Nat Hazards (2018) 91:S29–S57
https://doi.org/10.1007/s11069-017-3102-1

ORIGINAL PAPER

Opportunities provided by geographic information systems and volunteered geographic information for a timely emergency response during flood events in Cologne, Germany

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Received: 26 October 2016 / Accepted: 31 October 2017 / Published online: 10 November 2017

Abstract The occurrence of disasters such as extreme flooding in urban environments has severe consequences, not only on the human population but also on critical infrastructures such as the road networks, which are of vital importance for everyday living and particularly for emergency response. In this article, our main goal is to present-conceptually and in praxis-a model that could be used from the emergency responders for timely and efficient emergency management and response in an urban complex environment. For the city of Cologne in Germany, we aim to indicate possible ways to decrease the emergency response time during an extreme flood scenario through the development of an accessibility indicator, which consists of different components. Therefore, we will investigate the opportunities that occur, in a flood risk scenario, from the use of geographic information in different forms such as Volunteered Geographic Information (VGI) and open-source data in an ArcGIS environment, to increase urban resilience through the decreasing emergency response time. We will focus on network analysis for the fire brigades (first acting emergency responders) during a flood scenario to calculate their emergency response ranges and emergency response routes through flooded road networks, for the assistance of the possibly affected hospitals, refugee homes and fire brigades, which can be flooded. At the end of the paper, we suggest that the vulnerable community of the refugees could be taken into consideration as a new source of VGI, as an additional component that would lead to the decrease in the emergency response time. The geo-located information that could be provided by the refugee community can be very useful in emergency situations, such as those examined in this article where timely information can be forwarded to the proper authorities for a more focused and timely emergency response, increasing the resilience of the urban population and their community.

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Keywords Emergency management · Flood · Network analysis · Civil protection · Urban resilience · Critical infrastructures · Volunteered geographic information

1 Introduction and conceptual definition of the problem

Over the past few years, an increasing number of disasters caused by natural hazards have been observed and have drawn attention to environmental risks and their potential impact, guiding scientists to more focused research. In particular, there have been approaches targeted at improving community resilience, i.e. the capacity to resist, change or adapt to obtain a new framework for tracing a pattern in the occurrence of disasters (Norris et al. 2008).

The disaster risk management (DRM) framework through extensive risk analyses provides important means for the improvement of resilience and the mitigation of the impact of natural disasters (Baharin et al. 2009). One of the essential steps of risk analysis is to answer the question "What can go wrong?" (Kaplan and Garrick 1981). Relevant failure or damage scenarios can be identified in urban environments. After disastrous events and emergencies occurring in an urban environment apart from the population also, Critical Infrastructures (CI) are affected. CI are for instance, water, energy and transport lifelines such as roads. The knowledge regarding the vulnerability of CI plays a key role in the prevention, mitigation and the gathering of the consequences that disasters and emergencies have, especially in urban areas. Various interdependencies exist amongst critical infrastructures and are therefore relevant, not only in sustaining the day-to-day functioning of the urban centres, but also because not understanding the dynamics of their interplay may result in ineffective response and poor coordination between decision makers and disaster managers before, during and after a disaster (Baloye and Palamuleni 2016; Comes and Van de Walles 2014; Faturechi and Miller-Hooks 2015).

The development of spatial technologies has been driven by the need for better and easier decision-making (Mansor et al. 2004). Decision makers have used technology in making numerous tasks easier, and recently it has also being used in helping cities become more informed, more prepared and thus more resilient (GAR 2015). Emergency managers include strong spatial components in assessing the potential impact of a hazard or in identifying the best evacuation routes during disasters (Cova 1999). In dealing with extreme events such as floods or earthquakes, many of the critical problems that arise are inherently spatial. Spatial problems cover issues related to the extent of the disaster, on-site crisis, number of people in need with exact location, etc. Among other sources, the people at risk can provide such spatial information. People experiencing disasters may still be able to share messages and locations on different platforms, voluntarily supplying information regarding the affected areas via online social media (Twitter, Facebook, and mobile applications such as WhatsApp), collaborative platforms, or in situ and mobile sensors (Goodchild and Glennon 2010; Albuquerque et al. 2015; Resch 2013) such as the GPS-enabled devices (Middleton et al. 2014). Such information is crowdsourced, i.e. the so-called Volunteered Geographic Information (VGI), and can provide timely updates for estimating the disaster severity (De Longueville et al. 2010; Zook et al. 2010) when no other resources of timely information are available. For this study and in this article, we define as VGI (Volunteered Geographic Information) all the voluntarily exchangeable information that includes any geographic and spatial information, provided from the population (before and during a risk scenario) and is available through different VGI platforms (OpenStreetMap, social media platforms, mobile applications, etc.)

With the advances of information communication technologies, it is critical to improve the efficiency and accuracy of emergency management systems through modern data processing techniques (Xu et al. 2015) and new sources of data such as VGI. The resilience of a community, specifically in an urban environment, is enhanced by timely response and rescue which can save human lives (Crutchfield 2010). Timely emergency management and response require the right information in a short time frame in order to save lives and property at risk. Geospatial applications (including GIS) are extensively used at each emergency management stage. Geographic Information Systems (GIS) models and simulation capabilities are used to practice response and recovery plans during non-disaster times. They help decision makers understand near real-time possibilities during an event and to optimise emergency services delivery. GIS are ideal for developing frameworks that assist emergency managers. They are appropriate tools for different agencies for the analysis and the visual display of important information before and during an emergency event. One of ICLEI's (International Council for Local Environmental Initiatives) sessions with the title "Advancing urban resilience through the strategic use of spatial data" gave scientists an overview of how the use of GIS has transformed itself into an infrastructure essential for urban resilience.

In general, it is known that extreme weather events (Keller and Atzl 2014) and floods (Arkell and Darch 2006) have a serious impact on several CIs but specifically on the road network. The road network is one of the most important CIs for fire and rescue services. Research on transport network reliability and resilience to disasters demonstrates that a disruption to particular nodes of that network can have different degrees of disruption (Sakakibara et al. 2004) resulting in adversely affected travel on the degraded network. Therefore, it is essential to start to use road network analysis methods (Gil and Steinbach 2008) by adopting vulnerability and criticality assessments with geographic context (Jenelius et al. 2006). The vulnerability of the road network under disruptions that cover large areas (flooding, forest fires, etc.), in contrast to single link failures, indicates that the impacts of this kind of events are largely determined by the population concentration. More precisely, the travel demand within, as well as into and out of the disrupted area itself has greater influence, while the density of the road network has a smaller influence (Jenelius 2010). More recent examples of disasters, such as Hurricane Sandy in 2012, have also shown the importance of finding alternative transport routes when, for example, the subways are flooded. Meanwhile, large amounts of such collected spatial information can be updated and utilised in addition to conventional authoritative data (Adger 2006).

1.1 Conceptual steps and motivation for the development of the accessibility indicator through GIS

Prerequisites for taking right decisions when carrying out different tasks in different situations is the access to complete, credible and timely information about geographical objects and several factors. In a well-mapped urban area such as Cologne city, it is very important for the time effectiveness of emergency response activities, the responders to have up-to-date data, such as updated road network enriched with car speed and population density areas. The most up-to-date data that the emergency responders can have in hand before and specifically during a crisis (always depending on the type of crisis) are data that can be derived and utilised from open sources or even be produced voluntarily on site from the people in need.

In Fekete et al. (2016), the aim was to indicate for the city of Cologne, the need for more research and consideration of spatial distribution of shelters, their location within hazard zones and their dependence on emergency infrastructure services that might be affected by a flood or blackout themselves. Using this as a starting point, in this article and in the frames of an extreme flood scenario, we present the opportunities provided from the combination of GIS using authoritative OS data and VGI for a timely emergency response through the development of the accessibility indicator in the urban environment of Cologne.

The accessibility indicator, presented in this article for the emergency responders and for an extreme flood risk scenario, consists of the following components:

Preparedness: Situational analysis

Component A: Exposure assessment of the population of Cologne to flood

Component B: Exposure assessments of the CI, such as road network, fire brigades, hospitals and other critical points of interest including vulnerable population such as the refugee homes

Response

Component C: Optimised routing and response time analysis before and during a flood

Component D: VGI of different sources and forms for identification of level of damage and prioritization of the emergency response

Motivation for components A and B In Apel et al. (2004), it is mentioned that is important to identify significant sources of risk and to obtain a scenario that is representative for the risk situation under study. Hence, flooding, which is typical example for Germany, is selected as a risk scenario, as presented in this article, for the area of Cologne, since river floods and flash floods are common. In Rawls and Turnquist (2006), it is also mentioned that information on the level of damage caused by the disastrous event is needed and that each resource (e.g. police, fire fighters, rescue parties, medical assistance) responds with a different level of mitigation depending on the disaster effect (e.g. building collapse, fire, flood, power loss). Exposure and vulnerability assessments to specific risks through GIS provide information that is tied to a location or area. The information can be in regard to the number of people who are actually affected and the level of damage of some CIs. The information can be in regard to the amount of people that are actually affected and the level of damage of some CI's. By overlaying additional geospatial datasets, the system can reveal patterns in the data that might go unidentified without this mapping functionality. For instance, in an emergency response management plan, information on population density alone improves exposure information and indicates possible hot spots for evacuation. Moreover, the combination of travel time and population exposure data gives an indication of the number of people who are potentially unable to evacuate in the available time (Fraser et al. 2014). Unable to evacuate could be the disabled, the elderly who are of limited movement abilities and those with communication issues like the refugee community.

Using spatial risk assessments, Keller and Atzl (2014) address road and route interruptions due to extreme weather events. In most disasters, like hurricanes, earthquakes, terrorist attacks, some CIs (such as road and railway networks, schools, hospitals, shelters) become unstable, inaccessible, overused or even destroyed, and as a consequence, emergency responders cannot rely on the use of these existing network infrastructures and may deploy and use their own or look for other solutions. Such disasters as the aforementioned can cause immense damage to the infrastructure resulting in adversely affected travel on the degraded network (Balijepalli and Oppong 2014). Thus, there is a strong interdependency between the conditions of the road network (level of functionality) with the time of the emergency response. There are many studies using methodologies based on accessibility measures (Taylor et al. 2006) that analyse the vulnerability in sparse regional networks. Others are based on network topological measures (Latora and Marchiori 2001) and some use methods that consider the importance of the links and analyse the impact of complete disconnection between the networks (Jenelius et al. 2006). Furthermore, Jenelius (2010) studied the vulnerability of the road network under area-covering disruptions (such as flooding, heavy snowfall or forest fires). It was found that in contrast to single link failures, the impacts of these kinds of events are largely determined by the population concentration, more precisely the travel demand within, in and out of the disrupted area itself, while the density of the road network is of small influence (Fekete et al. 2016). Moreover, in real-life situations, after a disastrous event, roads may not always become completely unusable, but they may still be partially available for use (e.g. travelling through a flooded road network with flood depth allowing for drive).

Motivation for component C Routing has become indispensable as a key infrastructure service for navigating fire and rescue cars (Fekete et al. 2016). While there are many applications for routing, specific crisis situations are still under-researched. Network analyses, e.g. routing calculations and calculations of isochrones (response time analysis/service range analysis), do not account for routing through a road closure, such as due to a flood that allows routing up to a specific depth level. A flooded road network is considered as a barrier (a not usable road network) and up to now has been excluded from the routing calculations as in Eckle et al. (2016), King (2016). Specifically Eckle et al. (2016) used OS data from the OpenStreetMap project and through an online platform; they provided routing calculations for shortest paths to be followed in case of flooding. Nevertheless, routing through a flooded road network is not calculated because the flooded road network is considered as a barrier, forcing the algorithm to suggest routing paths outside these barriers. Nevertheless, routing through a flooded road network is not calculated because the flooded road network is considered as a barrier, forcing the algorithm to suggest routing paths outside these barriers. The same was also observed by King (2016) who used a network analysis for routing calculations to create an algorithm, which takes road closures into consideration. Road closures caused by crashes, bushfires, landslides and flooding are integrated as a barrier for the routing calculations of the shortest paths through an iterative network analysis model. de la Torre et al. (2012) through an extensive literature review on disaster relief routing, which also includes reviewing articles regarding transport of goods after and during a disastrous event, addresses disaster relief transportation and distribution problems. Specifically, it states that Shen et al. (2008), Mete and Zabinsky (2010), Rawls and Turnquist (2006), Van Hentenryck et al. (2010) model uncertainty in travel time. In these articles, travel times are scenario dependent and revealed in the second stage. To our knowledge, only Salmerón and Apte (2010) address delayed travel time through flooded road network in a US ground in a strategic planning and resource allocation for humanitarian aid in future cyclic, natural disasters. As identified, in most of the above-mentioned literature, routing calculations were conducted, without taking the delayed travel times through a flooded road network into consideration. Specifically, this paper on developing an accessibility indicator for timely, effective emergency responses, takes routing through a flooded road network into consideration. Furthermore, to our best knowledge, service range calculations have not taken the flooded road network as a hindrance for travel into consideration, and in this article we will research that, too.

Motivation for component D Rapid evaluations of hazardous events are needed for efficient response both in emergency management and in financial compensation and reconstruction planning. Estimates of monetary loss to be expected in a certain hazard scenario can be provided by damage models (Fohringer et al. 2015).

An emergency management plan is carried out with datasets and information that is currently available. Therefore, the prioritization areas of response, routing and service range calculations might be outdated (depending on frequency of updates of the emergency plans) or even not valid (e.g. increasingly roundabout traffics and traffic calming, change of traffic flow direction). VGI is proving to be valuable where traditional sources of fundamental spatial information do not exist or are not publicly accessible. A big portion of such collected spatial information can be updated and utilised in addition to the conventional authoritative data (Adger 2006) in several VGI platforms such as OpenStreetMap (OSM), etc., specifically, in densely populated urban environments where sources of large and credible amounts of data in, between, and after cascading effects such as extreme flood scenarios. Fohringer et al. (2015) mentioned that information provided by citizens via the internet can improve the information basis for disaster response after natural disasters (Doris et al. 2013; Poser and Dransch 2010).

Some other data derived from VGI information (such as twitter messages and photos of the affected areas collected from users) that can be used in extreme flood scenarios and can be derived from VGI information, are GPS water level near real-time measurements. Volunteered Geographic Information (VGI), which is a rather new means of improving the coverage of monitored areas, is able to supply supplementary information, and therefore it can enrich a spatial decision support system for emergency management with valuable information. Specifically in crisis situations, such as after the earthquake of Nepal in 2015, a timely information regarding the road network connectivity (i.e. whether a road segment is still accessible after a disaster or not) is very valuable for decision makers since this type of information can be commonly observed and is critical for planning rescue routes (Hu and Janowicz 2015).

For instance, Herfort et al. (2015) examined the spatial relation between location-based social media and flood events. Their results show that tweets, which are geographically closer to flood-affected areas, contain more useful information capable of improving situational awareness than others. Therefore, at the end of our paper, we suggest a new VGI source that could be an additional element to be taken into consideration for the emergency response management for the area of Cologne and regarding the extreme flood scenario examined. Furthermore, we also explain why this new source of VGI has the potential and the means to provide quick and reliable information to the emergency responders, assisting their own rescue but we also give a brief insight for the disadvantages of the implementation of such information in an emergency management framework.

1.2 Research questions and overview of the article

With authoritative data, open-source (OS) and volunteered geographic data (Gillespi et al. 2016), we aim to enhance the resilience of the urban area of Cologne in Germany. This enhancement will be achieved by providing information to improve the emergency response, in the means of time, for flooded hospitals and refugee homes (accommodation facilities provided by the city) taking also into account the delayed travel time of fire trucks through a flooded road network. Finally, we argue that, the knowledge about increased flood risk and accessibility challenges with exact additional time demands, which is combined with geographic information (GI) that can voluntarily be provided from the community of the refugees at risk, can be a valuable information source for the first line emergency responders.

We mainly proceed with our study using up-to-date OS data so as to investigate the opportunities that are provided through GIS regarding the:

(a) Assessment of the exposure of the vulnerable population of Cologne including the refugee community (refugee homes), the hospitals, and the fire brigades themselves.
(b) Combination of authoritative OS data with VGI for improving the emergency response in matters of time.
(c) Enhancement of the emergency response time through flooded road networks, aiming to an increase in the urban resilience by adding more knowledge to the Standard of Cover (SOC) plan of the fire brigades of Cologne.

To do so, the following research questions and sub-questions are proposed:

RQ1 To which degree can the road network, the population, the hospitals, the refugee homes and the fire brigades be affected from an extreme flood scenario of low probability in Cologne, Germany?

RQ2 What are the opportunities that are provided from GIS through the use of specific ArcGIS tools for enhancing the emergency response time during an extreme flood?

RQ3 Can authoritative OS data of low quality be combined in a GIS environment for improving the emergency response in an efficient way?

RQ3.1 Which are the quickest routes to be followed before and during an extreme flood scenario by the fire fighters that will lead to a time- and cost-effective emergency response?

RQ3.2 How quickly will the flooded hospitals and refugee homes be served from the emergency responders also through flooded roads?

RQ4 Which “new” VGI source could be taken into consideration in an urban environment such as Cologne, which is highly vulnerable and susceptible to flooding?

RQ4.1 What are the advantages and limitations of the use of VGI data in emergency response management?

Basically, this article will address these questions by illustrating how GIS, OS data (of low quality) and VGI information, provided by different platforms and sources, can provide useful information during a flood for emergency response for Cologne. More specifically, the article starts with an exposure assessment to an extreme river flood scenario. Layers of population density are added in a GIS environment, in order to indicate concentrations of people in need. From here, we select specific vital infrastructures such as hospitals, fire brigade stations within the city and other critical points of interest such as the refugee homes. On a next step, we indicate how these emergency infrastructures are closely related in a flood situation; the fire brigades need to access the hospitals and the refugee homes for help in case of evacuation and other situations. This interdependency, which is then illustrated, produces its own risks, for instance, when roads are flooded. The article details how novel applications allow routing through flooded streets in a GIS environment, using OS data. The article investigates potentials to validate and improve the results, which are compared with expert opinions, authoritative data and manual calculations. Finally, the role of producers of OS data and upcoming opportunities by a specific group, the refugee community of Germany, are briefly outlined in a separate section. The article then discusses the usability of GIS and VGI based on own insights and in comparison with key literature.

2 Geographic information management and GIS opportunities for timely emergency management

2.1 GIS methodology, case study, data and tools used

Methodologically, a static exposure assessment was conducted as a first step, which resulted in the identification of highly vulnerable urban areas in the broader area of Cologne. The data used in this assessment were open source (OS) CI data, OS demographic data and the positions of the fire brigades, the hospitals and the refugee homes that could be affected from the extreme flood scenario. Proceeding to a network analysis with the help of GIS, isochrone maps were created for each fire station before and during the flood event. The maps were used as a first overview of the temporal range in the fire brigade emergency response. Then, a network analysis was conducted through which our routing calculations showed the shortest routes that the fire fighters could take to the flooded hospitals and refugee homes, before and after the flood event, also taking the delays through a flooded road network into account. Here, we argue that transportation through a flooded road network is a factor that could play a key role in planning a timely emergency response. As aforementioned, to the best of our knowledge, the delaying travel factor has not been taken into consideration for any routing calculations in Germany. Then, the outcomes of the methodology proposed were validated with the isochrone maps from the Office of Fire Protection and Emergency Services and Civil Protection of Cologne, which were obtained from empirical measurements of fire truck speeds. For such an extreme flood scenario in urban areas with dense road networks, such as in Cologne, improved routing algorithms in a GIS environment allow computing the delay caused by driving through a flooded road network at depths that still permits driving. If the fire fighters can assist hospitals and refugee homes, by driving through flooded road networks in a time–cost-effective way, this will lead to an increase in the urban resilience of the city. Lastly, we address the fact that the Standard of Cover (SOC) plan of the fire brigades of Cologne could be further enriched with information derived from VGI that is provided by the vulnerable population of the refugee community with near real-time spatial information. This information can lead to a time effective emergency response, thus shortening the time of their own rescue and minimising the time of recovery.

2.1.1 Data, methodology and tools used

The future of spatial enablement, and therefore the realisation of a spatially enabled society incorporating government, industry and citizens, lies in it being a holistic endeavour where spatial (and land data) and non-spatial data are integrated according to evolving standards and with a Spatial Data Infrastructure (SDI) providing the enabling platform (Rajabifard and Coleman 2012). The combination of spatial and non-spatial information can lead to a more holistic overview of the vulnerability of the urban area of Cologne, mostly based on the population exposed to specific risks.

Different sources of data have been used to develop the disaster risk management and emergency response database. In this study, the utilisation of available, OS geodata from projects such as OpenStreetMap, provided and maintained by the community of Geofabrik (https://www.geofabrik.de/en/), the city of Cologne (http://www.offenedaten-koeln.de/dataset) and the international commission of the Rhine (http://www.iksr.org/), on actual damages, flood extent, etc., indicated how improved emergency response plays an increasing role in civil protection and Disaster Risk Reduction (DRR) in general. This was observed through the implementation of routing algorithms and the calculation of isochrone polygons of emergency response in a GIS environment. Specifically we used data (see Fig. 1) from the Rhine Atlas from 2001 (IKSR 2001) and its newly updated online version from 2015 (Rhine Atlas 2015). The project Rhine Atlas together with uses adapted to floods, it also supports the implementation of preventive measures in the planning area. From the probabilistic zonation of the online inundation map, focusing to the study area which is the centre and the broader area of Cologne, we use additional data, provided by the city of Cologne, based on their own flood zonation maps, derived from LIDAR data which are freely available.

In accordance with Directive 2007/60/EC, floods with the following probabilities should be integrated into flood hazard maps:

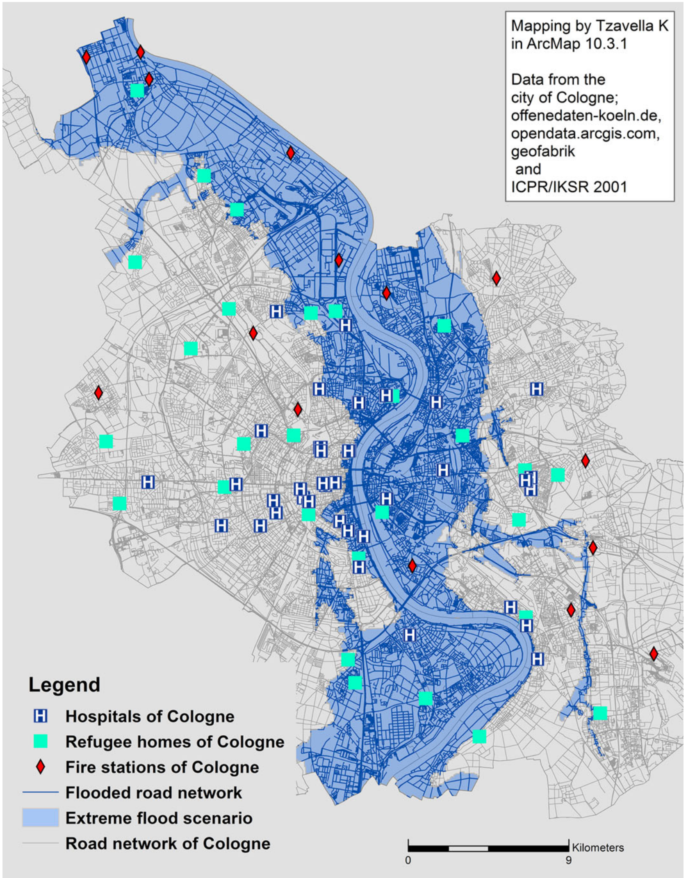

Fig. 1 Data used for this study mapped in ArcMap 10.3.1

- Low probability (extreme event scenarios),
- Medium probability (HQ-100 scenario corresponds to a statistical flood recurrence interval $\geq$ 100 years)
- High probability

The Cologne extreme flood scenario is termed as HQ500, hence, a 500-year period of return, which is a low probability scenario. All return-period models undergo changes when additional flood events, such as in 1993 and 1995 and later, modify knowledge and calculations of the return periods. The extent of the extreme flood that is used for this study was extracted from the Rhine Atlas project, but only the perimeter of the extreme flood was kept. In addition, current data from the city of Cologne were added to the extreme flood perimeter based on more accurate modelling of an extreme river flood including failure of levees and overflow of protection measures and groundwater intrusion. The perimeter resulted from aggregating the data in the ArcMap with the help of the aggregation function. Other data which are used are the districts of Cologne, the population density of each district, the road network and the fire stations, the hospitals and refugee homes of Cologne (Fig. 1).

The databases and later the shapefiles of the hospitals and the refugee homes were created as shown in the workflow in Fig. 2. Table sheet files (.csv format) of statistical data and lists of addresses of several facilities were downloaded from an open data portal (offenedaten-koeln.de). In order to achieve data interoperability, we used several tools from the ETL method (Extract-Transform-Load) (https://pro.arcgis.com/en/pro-app/help/data/data-interoperability/spatial-etl-tools.htm).

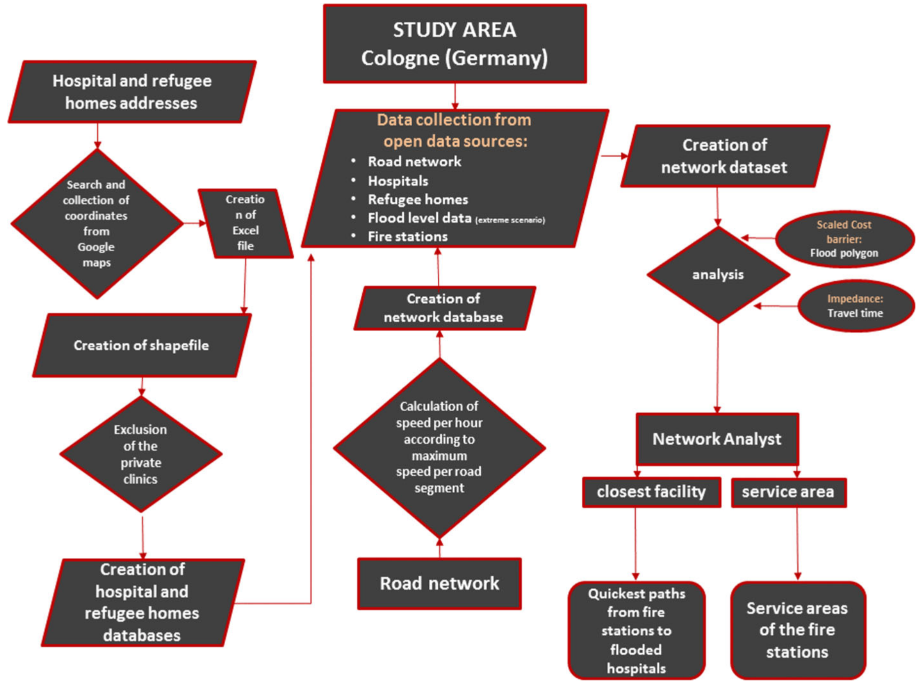

Fig. 2 Workflow of the methodology followed for the extraction of isochrone polygon areas and quickest routes

We prepared and then processed the data in an ArcGIS environment.

2.1.2 *Overview of the spatial range of emergency response of the fire brigades and routing calculations under flooded conditions*

Routing is the act of selecting a course of travel, and it is the most fundamental logistical operation in network analysis. Finding the closest facility for any location is similarly a matter of finding the shortest path from a point of interest (POI) to each possible facility and choosing the shortest of these solutions. Therefore, the entire suite of the network analysis functions implemented in GIS is composed of derivatives of the shortest path algorithm. A very common research interest is routing across networks so as to minimise the cost of the route. Cost can be defined and measured in many ways, but it is frequently assumed to be a function of distance, time, or impedance in crossing the network. There are many different efficient algorithms for determining the optimal route but the most widely cited is the one developed by Dijkstra (1959). Dijkstra's algorithm (Fig. 3) is the one that is used in the Network Analyst tool from ESRI. In this algorithmic environment, the terms intersection, road and map are translated as vertex, edge and graph, respectively.

The shortest path routing was fully integrated into ArcMap. The determination of a service area for a facility is a matter of finding the shortest route from the facility to points of interest (POI) in the network and allocating them (or the associated network locations) to their nearest facility. In general, there are many more parameters that can be set in order to define more complex versions of shortest path problems, and there are innovative ways in which users of different scientific backgrounds can combine these operations to conduct more complex analyses. However, the underlying overall dominance of shortest path routing remains clear. The determination of the service areas in the form of isochrone zones will show the range of the emergency response in time and space for each Cologne fire brigade.

The ArcMap 10.3.1 version from the ESRI standard network analysis package provides four fundamental operations that can be performed, all of which are derivatives of route finding algorithms. These functions are:

```
function Dijkstra(Graph, source):
    for each vertex v in Graph:            // Initialization
        dist[v] := infinity                // initial distance from source to vertex v is set to infinite
        previous[v] := undefined           // Previous node in optimal path from source
    dist[source] := 0                      // Distance from source to source
    Q := the set of all nodes in Graph     // all nodes in the graph are unoptimized - thus are in Q
    while Q is not empty:                  // main loop
        u := node in Q with smallest dist[ ]
        remove u from Q
        for each neighbor v of u:          // where v has not yet been removed from Q.
            alt := dist[u] + dist_between(u, v)
            if alt < dist[v]               // Relax (u,v)
                dist[v] := alt
                previous[v] := u
    return previous[ ]
```

Fig. 3 Pseudocode of Dijkstra's algorithm. *Source* http://www.gitta.info/Accessibiliti/en/html/Dijkstra_learningObject1.html

a. Finding a route between point locations.
b. Determining the service area for a facility.
c. Finding the closest facility across the network.
d. Creating an origin–destination matrix.

3 Results

Highly vulnerable urban zones can be defined, as aforementioned, not only according to the density of the population as in many case studies (Cutter et al. 2003) but also according to other factors such as income, migration background In this article, we only focus on the population density of the study area, since we are interested in investigating potential impacts of extreme flood scenarios upon the travel time. Or more precisely, the travel demand within, into, and out of the disrupted area itself. The first outcomes of applying this methodology, as suggested in this article, follow.

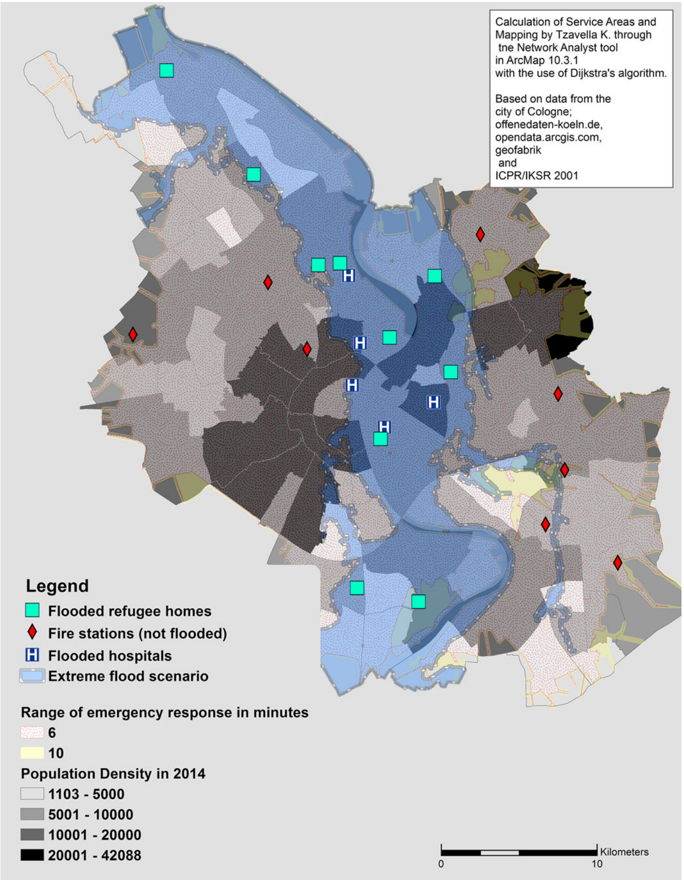

Fig. 4 The extreme flood static exposure assessment resulting from visualising the data used for this study (map produced in ArcMap 10.3.1)

Specifically, the static exposure assessment (in Fig. 4) shows that 7 fire stations, 5 hospitals (excluding the private clinics) and 10 refugee homes are exposed to the risk of river-flooding. Additionally, several thousands of people (according to population data of 2014) are potentially exposed to the risk of the extreme flood scenario including the vulnerable population of patients in the flooded hospitals and the refugees in the flooded refugee homes (Table 1).

Population density information affects the response of transit agencies in an emergency evacuation and indicates possible hot spots that are useful for evacuation planning, which could provide knowledge to the emergency planners (Report: Transportation Research Board 2008). The fire stations house the search and rescue teams that are vital for any type of large-scale emergency rescue such as an extreme flood event. The emergency response planning is assisted by calculating the quickest routes between the Cologne fire stations and the hospitals and refugee homes that might be affected by the flood. Fire trucks need to access and serve specific sites in a crisis scenario, within a specific time frame for an effective emergency response.

So to address the RQ3.1, we used the function of finding the closest facility across the network. The road network used in this study was provided by the OpenStreetMap project through the website of the Geofabrik community. However, its database is not enriched with road segment length and speed limit, which are needed to compute the travel time for road links. Therefore, we computed the road segment lengths for each road segment for which the information regarding the speed limit was available and calculated the travel time needed to cross each one of them.

This procedure provided each individual road segment with a travel time value; however, this value is only an approximation. This value does not take into consideration time delays associated with traffic control and traffic congestion. The application of dynamic variables, like historical traffic count data, can help emergency response vehicles avoid traffic congestion and improve response times.

The shortest travel paths were calculated from the fire stations to hospitals (see Fig. 5) and to the refugee homes (see Fig. 6) before and during an extreme flood scenario. The maximum speed for all the road segments was not taken into account, since the database was incomplete (low quality OS data) and due to the restriction of the one-way roads. Traversing each road link into the flooded area will cost more in matters of time and there is an increase in travel time by a factor of 3.0. This factor is set in the configuration of the model through the network analyst's closest facility tool.

The quickest routes from the hospitals and the refugee homes alter when the delaying parameter of travel time (extreme flood zone) is added. The delaying parameter is the factor 3.0. Focusing on the extreme flood scenario for the city of Cologne, we conducted the analysis before and during the extreme flood scenario so as to have comparative results. During the extreme flood scenario, a scaled cost line barrier (the shapefile of the extreme flood scenario) was set. A scaled cost barrier does not restrict travel on the edges and junctions it covers but it scales the cost of traversing the covered edges and junctions by a

Table 1 Results of static exposure assessment

Potentially exposed to the extreme flood scenario (number)			
Hospitals (Excluding private clinics)	Fire stations	Refugee homes	Population (Number of people)
5	7	10	Several thousands

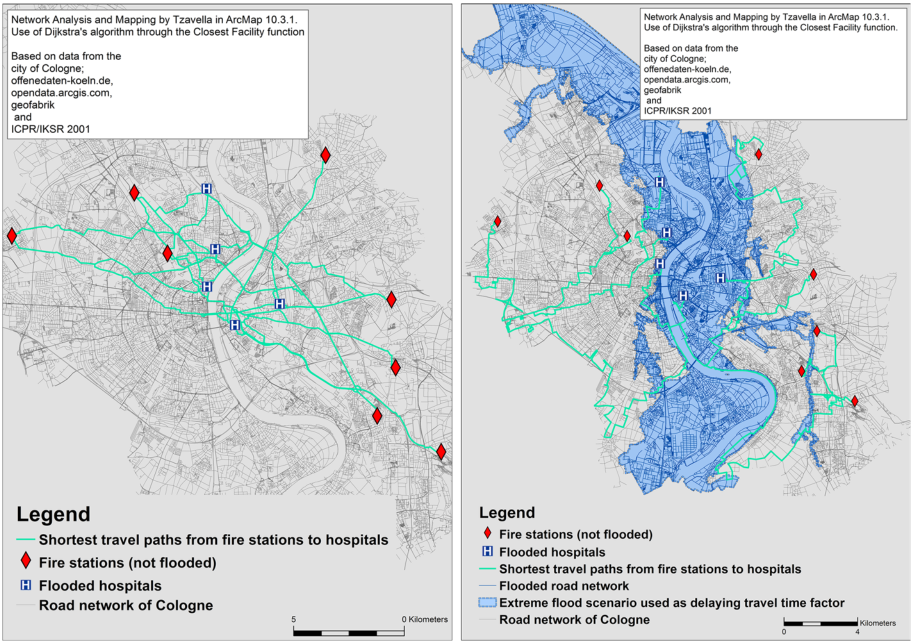

Fig. 5 Quickest routing paths recommended for timely emergency response aiming at assisting the affected from the flood hospitals before (on the left) and during the extreme flood scenario (on the right)

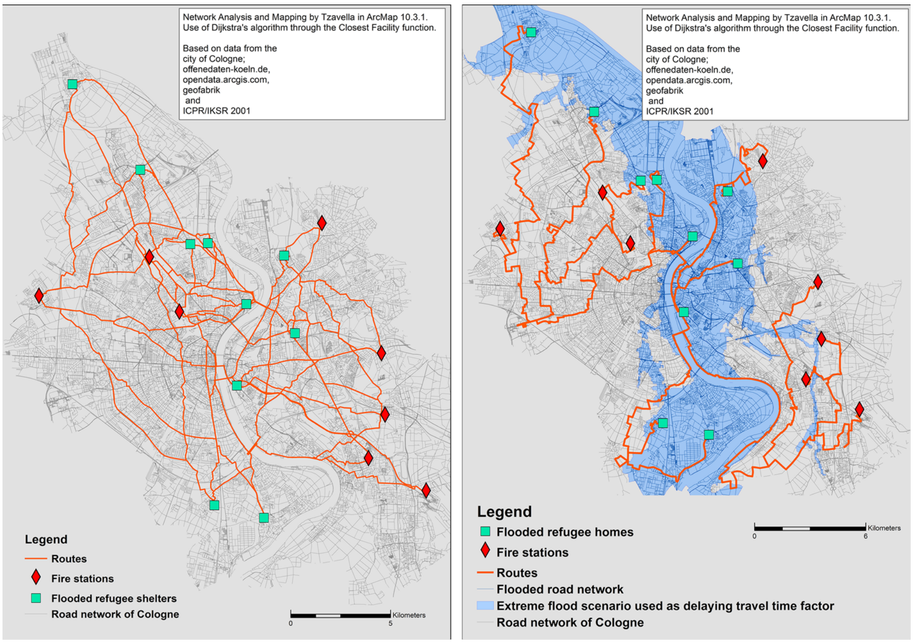

Fig. 6 Quickest routing paths recommended for a timely emergency response so as to assist the refugee homes that were affected by the flood before and during the extreme flood scenario

specified factor. Barriers are, in general, featured classes in network analysis layers that restrict or alter impedances of the underlying edges and junctions of the associated network dataset. Barriers are split into three geometry types (point, line, and polygon) and are designed to model temporary changes to the network (Tutorial–ArcGIS for Desktop. http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/what-is-network-analyst-.htm). This zone (polygon) contains an underlying flooded road network. In this paper, we take the flooded road network in our routing calculations into account by setting the scaled cost barrier. Moreover, we assume that the emergency response through a flooded road network will be slowed down by a factor 3.0. It is the factor by which the impedance of edges underlying the barrier are multiplied, which means that a factor of 3.0 would mean it is expected to be three times longer than normal (normal day).

Continuing with our analysis and to address the RQ3.2, we used the function of determining the service area of a facility across a network. In general, a network service area is a region that encompasses all accessible streets (that is, streets that are within a specified impedance). Service areas created by Network Analyst also help evaluate accessibility (Tutorial–ArcGIS for Desktop. http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/what-is-network-analyst-.htm). Concentric service areas show how accessibility varies with impedance and for this case, impedance of time was calculated in minutes. With the Network Analyst's tool that determines the service area of a facility (in minutes or length; in our case study, the fire stations), we calculated the service areas of each fire station without taking the traffic data into consideration and partially took the restriction of the one-way roads into account. That means that wherever there are one-way roads, the algorithm considers these areas as non-traversable. Therefore, it seeks traversable road segments. The difference between the two modelling results is obvious in Fig. 7. The restriction of the one-way roads results in isochrone polygon areas of 10 min

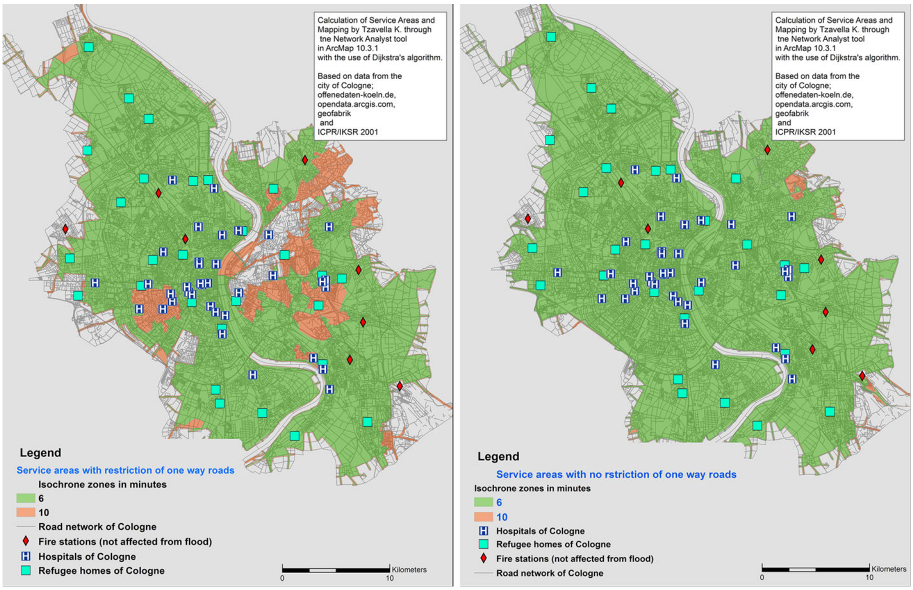

Fig. 7 Isochrone polygons for 6 and 10 min travel times before the extreme flood scenario with the restriction of the one-way roads on the left and on the right without the restriction of the one-way roads

close to some of the fire stations, which can be considered as false results. In areas where there are one-way roads, the results are isochrone polygons of 10 min and only in some remote areas away from the hospitals and the refugee homes (facilities at risk for this case study).

Using the shapefile of the extreme flood scenario as a scaled cost barrier, the results are isochrone zones (polygons) of 6 and 10 min. These include all the area around the fire brigades that can be reached through the road network (even when flooded) within 6 and 10 min having each fire station as the starting point of the emergency response during the extreme flood scenario (see Fig. 8). During the extreme flood scenario within the flood zone, additional delays due to flooded roads are integrated into the assessment. To compute this, each road segment of the network was assigned a maximum speed and was multiplied by the factor 3.0 (increased travel time). This is the factor by which the impedance of edges underlying the barrier are multiplied, i.e. this factor of 3.0 indicates that the travel time it is expected to be three times longer than normal (on a normal, non-flooded day).

The network analysis was conducted in two phases: Including the one-way roads as a restriction to the calculations and not. The road network database is not complete (a common issue of the OS data is low quality), that is, there are no assigned maximum speed limits for each road segment of Cologne and many of the roads are not categorised so as to be part of the calculations. Therefore, there are isochrone polygons of 10 min even around the fire stations which is a false (not corresponding to reality) result (Fig. 8, left map). Due to the incomplete road network database and the amount of the restrictions (one-way roads) entered into the model, the outcomes are far from reality. On the other hand, without taking into consideration the restriction of the one-way roads, the outcomes (Fig. 8, right) seem closer to reality and indicate areas around each fire station that can be reached in less than 6 min with 2 min given as preparation time for the fire fighters, even through a flooded road network.

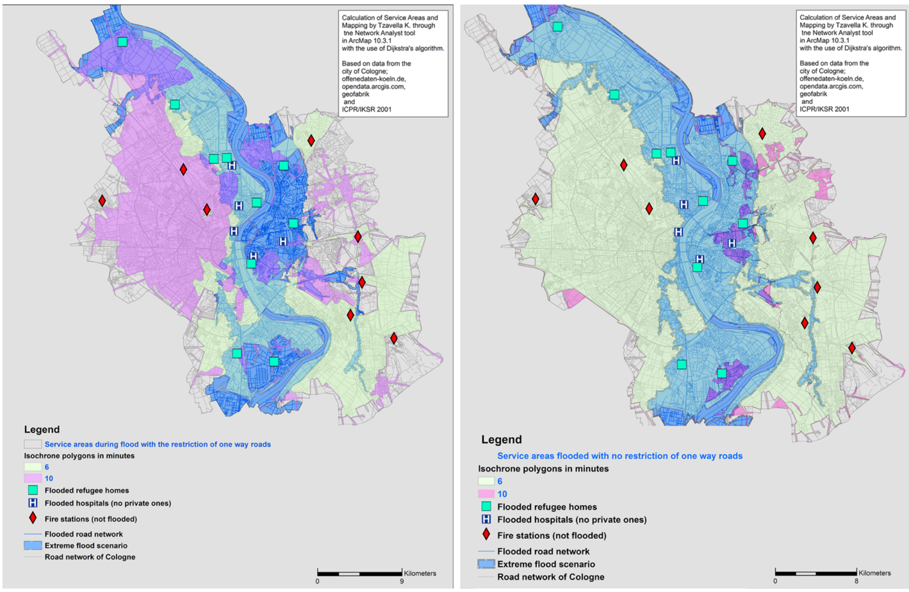

Fig. 8 Isochrone polygons for 6 and 10 min travel times during the extreme flood scenario with the restriction of the one-way roads on the left and on the right without the restriction of the one-way roads

3.1 Validation of the isochrone maps

Accordingly, qualitative assessment of interviews that were carried out with emergency response planners who are responsible for the coordination of emergency responses in cascading scenarios, is essential for deriving key parameters such as level of preparedness of each hospital and refugee home for such cascading scenarios. These parameters can be useful to produce awareness zones, which will help the emergency planners to focus their preparedness actions. In this article, we have only focused on the level of preparedness of the fire brigade department of Cologne and the way they conduct their routing and isochrone analysis for each fire brigade.

More specifically, we conducted an interview with Dr. Martin Wesolowski who is a planner at the central fire brigade office of fire protection and works at the department of Emergency Services and Civil Protection. We were provided with the isochrone zones of each fire brigade of Cologne, which were calculated by the rescue service department of the central fire station of Cologne. The isochrone zones that we calculated corresponded well with those from the rescue service departments, as can be seen in the next section. The response time for each fire station was calculated to be 6 min, given 2 min of preparation after the emergency alarm, which gives in total a maximum 8 min response time.

For the city of Cologne, the routing and isochrone calculations (Fig. 9) are made according to Schmiedel et al. (2012) with data such as the speed for each road segment within the city of Cologne, which is retrieved from real driving experience (use of empirical data). They already know according to experience combined also with road network maps in which type of road they are driving on and therefore they know what the speed should be. Dr. Wesolowski mentioned that each fire truck after the emergency call/ alarm must be at the destination of emergency within total of 8 min: 2 min of preparation and a 6-min drive. This already happens 90% of the time (achievement degree).

In the routing calculations that the Cologne fire stations use, the one-way roads are not considered as barriers, because the calculations are based on experience.

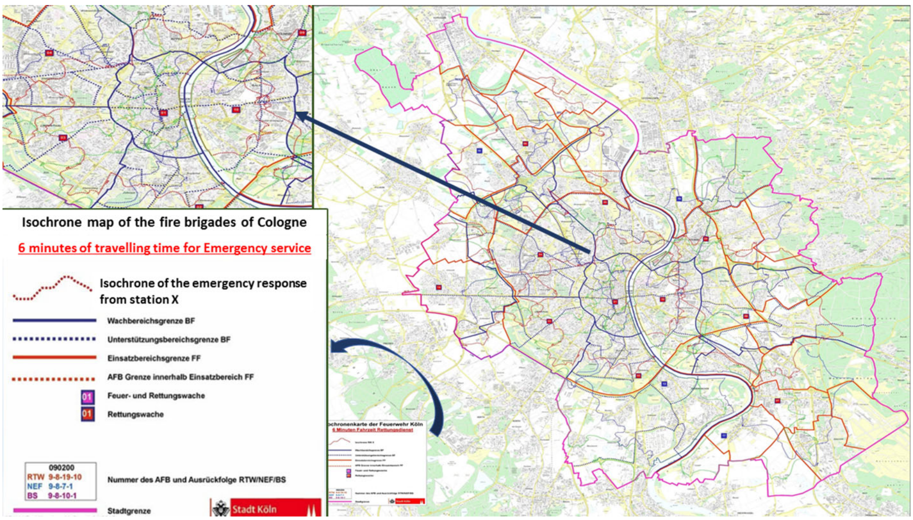

Fig. 9 Isochrone map of the fire department of Cologne indicating the area of emergency response in 6 min (dashed red lines)

A visual validation (Fig. 10) of the isochrone maps (Fig. 9) calculated by hand from the central fire brigade of Cologne for emergency response planning using empirical data are close to the results of the methodology applied in this article. In the fire department of Cologne, they are not taking also into consideration the restriction of the one-way roads but they are using own experience regarding the areas of emergency response for each fire brigade. It is also observed that the area where it is indicated from the network analysis that can be reached in 10 min is an area of nature with lakes and rural roads.

Future work planned is the validation of the route calculations since the road network databases (OS data used in this article and empirical data used from the fire brigades in Cologne) differ and integration of traffic information needs to be taken into account. Taking traffic information into consideration to ensure a more timely effective response was addressed as a key "must" also from Mr. Voßschmidt. Mr. Voßschmidt is a lecturer for legal basis of civil precaution and emergency care at the Academy for Crisis Management, Emergency Planning and Civil Protection (AKNZ) and managing director of the Association "German Society for the Promotion of Social Media and Technology in the

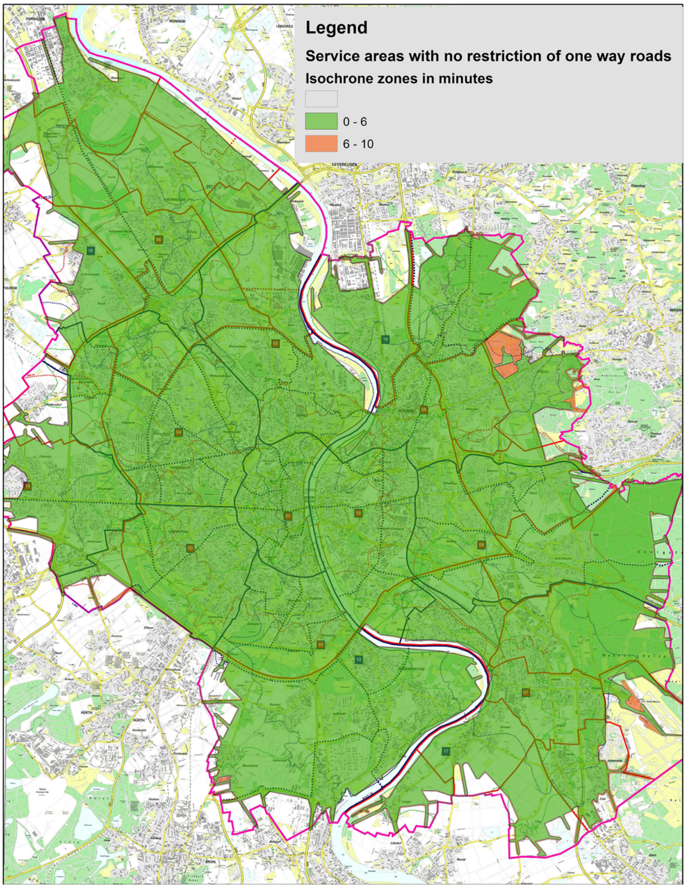

Fig. 10 Isochrones of 6 and 10 min of emergency response (traffic information and delays in conjunctions are not included)

Civil Protection (DGSMTech) e.V.," during an interview at the DGSMTech workshop in 2017 (http://dgsmtech.de/).

4 Discussion

4.1 Discussion of accessibility indicator

In Fekete et al. (2016) the aim was to indicate the need for more research and consideration of spatial distribution of shelters, their location within hazard zones and their dependence on emergency infrastructure services that might be affected by a flood or a blackout.

In this article, main goal was to investigate, in depth and in praxis, which information can be of use for emergency response planners in a minimum supply concept for a timely emergency response. The research was carried out through a combination of GIS and VGI from different platforms and sources and with the example of an extreme flood scenario. We suggest an accessibility indicator that can serve as an additional tool for emergency management. The proposed accessibility indicator consists of components (see Sect. 1.1) that can be considered as a prerequisite in both the preparedness and response phase in case of a flood risk scenario for the city of Cologne.

As aforementioned, in dealing with extreme events such as floods or earthquakes, many of the critical problems that arise are inherently spatial. Spatial problems cover issues related to the extent of the disaster, on-site crisis, number of people in need with exact location, etc. Therefore, in answer to RQ1., we presented through exposure and vulnerability assessments in GIS and, the degree that affected people, of hospitals, vital CI for the emergency response such as the roads and of civil protection infrastructures such as the fire brigades and how are intertwined for an extreme flood scenario. We also included the refugee homes, since the refugee community is a relatively big part of the vulnerable population of Cologne (due to language barriers etc.) and should be taken into consideration. Therefore, (answering RQ2.), we have presented ways indicating that GIS is a valuable tool for the emergency management in regard to situational analysis, even using data of low quality such as the OS data used for this research. OS data of different forms (Excel files, shapefiles, etc.) which, on the one hand, can be up to date but on the other hand may provide limited information, can be of great use for emergency management since limited information is better than no information in times of crisis. For this research, we proved with our GIS applications that the combination of OS data with authoritative data is a perfect combination for a timely emergency response providing results that are close to reality situations.

For the emergency response phase, we proceeded to carry out calculations (answering RQ3) in a GIS environment using the network analyst tool and VGI with OS data in different forms (shapefiles of road network, fire brigades and hospitals and refugee homes lists transformed to shapefiles later). We calculated the service range of the fire brigades (first acting emergency responders) before and during a flood scenario, taking into consideration one-way roads, by specifically calculating their emergency response ranges through flooded road networks for the assistance of the possibly affected hospitals, refugee homes and fire brigades (potentially flooded in case of an extreme flood scenario). The service ranges of the fire brigades (isochrone maps) that result from a network analysis before an extreme flood, and were compared to empirical data from the fire brigade of Cologne and Dr. Wesolowski (see Sect. 3). Dr. Wesolowski mentioned that the biggest problem they face is the fact that the empirical data that are used from the fire stations for the current emergency routing calculations are from 2002 and in the last 14 years, the road quality has changed (e.g. increased roundabout traffics and traffic calming). The comparison (see Sect. 3) has indicated that the service ranges of the network analysis that we conducted with low quality OS data and VGI (not complete databases) verifies our aforementioned statements regarding the use of VGI and OS data in a GIS environment to assist a timely effective emergency response answering RQ2. Since network analysis through flooded road networks is still under-researched (see Sect. 2) we proceeded with routing and service range calculations (isochrone maps) also through flooded road networks and present a new factor that should be taken into consideration when it comes to emergency response management. In general, the results show that GIS analysis utilising GI can be valuable for risk prevention and emergency response. The routing calculations before and during the extreme flood scenario conducted on a low quality road network database allowed estimating extended travel times. Shortening the travel time through a flooded road network (calculated for a maximum depth of 0.5 m.) will add value to the emergency response planning phase and lead to a more timely emergency response. The delay factor of 3.0 that was used in this study is only an assumption and was not based on own empirical calculations, which is something that should follow in research. For an even more robust network analysis, the traffic density in the areas of high exposure to flood risk, and the restriction of the one-way roads should be taken into consideration.

Since exposure assessments have indicated that also many of the refugee homes are expected to be flooded in an extreme flood scenario in Cologne—in answer to RQ4—and motivated from Fohringer et al. (2015) where it is underlined the greater relevance of the nearby to the risk event geo-located information, we suggest accessing the vulnerable community of the refugees as a new source of VGI. Section 4.2 could be considered as an outlook of the relevance of mobile device usage and the usage of social media and messaging applications of the refugee community resulting to potential high amount of VGI in case of an extreme flood scenario. The source of VGI that is suggested, it is expected to give more relevant data, due to proximity to the risk scenario, assisting the emergency response with geo-located information regarding water depths, etc. This component can be integrated in an emergency management plan and basically it is the conceptual beginning for future research and further development of the accessibility indicator. We suggest that VGI from the refugee community in an extreme flood scenario as the one researched in this article and for the city of Cologne, can serve as an additional source that would lead to the decrease in the emergency response time assisting the prioritization of the emergency response (see also Sect. 1.2). In Sect. 4.3, we briefly, and thus not comprehensively, present the potentials and disadvantages of the use of VGI in emergency management to raise awareness that the method is strongly dependent upon many factors that still need to be researched and could affect the performance of the accessibility indicator.

4.2 Refugee community as a source of VGI information, assisting their own rescue

VGI can contribute to all phases of disaster management through the rapid exchange of geographic information between authorities and citizens during disaster response; thus, promoting connectedness and community engagement in disaster preparation practices (Haworth and Bruce 2015).

In this article, we argue that VGI produced from the population of the refugees at risk and of social media can be a valuable source in case of an extreme flood in Cologne.

According to Eurostat (see Fig. 11) and the asylum seekers, the refugee community consists of circa 50% Syrians.

The UN refugee agency for central Europe (Helping those with special needs. http://www.unhcr.org/ceu/96-enwhat-we-docaring-for-the-vulnerable-html.html) has stated that refugees, asylum seekers and the stateless make up one of the most vulnerable groups of people in the world. But within this group, there are people who are even more vulnerable: the elderly, children and people who are ill and physically challenged.

Specifically in Cologne, the refugees overall number approximately 13,000 (see Fig. 12); this is a considerable number of people being added to the vulnerable population of the city. The community of refugees can be considered vulnerable in case of cascading effects such as the extreme flooding that we are studying in this article, and it is assumed to that it will affect several refugee homes in case of occurrence. However, we argue that taking the outsourced VGI, which can be produced from this vulnerable community, into consideration and incorporating it into an emergency response framework will shorten the emergency response time, accelerate the procedures of their rescue, and contribute to their resilience.

Refugees use social media extensively and mobile applications through their smartphones, which are vital for their daily needs in Germany and during their flight even for their survival. Marie Gillespie, Professor of Sociology at the Open University (OU) of UK and a member of OU's Citizenship and Governance priority research area, commented: Our research (Gillespi et al. 2016) suggests that the information and news needs of refugees are not sufficiently taken into account by governments and news organisations as they make perilous journeys from war-torn parts of the world to Europe, and when they arrive. For refugees trying to reach Europe, a mobile phone is not a luxury. It is as important as the clothes on their backs or even the boat they climb into to cross the Mediterranean. Phone calls and messages are just a part of it; mobile apps, websites, social media, navigation tools and translation services, camera and audio recording all combine to make up a digital infrastructure that has become integral to any journey to Europe.

As stated in the World Factbook of the US Central Intelligence Agency in 2014, the penetration rate of mobile phones was 87% in Syria. In other words, almost 9 Syrians out of 10 have cell phones (https://www.cia.gov/library/publications/the-world-factbook/geos/sy.html). "Our phones and power banks are more important for our journey than anything, even more important than food," said Wael to Agence France Presse in Times of Israel

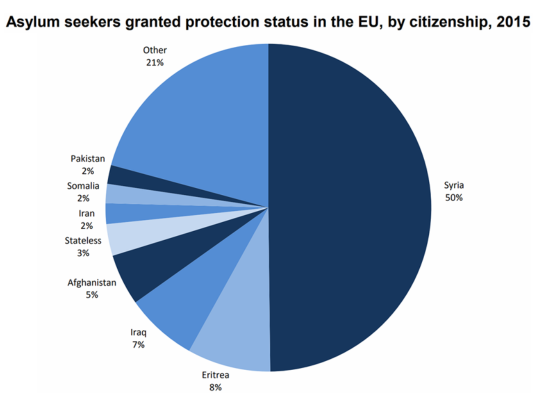

Fig. 11 Asylum seekers granted protection in the EU, by citizenship, 2015 (Reproduced with permission from EUROSTAT 2016)

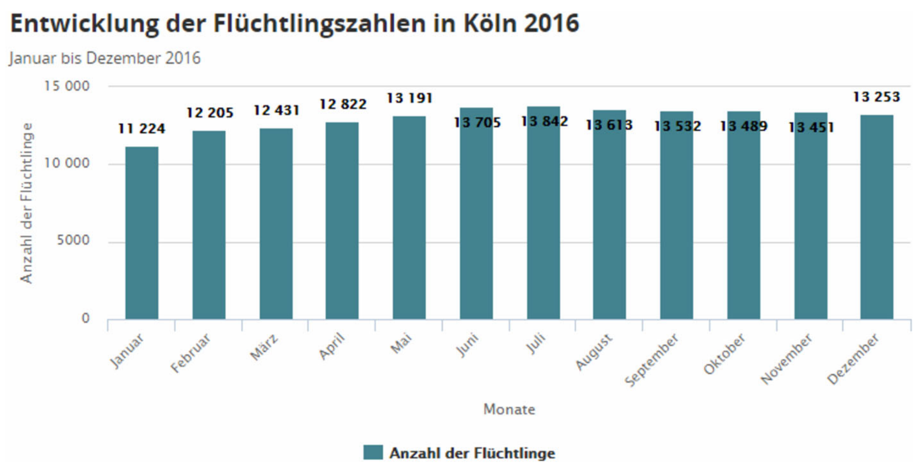

Fig. 12 Graph provided from the city of Cologne (http://www.stadt-koeln.de/leben-in-koeln/soziales/koeln-hilft-fluechtlingen/fluechtlinge-koeln) where the X axis shows the months and the Y axis shows the number of refugees counted from January of 2016 till November of 2016

(http://www.timesofisrael.com/); a 32-year-old from the devastated Syrian city Homs who reached the Greek resort island of Kos (Fig. 13).

When refugees arrive in Europe, they also need to know how to find legal representation, make an asylum claim as well as find food and shelter. Their phone is the only way to do it. This need has been already recognised from the Swedish community who wanted, since the beginning of the cascading refugee influx to northern Europe, to voluntarily help the refugees by providing to them smartphones (used or new ones), SIM cards and chargers, so they can stay connected with their families and friends and not only that. This community of Swedish volunteers started a project called Refugee Phones (http://www.refugeephones.co.uk/). “Refugee Phones” started in Sweden and runs in the cities of Gothenburg and Stockholm. In the UK, it is run by a small team of volunteers in London in partnership with CalAid (http://www.calaid.co.uk/), which is another volunteer project that aims at collecting smartphones, SIM cards, and chargers for refugees, asylum seekers and displaced people in Calais refugee camps. Social media generated by many individuals plays a greater role in our daily lives and provides a unique opportunity to gain valuable

Fig. 13 On the right, Syrian migrants take a picture after their safe arrival on an overcrowded dinghy to the coast of the southeastern Greek island of Kos from Turkey (AFP/Louisa Gioulamaki) and on the left a photo taken by Marko Djurica/Reuters showing people using their mobile phones near a Wi-Fi hotspot at a makeshift camp for refugees and migrants at the Greek–Macedonian border near the village of Idomeni, Greece

insight on information flow and social networking within a society. Through data collection and analysis of its content, social media support a greater mapping and understanding of the evolving human landscape. Facebook played the role of the tour guide in the recent refugee flux. The refugees use Facebook groups with tens of thousands of members to share photographs and experiences, find smugglers' phone numbers, map their route from Turkey to Greece and further to northern Europe, and to calculate expenses. However, they can be misled too by criminal gangs ready to exploit them. WhatsApp is an important tool for emergency responders (i.e. coast guards) specifically for the case of the refugees crossing the marine borders between Turkey and Greece. The most popular map shared between thousands of Syrians is shown in Fig. 14, and it represents their route to a better life in Germany. Of course, there are also language barriers and other constraints that should be taken into consideration when such VGI is produced and thus we will present some examples in Sect. 4.2.

4.3 Advantages and limitations of the usage of VGI in emergency response management

Answering RQ4.1, in this sub-section are investigated the advantages and limitations of the use of VGI for an emergency management planning. This section could be part of a

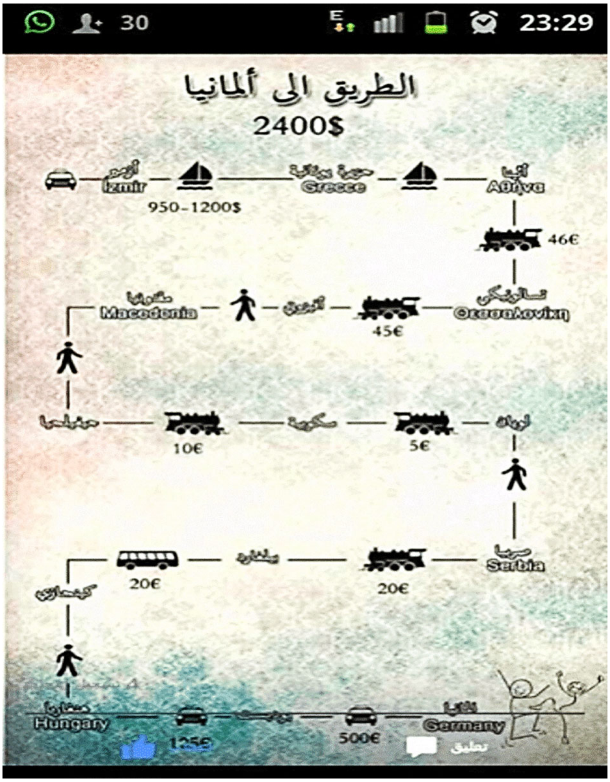

Fig. 14 WhatsApp map: from Izmir to Germany sent to a refugee interviewed in Paris (Reproduced with permission from Gillespi et al. 2016)

handbook for emergency managers interested in the implementation of this methodology underlining the advantages and disadvantages of the use of VGI in addition to the authoritative emergency management plans. We acknowledge though that this chapter, it is not an extensive presentation of the advantages and disadvantages of the use of VGI.

An approach examined the microblogging text messages in Twitter platform (tweets) produced during the River Elbe Flood of June 2013 in Germany. The results showed that quantitatively assessing social media messages based on authoritative data, can be a viable and useful way to improve the identification of messages that contain useful information for managing disasters (Tulloch 2008). Therefore, in this article in addition to the opportunities and the constraints, a new source of VGI (volunteered GI provided from social media etc.) is suggested. This new source of VGI, as aforementioned, is the vulnerable community of the refugees. This section and Sect. 4.2 aim to raise awareness of the potentials of the use of VGI, of different forms, in the emergency management for the area of Cologne, indicating also the disadvantages that should be taken into consideration.

Apart from the fact that VGI can provide supplementary information and therefore it can enrich a spatial decision support system for flood risk management with valuable information (Horita et al. 2015) by improving the coverage of monitored areas, it can be hindered due to its questionable quality, availability, readiness, etc. Some of the constraints and issues that are important and need to be taken into consideration in an emergency scenario are discussed below.

There are multiple ways of evaluating spatial data quality, which are discussed briefly in (Haklay 2010) and in a more comprehensive way in (Oort 2005). In general, social networks have been used to overcome the problem of incomplete official data. They can provide a more detailed description of a disaster since they can provide a pool of social media messages that can be used for composing a picture of what is happening in a specific place (Albuquerque et al. 2015; Gao et al. 2011). Many studies have focused on the identification of useful information from social media that could be valuable for improving situation awareness (Yin et al. 2012). It is useful to analyse the social media usage and the importance of messages in disasters that identify a distinct role of users who are local to the event and who are more probable to generate useful information for improving situational awareness (Assis et al. 2015; Kounadi et al. 2015; Vieweg et al. 2010; Starbird et al. 2010). On the one hand, VGI data can have the problem of “False Observation”, i.e. wrong data collected by users (deliberately or accidentally), but on the other hand though, when the concurrent number of VGI is large, false observations can be invalidated with standard techniques of large-deviation filtering (Fekete et al. 2015). However, filtering relevant messages on-the-fly remains challenging due to the large amount of misleading, outdated, or inaccurate information. Hence, according to Haklay (2010), with respect to emergency responders’ uncertainty as to whether the VGI quality is good, it is important for them to recognise and account for the uneven nature of crowdsourced data. Moreover, significantly higher amounts of credible data are produced in dense urban environments. This is not to imply that data are less accurate in non-urban areas, but that fewer numbers of contributions and error correctors make authoritative datasets more complete and reliable. In other words, there is a spatial discrepancy between well-mapped and not-so-well mapped areas (Haklay et al. 2013).

In general, with the help of GIS, spatial indicators, are widely applied for “measuring” (in a quantitative or semi-quantitative and relative sense) and communicating phenomena such as natural hazards, deforestation, land use change, wildfires, floods, earthquakes, tsunami and climate change (Fekete et al. 2015) in most cases with the use of authoritative data. Specifically, crowdsourcing and mobile technologies are changing the perception that authoritative data is a prerequisite for good decision support and therefore such approaches can be the kick to trigger further research in urban areas such as Cologne, where the amount of highly credible VGI information can be even higher. VGI offers the possibility of including subjective, emotional, or other non-cartographic information and can be useful for one of the main problems in emergency response acquiring situation awareness (Yin et al. 2012).

Data generated within an emergency scenario are always considered critical and cannot/should not be lost. Disruptions can occur because of the emergency itself, and therefore disruption-tolerant networks may need to be considered. The usual problem in emergency situations is the lack of network infrastructures upon which the communications rely on. In these cases, the use of opportunistic networks (delay and disruption tolerant) may be considered as a solution. However, in most disasters, for example, hurricanes, terrorist attacks, earthquakes, these networks become unstable, inaccessible, overused or even destroyed, and as a consequence, emergency personnel cannot rely on the use of these existing network infrastructures and may have to deploy and use their own or look for other solutions. In this article, we would like to bring the risk of a power failure also to the forefront during such situations: A power failure can occur after such an extreme flood scenario due to affected (flooded) transformer stations. In such disastrous scenarios, people who are at risk intuitively and voluntarily start communicating through their mobile phones either asking for help or sharing information regarding their position and status. However, we have to consider that VGI might not be able to be distributed due to either unstable or destroyed Wi-Fi networks. Wi-Fi is one of the backbones for utilising VGI; thus, the downtime or interruption of this infrastructure will hamper immediate and post-disaster VGI data delivery. In a risk scenario as described above, such information could be useful for the emergency managers in a prioritization framework for the use of the available electrical power for a holistic emergency management plan and further research is suggested.

5 Conclusions

By understanding the objectives of each step in the response sequence, fire departments can measure their current performance against these objectives. Such an understanding provides the necessary framework for assessing the cost of reducing response time during any of these steps. The use of GIS and VGI for emergency response is valuable. For the use of GIS aiming to a timely effective emergency response, it is essential to effectively collect as much relevant data as possible. Such data can be a combination of OS and authoritative data, which can be acquired from different providers such as Geofabrik, FLOSM, governmental open data archives, the different geo-portals of cities and municipalities and the international supplier of GIS software, web GIS and geodatabase management applications ESRI. In times of crisis, the combination of authoritative and OS data with low quality, (not complete and nor up to date databases), can bring valuable results regarding the emergency routings and the SOC; thus, providing the first emergency responders with valuable information for a timely emergency response that will enhance the resilience of the urban area. Combination of all forms of VGI (see definition in Sect. 1) with the aforementioned data in the suggested framework and the readiness for including more from new parts of population added (refugee community) to the present population (registered citizens in the city of Cologne), can lead to a time effective emergency response, thus enhancing urban resilience.

For future work, we suggest that, the accessibility indicator developed in this article, should include the following:

1. Up-to-date data of the ground cover, such as the updated road network system enriched with car speed information and amount of accidents per city district or per road segment
2. Delays of car speed in conjunctions of road networks
3. Traffic information (exposure assessments in combination with traffic information can lead to more focused routing calculations (prioritized areas first served) and allow for a time effective response
4. Population density areas (optional: other vulnerability indicators too)
5. VGI (volunteered GI available in the form of Excel lists, shapefiles, social media posts, etc.) from different sources, in an attempt to reduce emergency response time for both fire and medical emergency response.

We also suggest, enriching the social vulnerability index (Fekete et al. 2012) with VGI information and specifically with OS data. This will result in the identification of very vulnerable zones for more focused and effective emergency preparedness and response, and assist in prioritizing.

Finally, in urban areas, which are more complex environments, fire brigades can profit from the integration of the proposed accessibility indicator in an emergency response management plan. The indicator could be a valuable tool for a timely emergency response and work as a sub-component of a resilience indicator. This study can also inform current applications of the resilience concept and deliver information about emergency response and recovery speeds to planners and researchers by also suggesting a new source of VGI information. As aforementioned, the geo-located information that could be provided from the refugee communities can be very useful in emergencies similar to those examined in this article. Thus, where timely information can be forwarded to the proper authorities for a more focused and timely emergency response, increasing the resilience of their community too but also the resilience of Cologne. On the other hand, for the implementation of such information in an emergency management framework, there should be an awareness regarding the disadvantages too.

Acknowledgements We would like to thank the experts for their readiness for the interviews and provision of information. We would like to thank Lukas Edbauer and Jessica Bussing for assistance in certain data search and compilation. We would also like to thank the editors for giving us the opportunity to present our work inspired from the topic of the special issue.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interests.

References

Adger WN (2006) Vulnerability. Glob Environ Change 16(3):268–281

Albuquerque JP, Herfort B, Brenning A, Zipf A (2015) A geographic approach for combining social media and authoritative data towards identifying useful information for disaster management. Int J Geogr Inf Sci 29(4):667–689

Apel H, Thieken AH, Merz B, Blöschl G (2004) Flood risk assessment and associated uncertainty. Nat Hazards Earth Syst Sci 4(2):295–308

Arkell B, Darch G (2006) Impact of climate change on London's transport network, pp 231–237
Assis LFFG, Herfort B, Steiger E, Horita FEA, Albuquerque JP (2015) Geographical prioritization of social network messages in near real-time using sensor data streams: an application to floods. In: XVI Brazilian symposium on geoinformatics (GEOINFO). Campos do Jordão, SP, Brazil
Baharin SSK, Shibghatullah AS, Othman Z (2009) Disaster management in Malaysia: an application framework of integrated routing application for emergency response management system. In: International conference of soft computing and pattern recognition, 2009 SOCPAR '09, pp 716–719
Balijepalli C, Oppong O (2014) Measuring vulnerability of road network considering the extent of serviceability of critical road links in urban areas. J Transp Geogr 39(Suppl C):145–155
Baloye D, Palamuleni L (2016) Modelling a critical infrastructure-driven spatial database for proactive disaster management: a developing country context. J Disaster Risk Stud 8:14
Comes T, Van de Walles B (2014) Measuring disaster resilience: The impact of hurricane sandy on critical infrastructure systems. In: 11th International ISCRAM conference: 2014; University Park, Pennsylvania, pp 195–204
Cova TJ (1999) GIS in emergency management. Geogr Inf Syst Manag Issues Appl 2:580
Crutchfield M (2010) Phases of disaster recovery: emergency response for the long term in vol 2016
Cutter SL, Boruff BJ, Shirley WL (2003) Social vulnerability to environmental hazards. Soc Sci Q 84(2):242–261
de la Torre LE, Dolinskaya IS, Smilowitz KR (2012) Disaster relief routing: integrating research and practice. Socioecon Plan Sci 46(1):88–97
De Longueville B, Annoni A, Schade S, Ostlaender N, Whitmore C (2010) Digital earth's nervous system for crisis events: real-time sensor web enablement of volunteered geographic information. Int J Digit Earth 3(3):242–259
Dijkstra EW (1959) A note on two problems in connexion with graphs. Numerische Mathematik, http://eudml.org/doc/131436(1)
Doris D, Kathrin P, Joachim F, Christian L (2013) Volunteered geographic information for disaster management. In: Citizen E (ed) Participation in urban governance: crowdsourcing and collaborative creativity. IGI Global, Hershey, pp 98–118. https://doi.org/10.4018/978-1-4666-4169-3.ch007
Eckle M, Albuquerque JPd, Herfort B, Zipf A, Leiner R, Wolff R, Jacobs C (2016) Leveraging openstreetmap to support flood risk management in municipalities: a prototype decision support system. In: Antunes T, Moore B, Albuquerque Pd (eds) ISCRAM 2016 conference, Rio de Janeiro, Brazil
EUROSTAT (2016) Asylum decisions in the EU–EU member states granted protection to more than 330,000 asylum seekers in 2015–Half of the beneficiaries were Syrians. http://ec.europa.eu/eurostat/documents/2995521/7233417/3-20042016-AP-EN.pdf/34c4f5af-eb93-4ecd-984c-577a5271c8c5
Faturechi R, Miller-Hooks E (2015) Measuring the performance of transportation infrastructure systems in disasters: a comprehensive review. J Infrastruct Syst 21(1):04014025
Fekete A, Lauwe P, Geier W (2012) Risk management goals and identification of critical infrastructures. Int J Crit Infrastruct 8(4):336–353
Fekete A, Tzavella K, Armas I, Binner J, Garschagen M, Giupponi C, Mojtahed V, Pettita M, Schneiderbauer S, Serre D (2015) Critical data source; tool or even infrastructure? challenges of geographic information systems and remote sensing for disaster risk governance. ISPRS Int J Geo-Inform 4(4):1848–1869
Fekete A, Tzavella K, Baumhauer R (2016) Spatial exposure aspects contributing to vulnerability and resilience assessments of urban critical infrastructure in a flood and blackout context. Nat Hazards. https://doi.org/10.1007/s11069-016-2720-3:1-26
Fohringer J, Dransch D, Kreibich H, Schröter K (2015) Social media as an information source for rapid flood inundation mapping. Nat Hazards Earth Syst Sci 15(12):2725–2738
Fraser SA, Wood NJ, Johnston DM, Leonard GS, Greening PD, Rossetto T (2014) Variable population exposure and distributed travel speeds in least-cost tsunami evacuation modelling. Nat Hazards Earth Syst Sci 14(11):2975–2991
Gao H, Barbier G, Goolsby R (2011) Harnessing the crowdsourcing power of social media for disaster relief. IEEE Intell Syst 3:10–14
GAR (2015) Global assessment report on disaster risk reduction, 9789211320428. UNISDR
Gil J, Steinbach P (2008) From flood risk to indirect flood impact: evaluation of street network performance for effective management, response and repair, vol 118. https://www.witpress.com/Secure/elibrary/papers/FRIAR08/FRIAR08032FU1.pdf. WIT transactions on ecology and the environment
Gillespi M, Ampof L, Margaret Cheesman, Faith B, Iliadou E, Issa A, Souad Osseiran, Skleparis D (2016) Mapping refugee media journeys smartphones and social media networks. http://www.open.ac.uk/ccig/sites/www.open.ac.uk.ccig/files/Mapping%20Refugee%20Media%20Journeys%2016%20May%20FIN%20MG_0.pdf: The Open University/France Médias Monde

Goodchild MF, Glennon JA (2010) Crowdsourcing geographic information for disaster response: a research frontier. Int J Digit Earth 3(3):231–241

Haklay M (2010) How good is volunteered geographic information? A comparative study of openstreetmap and ordnance survey datasets. Environ Plan. https://doi.org/10.1068/b35097

Haklay M, Basiouka S, Antoniou V, Ather A (2013) How many volunteers does it take to map an area well? The validity of Linus' law to volunteered geographic information. Cartogr J 47(4):315–322

Haworth B, Bruce E (2015) A review of volunteered geographic information for disaster management. Geogr Compass 9(5):237–250

Helping those with special needs. http://www.unhcr.org/ceu/96-enwhat-we-docaring-for-the-vulnerable-html.html

Herfort B, Eckle M, Albuquerque JPd, Zipf A (2015) Towards assessing the quality of volunteered geographic information from OpenStreetMap for identifying critical infrastructures. In: ISCRAM: 24–27–05–2015, Kristiansand

Horita FEA, Albuquerque JPd, Degrossi LC, Mendiondo EM, Ueyama J (2015) Development of a spatial decision support system for flood risk management in Brazil that combines volunteered geographic information with wireless sensor networks. Comput Geosci 80:84–94

Hu Y, Janowicz K (2015) Prioritizing road network connectivity information for disaster response. In: Proceedings of the 1st ACM SIGSPATIAL international workshop on the use of gis in emergency management. ACM, Bellevue, pp 1–4. https://doi.org/10.1145/2835596.2835613

IKSR (2001) Rheinatlas. In: IKSR–Internationale Kommision zum Schutz des Rheins (International Commission for the Protection of the Rhine). Koblenz

Jenelius E (2010) Large-scale road network vulnerability analysis. Stockholm: KTH, School of architecture and the built environment (ABE), transport and economics, transport and location analysis

Jenelius E, Petersen T, Mattsson L-G (2006) Importance and exposure in road network vulnerability analysis. Transp Res A Policy Pract 40(7):537–560

Kaplan S, Garrick BJ (1981) On the quantitative definition of risk. Risk Anal 1(1):11–27

Keller S, Atzl A (2014) Mapping natural hazard impacts on road infrastructure—the extreme precipitation in Baden-Württemberg, Germany, June 2013. Int J Disaster Risk Sci 5(3):227–241

King G (2016) A spatial framework supports road investment decisions arcuser. http://www.esri.com/esri-news/arcuser/fall-2016/a-spatial-framework-supports-road-investment-decisions, ESRI, 2016

Kounadi O, Lampoltshammer TJ, Groff E, Sitko I, Leitner M (2015) Exploring twitter to analyze the public's reaction patterns to recently reported homicides in London. PLoS ONE 10(3):e0121848

Latora V, Marchiori M (2001) Efficient behavior of small-world networks. Phys Rev Lett 87(19):198701

Mansor S, Mohammed AS, Lawal B, Iwan S, Faisal J (2004) Spatial technology for natural risk management. Disaster Prev Manag 13(5):364–373

Mete HO, Zabinsky ZB (2010) Stochastic optimization of medical supply location and distribution in disaster management. Int J Prod Econ 126(1):76–84

Middleton SE, Middleton L, Modafferi S (2014) Real-time crisis mapping of natural disasters using social media. IEEE Intell Syst 29(2):9–17

Norris FH, Stevens SP, Pfefferbaum B, Wyche KF, Pfefferbaum RL (2008) Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. Am J Community Psychol 41(1–2):127–150

Oort P (2005) Spatial data quality: From description to application. In: Nederlandse Commissie voor Geodesie, NCG, Delft

Poser K, Dransch D (2010) Volunteered geographic information for disaster management with application to rapid flood damage estimation. Geomatica 1:89–98

Rajabifard A, Coleman D (2012) Towards spatial enablement and beyond. In: Rajabifard A, Coleman D (eds) Spatially enabling government, industry and citizens: research and development perspectives. GSDI Association Press, Needham, pp 9–22. http://hdl.handle.net/11343/32694

Rawls CG, Turnquist MA (2006) Pre-positioning of emergency supplies for disaster response. In: 2006 IEEE international symposium on technology and society, pp 1–9

Report: Transportation Research Board (2008) The role of transit in emergency evacuation. http://onlinepubs.trb.org/Onlinepubs/sr/sr294.pdf

Resch B (2013) People as sensors and collective sensingcontextual observations complementing geo-sensor network measurements. In: Krisp JM (ed) Progress in location-based services. Springer, Berlin. https://doi.org/10.1007/978-3-642-34203-5_22

Rhine Atlas (2015) http://www.iksr.org

Sakakibara H, Kajitani Y, Okada N (2004) Road network robustness for avoiding functional isolation in disasters. J Transp Eng 130:680–687

Salmerón J, Apte A (2010) Stochastic optimization for natural disaster asset prepositioning. Prod Oper Manag 19(5):561–574

Schmiedel R, Behrend H, Betzler E (2012) Regelwerk zur Bedarfsplanung Rettungsdienst: Mendel Verlag

Starbird K, Palen L, Hughes AL, Vieweg S (2010) Chatter on the red: what hazards threat reveals about the social life of microblogged information. ACM, Savannah. https://doi.org/10.1145/1718918.1718965

Taylor MAP, Sekhar SVC, D'Este GM (2006) Application of accessibility based methods for vulnerability analysis of strategic road networks. Netw Spat Econ 6(3):267–291

Tulloch D (2008) Is volunteered geographic information participation? GeoJournal 3:72

Tutorial–ArcGIS for Desktop. http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/what-is-network-analyst-.htm

Van Hentenryck P, Bent R, Coffrin C (2010) Strategic planning for disaster recovery with stochastic last mile distribution. In: Lodi A, Milano M, Toth P (eds) Proceedings of 7th international conference integration of AI and OR techniques in constraint programming for combinatorial optimization problems, CPAIOR 2010, Bologna, Italy. Berlin, Heidelberg, pp 318–333. https://doi.org/10.1007/978-3-642-13520-0_35

Vieweg S, Hughes A, Starbird K, Palen L (2010) Microblogging during two natural hazards events: what twitter may contribute to situational awareness. In: Human factors in computing systems, Atlanta, Georgia, USA. https://doi.org/10.1145/1753326.1753486

Xu Z, Sugumaran V, Zhang H (2015) Crowdsourcing based spatial mining of urban emergency events using social media

Yin J, Lampert A, Cameron M, Robinson B, Power R (2012) Using social media to enhance emergency situation awareness. IEEE Intell Syst 6:52–59

Zook M, Graham M, Shelton T, Gorman S (2010) Volunteered geographic information and crowdsourcing disaster relief: a case study of the Haitian earthquake. World Med Health Policy 2(2):7–33