., 2008). Local assessment examples can not only help local planners and emergency management to better allocate their resources but also connect researchers and decision-makers worldwide by sharing the assessments and insights (Priest, 2019). This article contributes to such local spatial assessments by utilising open access data and tools that can be used in many other regions, too.

Cologne city is a good practice example of flood defence and flood risk; Cologne has experienced several large-scale flood events, for example, 1993 and 1995 (Merz & Thielen, 2009), with the 1995 event slightly higher yet less damage occurred, probably because of remembrance of the 1993 event (Fink, Ulbrich, & Engel, 1996; Merz et al., 2010). Afterwards, Cologne established one of the most remarkable flood defence systems in Germany with mobile flood defences, regulation, retention areas, sewage control, specific flash flood pumping stations, a flood protection centre, and a citizen NGO (Disse & Engel, 2001; Herget & Meurs, 2010; Plate, 2002). The neighbouring mixed rural and urban county “Rhein-Erft-Kreis” has not seen such extreme river floods yet, but small events keep recurring (2009, 2016). Research studies on floods in Rhein-Erft-Kreis from rivers such as the Erft are rather rare. However, there is a flood information forecasting and damage system (Gretzschel, Jüpner, Grafe, & Leiner, 2010). There is more research available on the river Rhine, which also includes substantial flood discharge and flood risk curve modelling (Apel, Thielen, Merz, & Blöschl, 2006; Merz & Thielen, 2009), comparison with other natural hazards (Grünthal et al., 2006) or vulnerability of population and infrastructure (Birkmann, Bach, & Vollmer, 2012; Welle et al., 2014). Interestingly, discharge models on the Erft river are problematic, possibly related to domination of technical river training enabling brown coal mining (Eberle, Buiteveld, Beersma, Krahe, & Wilke, 2019).

Cologne and Rhein-Erft-Kreis were selected because it is important to conduct comparative analyses in order to gain more insights about a single area and about a concept that could be transferred to other areas. Cologne city has been thoroughly researched already in respect to flood exposure, damage, vulnerability, and, to a lesser extent, on CI and extreme events as shown above. However, recent studies are missing and especially, the combination of resilience and CI has not been assessed yet in spatial comparison in this area. Research on flood risk of the Rhein-Erft-Kreis is scarce and limited to studies carried out by administrative organisations and few scientific studies (Eberle, Buiteveld, Beersma, Krahe, & Wilke, 2002; Gretzschel et al., 2010; Weerts, El Serafy, Hummel,

Dhondia, & Gerritsen, 2010; Wurms & Westrich, 2007). Rhein-Erft-Kreis is an important case too, because it is spatially interrelated with Cologne and because of interdependencies of CI and commuters. Rhein-Erft-Kreis also expects a (moderate) population growth in the coming years (BertelsmannStiftung, 2016). In addition, the region will undergo major transformations when coal mining is finally phased out in Germany and large investments will be made for transforming the region economically and socially, to enable new job markets. In a recent research project, CI resilience as a minimum supply concept (CIRmin), CI interdependencies and risk such as floods are being analysed in a transdisciplinary setting with many stakeholders from civil protection, city and county administration, CI operators, and research institutions (Fekete, Setiadi, Tzavella, Gabriel, & Rommelmann, 2018). The following insights and case study results stem from work in this project.

From this conceptual background and research requirement of the flood risk assessments in Germany as outlined above, the following Research Questions have been derived:

Main research question (RQ): How can resilience not only be conceptualised but also be analysed in a concrete setting?

1. How can resilience aspects be identified in spatial assessments?
2. How can resilience of infrastructure be identified using open data?
3. Which aspects of CI and cascading effects aggravate flood risk?

## 2 | SPATIAL ASSESSMENT OF RISK AND RESILIENCE

The following assessment utilises a place-based approach commonly used to assess risk and resilience (Cutter et al., 2008) using the case study area as an example.

### 2.1 | Case study

Cologne borders Rhein-Erft-Kreis and both are located in the western part of Germany, in the state of North-Rhine Westphalia (NRW). Cologne is one of the largest cities in Germany with just over 1 million residents, while Rhein-Erft-Kreis has almost half that number. River floods are re-occurring, with smaller floods being seasonal and quite common, while major events such as the 1993 and 1995 floods mentioned earlier recur irregularly (Merz & Thielen, 2009). Discharge values for the 1993 flood were

10,600 m<sup>3</sup>/s and for the 1995 flood 10,700 m<sup>3</sup>/s (BAFG, 2019). The 100-year return period statistical design flood value was (re-)set to 12,000 m<sup>3</sup>/s in 2002 (BAFG, 2019). While these values are used for developing the hazard models, the administrative institutions dealing with flood risk (such as the flood protection centre in Cologne) communicate gauge heights to the population and other institutions that can more directly use such flood height measures to decide evacuations or halt shipping on the Rhine river. The flood height in 1993 was 10.63 and 10.69 m in 1995 (Archive NRW, 2019). Similar flood heights occurred above 10 m before only in 1948 and 1926, but flood heights above 9 m occurred in the 1980s, 1970s, 1950s, and earlier and interestingly, there has been a gap since 2003 (Archive NRW, 2019). Major floods in Germany since then mainly occurred in other areas such as along the Elbe or Danube rivers, for example.

Roads are types of infrastructure that are important to analyse, especially when they undergo damage. However, the top value at stake is human lives, not economic damage, in the line of argumentation of this article. The river floods in this region typically have a prewarning time of around 2–3 days for the Rhine, from when the flood peak wave travels from gauges such as Maxau downstream to Cologne. Human casualties on roads are therefore unlikely by sudden onset floods, more likely by car drivers who miscalculate the flood depth and their driving skills. Roads are much more important as a CI in this case as a supporting secondary infrastructure enabling accessibility of flood affected settlement areas or points of interest such as hospitals by rescue cars. Roads are important types of cross-cutting support infrastructure for a great number of other infrastructures. A road is also an example of a resilience component: rapidity of accessibility but also rapidity of repair. Roads are key infrastructures that enable access of maintenance and repair cars and trucks to assets either flooded or damaged or those that need to be checked onsite.

## 2.2 | Data

In the following, the most extreme flood scenario available by official sources (geoportal.nrw, 2019; geoportal of the state of NRW: [www.geoportal.nrw/](http://www.geoportal.nrw/)) has been selected, because it includes the effects of failed or overtopped dikes or mobile flood defences or intrusion of ground water into old river arms. This follows the observations of White (1945) that the flood risk effects will be most severe where people are taken by surprise, residing in false perceptions of safety behind the dikes. And while it must be assumed that modern dike systems and the manifold outstanding flood preparedness measures by the city of Cologne and in

Rhein-Erft-Kreis will withstand floods below the extreme flood level, it is still useful to analyse a seemingly unrealistic extreme event. Not only for assumed higher frequencies of extreme events driven by climate change, but also for planning and training purposes of civil protection, which must take into account even failures of seemingly fail-safe solutions. And the flood scenario used is required as mandatory by the European flood directive (EC, 2007) as well and is available for all major rivers in Germany, which permits a certain comparability of results. Of course, a flood zonation extent does not resemble a real flood scenario; floods are dynamic events and not all areas mapped, as being potentially flooded will be flooded in a real event. However, for planning purposes, such a scenario, based on hydrological calculations, is better than only using previous flood extent data for example, because it allows planners to identify any place exposed for different dynamic real events.

Regarding other GIS data on infrastructure, open source data from federal and local administrative agencies' online platforms (Geo-Portal.nrw, IT NRW, 2019) and Open Street Map (OSM) were used (Figures 1–3). Using open data and software has many advantages, in this case, accessibility by fellow researchers or students wishing to follow or expand on the examples presented. Certainly, there are known limitations of open data such as completeness and subjectivity of data. Open data avoids some of the problems of data sensitivity because it is data anyone can access already. Still, caution is taken not to provide sensitive targets of major weak spots to parties with malicious intent by data aggregation and display. Hence, the choice of scale and level helps here, too, because the level selected is coarse enough to hide details. Yet, the selected county and community levels help to compare risks at a level that meets the regulatory

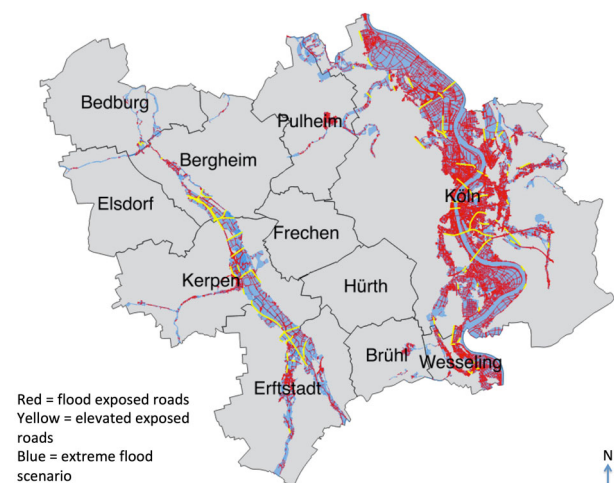
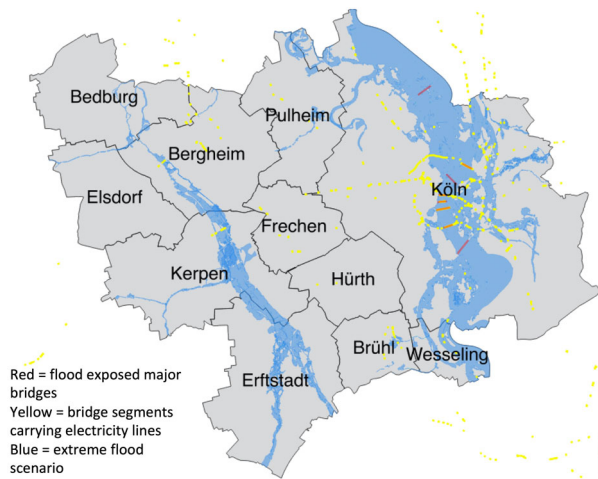
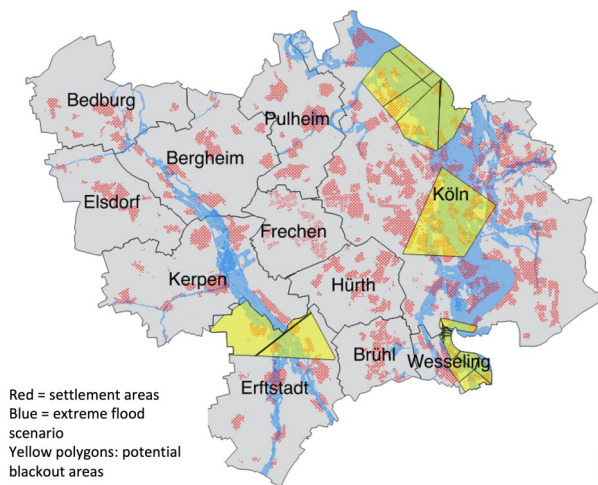


FIGURE 1 Road segments exposed to floods



**FIGURE 2** Bridges and bridge segments carrying electricity lines exposed an extreme flood scenario



**FIGURE 3** Potential blackout areas as a result of transformer stations exposed to floods

responsibility of the local authorities in the city and county governments, including their fire brigades and infrastructure operators. In Germany, the subsidiarity principle is applied, which means that communities and counties have to take administrative responsibility for flood preparedness, response and recovery first. However, because resources are often limited, especially rural communities with small populations often transfer their responsibility up to the county level, which is why the county level was selected for this study. Scale selection, conceptual approach, choice of methodology, indicators and knowledge about end user needs have been documented in past projects as well as in the current CIRmin project (Dierich, Setiadi, Tzavella, Fekete, & Neisser, 2019). CIRmin covers Cologne, Rhein-Erft-Kreis, and also includes stakeholders from other areas and therefore

enables further investigation into the usability and validity of the results presented here.

Roads have been extracted as polyline features from OSM download datasets and then clipped with the flood polygon within the administrative areas. Additional roads outside of the flood mask were also mapped. These roads are fully surrounded by flooded area, but are not flooded because of elevation. While these slightly elevated road tracks are not flooded, it can be assumed that after a longer period of floods standing in this area, the road or rail track basis could be soaked and driving restricted or halted. This happened in one of the last major floods in Germany, when the rail track of the important high-speed rail connection between Hannover and Berlin was closed for a period of 5 months (Thieken et al., 2016). These tracks were mapped manually by comparison with a detailed official topographic map in scale 1:25,000 (geoportal.nrw.de). We have selected transformer station point data from OSM data and calculated Voronoi polygons in the GIS, Voronoi polygons allow mapping the area of equal distances between points.

### 2.3 | Assessment methodology

The methodology consists of a spatial assessment using an open source Geographic Information System. Spatial assessments are used in place-based approaches of resilience assessment (Cutter et al., 2008). Resilience is used here according to the definition of UNISDR as quoted here:

“The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.” UNISDR, Feb 2, 2017.

As emphasised in this definition, resilience can be addressed “through risk management.” Therefore, resilience in this article is understood as “an ability of a system.” In this case, the risk managers or emergency staff such as fire brigades and rescue teams by the cities and municipalities in Cologne and Rhein-Erft-Kreis. This ability to act “in a timely and efficient manner” is analysed here according to how infrastructure enables their resilience. Infrastructure is critical to a country (US Government, 1996) or any system (Fekete, 2011) such as risk and emergency managers at the county level in this case. CI impairs its resilience when destroyed or interrupted. Therefore, resilience of infrastructure lifelines such as roads, bridges or electricity is key to the functioning of risk and emergency managers and staff. From the range of conceptual resilience components (Bruneau et al., 2003), redundancy is analysed in this article. As a

cascading effect (Robert, 2004) related to infrastructure interdependencies (Rinaldi et al., 2001), electricity blackout areas (Vaiman et al., 2012) are also analysed.

## 2.4 | Results

As a result of the spatial assessment, the total length of road segments potentially exposed to floods sums up to 2,203,073 m, or about 2,203 km (Figure 1). The additional mapping of bordering and flood enclosed road and rail bases sums up to about 73 km. The resilience of emergency management teams is impaired by such exposure, when roads cannot be used to access service areas such as hospitals or people's homes. And while roads are very networked in this area, the range of redundant access ways is diminished by such large-scale flooding. For emergency teams, such information is important during a flood to know where to navigate or find alternative, redundant, roads (Tzavella, Fekete, & Fiedrich, 2017). For risk managers, such maps can be used before a crisis to plan routes as well as location allocations of new service stations (Fekete, Neisser, Tzavella, & Hetkämper, 2019).

Bridges are connectors between areas that otherwise would be cut-off or would be reliant on ferries and other transporting ships. The severe floods at the Rhine or Erft river could flood not only the bridge tracks but their bases and access roads, aggravating transport and accessibility problems that already exist for the road network at specific, critical nodes. In addition, bridges often also carry other infrastructure lines such as gas, water, telecom or electricity lines. In Figure 2, it can be seen that the Erft crossing has numerous smaller bridges, but also Cologne has eight large bridges over the Rhine. Bridges or their segments highlighted in yellow display those bridges carrying electricity cables, representing geographical interdependency hubs (Rinaldi et al., 2001). The eight bridges over the Rhine further permit analysis of redundancies as an example of a resilience component; four bridges are for highways, two for city roads, and two for rail. Especially, rail therefore only would have one redundant bridge or crossing over the Rhine, in case one bridge would be closed.

Electricity blackouts and resulting failures and losses are common phenomena in the wake of floods (Jonkman & Kelman, 2005; Thieken et al., 2016). However, it is difficult to map potential exposure zones of the electricity grid without knowledge of the grid operators, who are cautious in sharing such sensitive information. In a former study (Fekete, Tzavella, & Baumhauer, 2017), we conducted a similar assessment with transformer substations and the operator feedback of this analysis was supportive as a good rough estimation. Figure 3 depicts

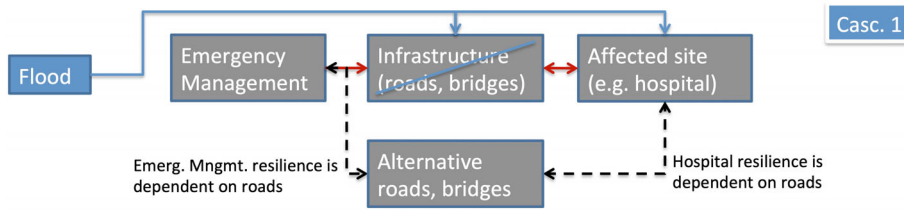
potential power failure areas between transformer stations potentially exposed to floods. However, an even greater blackout area is conceivable, if the area until the next nonexposed transformer station is fully taken into consideration. This area, which additionally affects settlement areas as well as service stations of fire brigades or any other CI by failure of power is a cascading affect, aggravating the situation in an area already flooded.

The overall result is a picture of several interdependencies and cascading effects between the flood as a stressor and affected sites and infrastructure assets. Figure 4 summarises the previous results (see also Figures 1–3) in a conceptual illustration of the different cascading paths. The first cascade illustrates the interdependencies (i.e., mutual dependencies) between emergency management and roads, as well as affected objects such as hospitals and roads. Floods can affect all of them and roads are an example of a lifeline infrastructure that is a networking and connecting asset. The resilience of both emergency management and hospitals is dependent on the accessibility of the road network. When impaired, this network still provides redundancies in many cases, by alternative routes. However, of course, there also exist single access routes without redundancies (for a detailed analysis, see Tzavella et al., 2017). The second lower part of Figure 4 illustrates two additional cascades. The second cascade is triggered by an additional failure of the electricity grid due to the flood. This is a one-sided dependency of emergency management (telecommunications etc.) and hospital (elevators, registration system etc.) on electricity. Failure of supporting electricity severely impairs the resilience of both systems. The third cascade is an example, where the mean time to repair as a resilience measure of CI is affected. Electricity transformer substations and many other objects of the grid need repair after floods or access to remove them before the flood arrives. Repair teams need accessible roads and therefore, the flooded roads from Cascade 1 can also result in another Cascade 3 delaying recovery of the electricity grid.

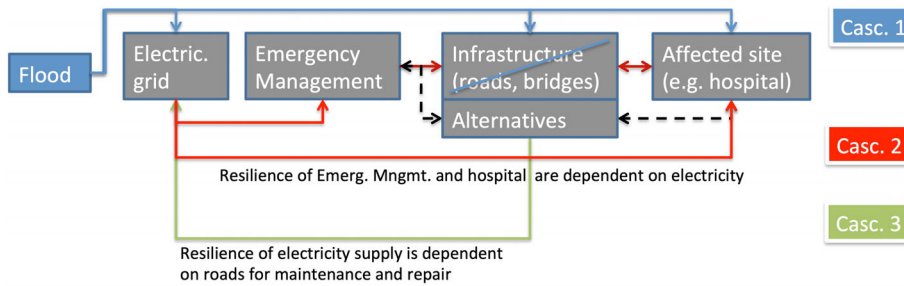
## 3 | DISCUSSION OF THE RESEARCH QUESTIONS AND LIMITS OF THE APPROACH

The spatial assessment sequence demonstration illustrates possible answers to the research questions outlined in this article and shows applications to the main RQ: How can resilience not only be conceptualised but also be analysed in a concrete setting? In answering specifically RQ1, How can resilience aspects be identified in spatial assessments?, the previous sections have shown

### 1) Interdependencies with road infrastructure



### 2) Additional dependency on electricity



that a whole sequence of a comprehensive risk management approach can be analysed using spatial data, even with data that is only openly accessible, with all the constraints (completeness, correctness, liability) known to open data, but also with all the benefits (accessibility, transferability, user participation, continuous improvement). The demonstration example certainly contains a number of shortcomings, such as limitation to examples out of a range of many more possible ways to analyse exposure, or vulnerability. Also, many assumptions such as the extreme flood scenario can be disputed by specialists in their fields such as hydrological modelling or flood protection or else. And because the data set does not completely represent current reality, the results are only usable for academic demonstration purposes, not for planning yet. However, the main ambition is to identify a methodology that is interdisciplinary, covers a whole suite of risk and resilience components and allows integration of different types and layers of data to enable combination and comparison. GIS and spatial assessment offer this and provide overviews based on digitised data but can easily be complemented with other maps and satellite or aerial imagery that permit validation and continuous monitoring based on visual documentations of real existing situations before, during and after floods.

Regarding RQ2, how can resilience of infrastructure be identified using open data? The examples in the assessments show that certain aspects can also help in interpreting resilience components such as redundancies (of bridges, road segments or areas with electric power). This is a major constraint, when using open data: this data are not reliable; there are many gaps and what

**FIGURE 4** Conceptual illustration of cascading paths due to floods

might look like a low number of objects could in fact just be a mapping gap. In this case, local knowledge, additional expert judgement or simply, the use of available topographic maps can help. However, because open source data are continuously being improved in quality and quantity and because other data are not available as a result of many reasons (sensitivity of data for instance), it is important to pursue research on open source data. Therefore, the results presented above were described as exemplary, and are for demonstration purposes to indicate what can (already) be achieved by using them. The added value of this study is to demonstrate the feasibility of the assessment, while at the same time being scientific in also outlining the shortcomings. For planners in the area, the information on the length of road segments potentially flooded as well as number of hospitals, supermarkets or humans exposed is also already an important information to guide future resource planning for rescue teams, flood defence and roads to navigate for fire brigades (Dierich et al., 2019). Another component of resilience (Bruneau et al., 2003), rapidity (of reaction of emergency management), is also related to mapping road segments potentially flooded, as well as bridges or rail tracks. The interruption of roads already slows down rapidity and in other studies, we have shown how routing analyses, even through flooded roads, can help to identify changes in rapidity (Tzavella et al., 2017). Other studies have also demonstrated how resilience can be measured for roads and transportation through flooded segments and how rapidity can be increased by adding just one more redundancy (Murdock, de Bruijn, & Gersonius, 2018). This usage of rapidity as a resilience measure is

also connected to repair or maintenance teams needing roads to access flooded or potentially flooded assets. Mean time to repair or recovery (MTTR) (Cao, Kumar, Lahiri, Li, & Putzolu, 2006; Kullstam, 1981) are also known key elements of CI and help to bridge this study with a focus on emergency management and civil protection to other CI assessment more focused on technical or physical aspects only.

This also relates to the last RQ3: Which aspects of CI and cascading effects aggravate flood risk? MTTR is one aspect, availability of CI is another in general, and especially the cascading effects in how one CI can be a key element in a whole rescue activity chain has been one demonstration focus of this study. Figures 1–4 show how physical assets such as roads, bridges, or electricity assets are potentially exposed, therefore adding a cascading step to human settlements already exposed and potentially widening the area needing support from emergency management and repair teams. The following sequences show two examples of cascading paths presented above (all items directly affected by the flood are underlined>):

1. Multiple flood cascading Path 1 (supporting infrastructure failure path): Flood -> bridges -> roads -> rescue cars -> hospital.
2. Multiple flood cascading Path 2 (secondary hazard triggered): Flood -> electricity -> human settlements and hospitals.

The topic of cascades is very much linked to the topic of interdependencies. And as one hallmark but also a major constraint of spatial assessments, the interdependency type of geographical overlap (Rinaldi et al., 2001) is the most feasible to analyse using spatial data. Other types of interdependencies (logical, cyber, physical) are all possible to integrate into GIS, when additional data would be made available and, it is possible to locate it to a point, line or polygon object. However, CIs can definitely be mapped and cascading interrelations between hazard, vulnerable groups of people, objects and resilience be conceptualised.

## 4 | CONCLUSION

This article shows implications of resilience for flood risk management and research. From the breadth of implications, it is shown that resilience can be integrated into existing risk concepts and components for analysis. CI is presented as a crosscutting topic that is only at the start of being assessed by resilience concepts and components for flood risk. Moreover, this study shows ways for operationalising the resilience concept in combination

with the topic of CI by spatial assessments using GIS. The assessment presented is directed towards the needs of disaster and emergency management; especially in fields where planning and therefore, risk assessments, are necessary or developing.

Open data and big data are recent topics in many scientific fields and this study also shows which sources and data types can be utilised to analyse a case study area in the western part of Germany. Limitations of the approach are also discussed, such as choice of variables, data type, scale and resolution, data quality and others. Demonstrating feasibility and possible pitfalls is important to guide and convince decision makers of the potential of using spatial and open data. While this might appear state of the art since the introduction of GIS, it must be stated that the same is true for resilience, which has been used by researchers in the same field since at least the 1970s (Alexander, 2013) and has only in recent years become an academic and practitioner trend phenomenon. As for the practitioners on the ground in the case study area, we know from cooperating with them in a current research project, CIRmin, that planning is hardly based on spatial risk information, and when so, is often still conducted by pen and paper. As a start, it is important to present planners with a stepwise approach as a guideline on how to combine more conceptual guidelines on risk management steps (FMIG, 2011) with concrete data sources and discussion of feasibility and limitations, as presented in this article.

This study is both a conceptual suggestion for integrating the topics and concepts of flood risk with resilience and CI and is also a case study demonstration. For future research, especially the integration and explicit placing of different types and terms for cascading effects into a disaster time line concept will be useful. Up to now, studies on cascades or chains of events or pathways often overlap without being aware of this. Or they are duplications or are missing out on certain phases of the disaster time line. And while studies on transformation research and global change are mushrooming, qualitative and quantitative approaches are often hardly integrative, but rather are kept segregated. The applied spatial approach presented here as well as a mediating stance on resilience can help bridging interdisciplinary gaps.

As an application beyond case study area users, it should be explored how results from local case studies on flood risk and resilience can be reported to international audiences. Options are provided for the field of Disaster Risk Reduction by the Sendai Framework process, for example, by the Sendai monitor, where indicators on disaster mortality and damage can be reported for whole countries. Case study results can also be reported to the Global Assessment Report (UNDRR, 2019) collecting

evidence on methodologies, concepts and disaster numbers worldwide. Urban disaster resilience is another field, supported also by UNDRR (formerly, UNISDR) but also private foundations and many others that is currently burgeoning.

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## CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

## DATA AVAILABILITY STATEMENT

These data were derived from the following resources available in the public domain: [http://www.archive.nrw.de/kommunalarchive/kommunalarchive\\_i-1/k/Koeln/InformationenUndService/AllgemeineInformationen/ZurKoelnerStadtgeschichte\\_Teil2.php](http://www.archive.nrw.de/kommunalarchive/kommunalarchive_i-1/k/Koeln/InformationenUndService/AllgemeineInformationen/ZurKoelnerStadtgeschichte_Teil2.php); [http://undine.bafg.de/rhein/pegel/rhein\\_pegel\\_koeln.html](http://undine.bafg.de/rhein/pegel/rhein_pegel_koeln.html); <https://www.geoportal.nrw>; <https://www.it.nrw/kommunalprofile-82197>; <https://www.unisdr.org/we/inform/gar>; <https://www.unisdr.org/we/inform/terminology>.

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