Assessment of social vulnerability under three flood scenarios using an open source vulnerability index

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February 18, 2015

Summary

This paper utilises an open source flood vulnerability index to assess changes in social vulnerability within the English county of Norfolk under three flood scenarios. Open source demographics data are combined with flood zone data and GIS analysis of accessibility to key services to create the flood vulnerability index. The impact of flooding was found to be disproportionately distributed amongst those areas recording a high level of social vulnerability before flood risk was included. Analysis suggests those at risk of flooding are more likely to be elderly, poor and have long-term health problems.

KEYWORDS: Vulnerability, Open Source, Demographics, Flood Risk, Vulnerability Index

1. Introduction

Floods pose an environmental and fiscal challenge for the United Kingdom. More than five million homes and businesses are at risk of flooding (DEFRA, 2013) and an average of £1 billion in flood damages is incurred each year (EA, 2013). Flooding can have a far-reaching and long-lasting impact on a community (Bennet, 1970; Milojevic *et al.*, 2011). Those in society most often deemed vulnerable: the elderly, poor or unemployed, for example, often see their level of vulnerability increase during hazard events as both risk and exposure increases. The features of a person's life that makes them vulnerable are often intensified: the loss of income following a flood exacerbating poverty, for example. A greater knowledge of the spatial distribution of vulnerability within communities is therefore key to understanding how a population may be impacted by a hazard event (Cutter & Emrich, 2006). Highlighting those who are exposed to a hazard, as well as those who are potentially more vulnerable due to their circumstances, can aid emergency response and risk reduction strategies (Nelson, *et al.*, 2007).

This paper utilises an open source vulnerability index (OS-VI), previously created by the authors (Garbutt *et al.*, 2014), to assess changes in social vulnerability within the English county of Norfolk under three flood scenarios. Norfolk has a substantial coastline and a lengthy history of flooding, including being severely impacted by the 1953 North Sea Flood, as well as a substantial elderly (23%) and potentially vulnerable population (DCLG, 2011). The revised OS-VI presented herein, which incorporates updated demographics data recently released by the Office for National Statistics, provides a place-based assessment of vulnerability and when combined with flood risk scenarios can provide

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non-governmental organisations (NGO) and local authorities with valuable context and guidance when planning for or responding to flood emergencies.

2. Background

The British Red Cross (BRC) works throughout the UK and internationally preparing communities for disasters, supporting post-disaster recovery, delivering and teaching first aid and assisting individuals with health and social care needs. Since 2010 the BRC has operated a Mapping Team that utilises Geographical Information Systems (GIS) and the growing wealth of spatial data to support the organization's work. For the BRC, vulnerability analysis and mapping provides context to hazards and provides information that can guide service delivery and the provision of community resilience building programs.

The development of vulnerability indices is an increasingly common method to capture the geographical distribution of vulnerability across regions, countries or sub-national areas (see: Cutter *et al*., 2003; Johnson *et al*., 2012). Vulnerability indices are regularly used, in conjunction with needs assessments and on-the-ground research, to target service provision and justify resource allocation (Flanagan *et al.*, 2011). Further, such indices are increasingly being coupled with hazard assessments to create integrated risk analyses and feed into emergency response strategies (COES, 2010; Dunning & Durden, 2011; Siagian, *et al*., 2013). To produce such practical analysis and assessment of vulnerability, many socio-economic elements that influence vulnerability must be assigned measureable numeric indicators (Atteslander *et al*., 2008). However, past work on measuring and mapping vulnerability has been limited by a focus on income-related indicators, a lack of consideration of accessibility, the production of large resolution indices (county or country scale), and the reliance on proprietary data and/or methodologies, with limited attention paid to open source data (Garbutt *et al.*, 2014).

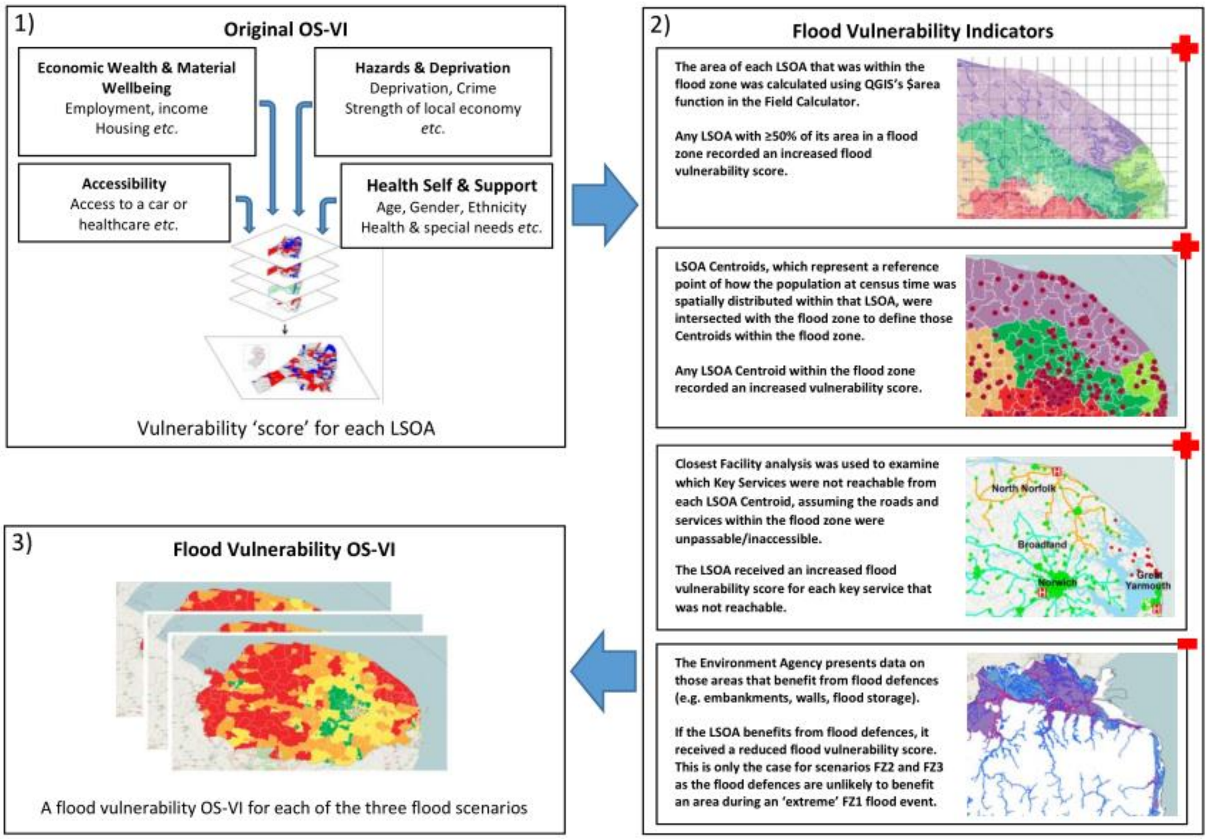
3. Methodology

The authors previously created an Open Source Vulnerability Index (OS-VI), a deductive indicator-based index that incorporated 53 different vulnerability indicators shown to influence vulnerability (Garbutt *et al*., 2014). Unlike many vulnerability indices, the OS-VI was produced using open source demographic data only and incorporated indicators of flood risk as well as accessibility and the loss of capabilities and access to key services (health facilities and food stores) when determining an area's level of social vulnerability. The OS-VI provided a mechanism whereby quality open source data on the core drivers of vulnerability could be used to create a vulnerability index with a sufficiently small resolution to examine vulnerability at the community level. Here, the OS-VI is used as a starting point to examine the impact of three flood scenarios (presented in table 1) and is supplemented with spatial analysis to generate four flood vulnerability indicators for each of the 539 Lower Layer Super Output Areas (LSOA) within Norfolk (see figure 1).

Table 1 Flood Scenarios (adapted from Environment Agency, 2014)

Scenario	Probability
Very Low (FZ1)	Land assessed as having less than 1 in 1,000 (0.1%) annual probability of flooding. This scenario is described as an 'extreme flood'.
Low (FZ2)	Land assessed as having between a 1 in 200 (0.5%) annual probability of flooding.
Moderate (FZ3)	Land assessed as having a 1 in 100 (1%) or greater annual probability of flooding.

The results of the four flood vulnerability indicators are combined with the social vulnerability indicators within the original OS-VI to produce an overall vulnerability score for each LSOA in Norfolk. The results are mapped and the changes in vulnerability examined.



The area of each LSOA that was within the flood zone was calculated using QGIS's $area function in the Field Calculator.

Any LSOA with ≥50% of its area in a flood zone recorded an increased flood vulnerability score.

LSOA Centroids, which represent a reference point of how the population at census time was spatially distributed within that LSOA, were intersected with the flood zone to define those Centroids within the flood zone.

Any LSOA Centroid within the flood zone recorded an increased vulnerability score.

Closest Facility analysis was used to examine which Key Services were not reachable from each LSOA Centroid, assuming the roads and services within the flood zone were unpassable/inaccessible.

The LSOA received an increased flood vulnerability score for each key service that was not reachable.

The Environment Agency presents data on those areas that benefit from flood defences (e.g. embankments, walls, flood storage).

If the LSOA benefits from flood defences, it received a reduced flood vulnerability score. This is only the case for scenarios FZ2 and FZ3 as the flood defences are unlikely to benefit an area during an 'extreme' FZ1 flood event.

Figure 1 Flow Chart outlining the methodology used to develop the flood vulnerability OS-VI presented herein. 1) Use of original OS-VI; 2) production of flood vulnerability indicators; 3) combination of both to create a Flood Vulnerability OS-VI for each flood scenario under analysis.

4. Results

As can be seen in figures 2 and 3, the major clusters of LSOA with high vulnerability ratings across the original OS-VI and all three flood scenarios loosely match those areas with greater exposure to the flood hazard. Although changes are slight, vulnerability ratings of areas already deemed highly vulnerable within the original OS-VI were found to increase as the impact and extent of flooding increased across the three flood scenarios examined. The impact of flooding was found to be disproportionately distributed amongst those LSOA recording a *high* or *moderate-high* vulnerability rating: roughly 66% of LSOA with the majority of their area within the flood zone and 76% with their Centroid within a flood zone recorded a *high* or *moderate-high* vulnerability rating.

Of those highlighted as at risk of flooding, our analysis suggests residents are also more likely to live alone and be aged 65+; have an income below the national median; lack central heating in their home; have bad or very bad health and limited actions due to a long-term health problem/disability; provide in excess of 50 hours care to another per week. An underlying relationship between the presence of flood hazard in an area and its socio-economic and health vulnerabilities is therefore suggested, although the relationship is unclear and further study is needed.

In addition, analysis of changes in accessibility found that those populations highlighted above are also more likely to live in an area where travel time to key services is in excess of the national average. Travel time to key services was severely impacted under all flood scenarios. For example, under scenario FZ1, the local authority of Kings Lynn recorded a 223% increase in average travel time, from 21 minutes to 68 minutes, and the local authority of Great Yarmouth, which was identified as being the most vulnerable local authority in Norfolk as well as the most affected by flooding, recorded 43% of its LSOA as completely cut-off from healthcare facilities.

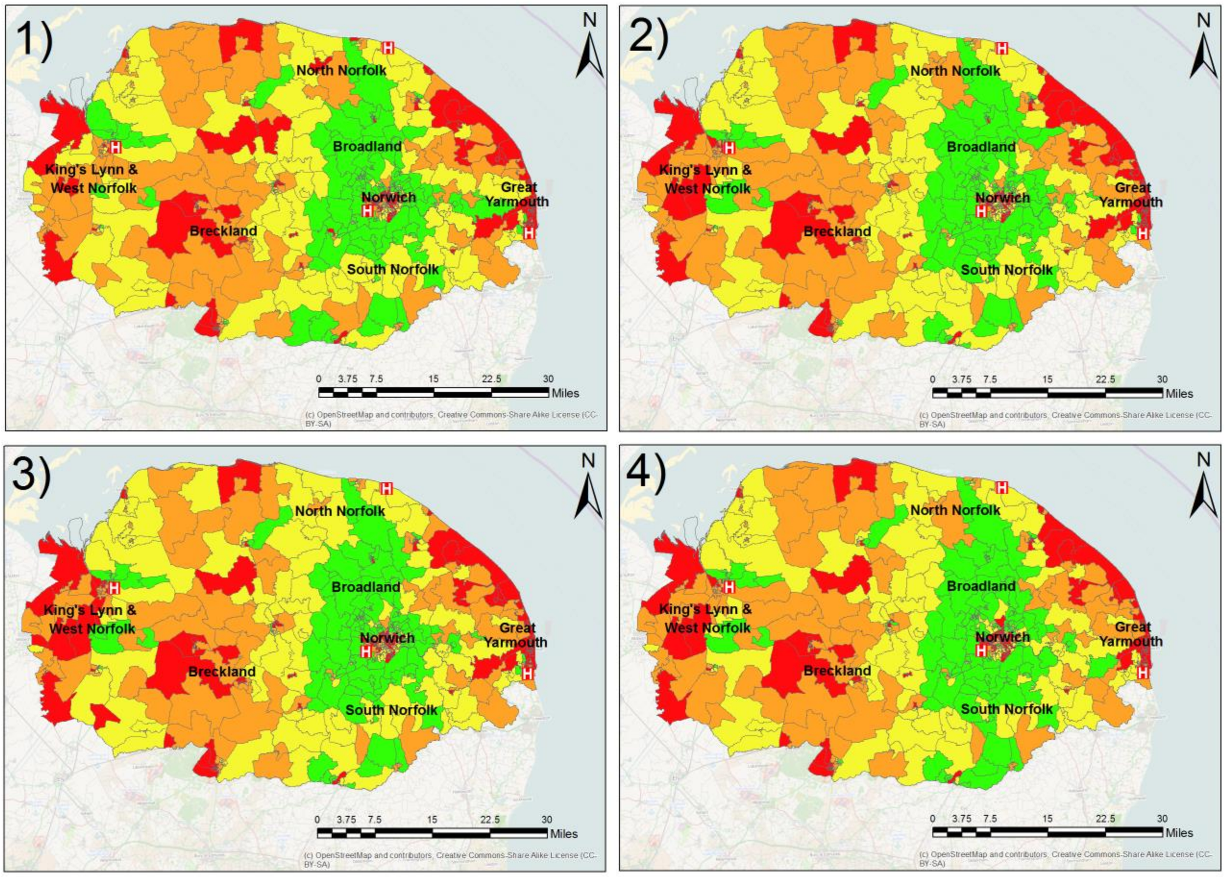


Figure 2 Vulnerability Indices. 1) Original OS-VI; 2) Vulnerability Index under FZ1 scenario; 3) Vulnerability Index under FZ2 scenario; 4) Vulnerability Index under FZ3 scenario.

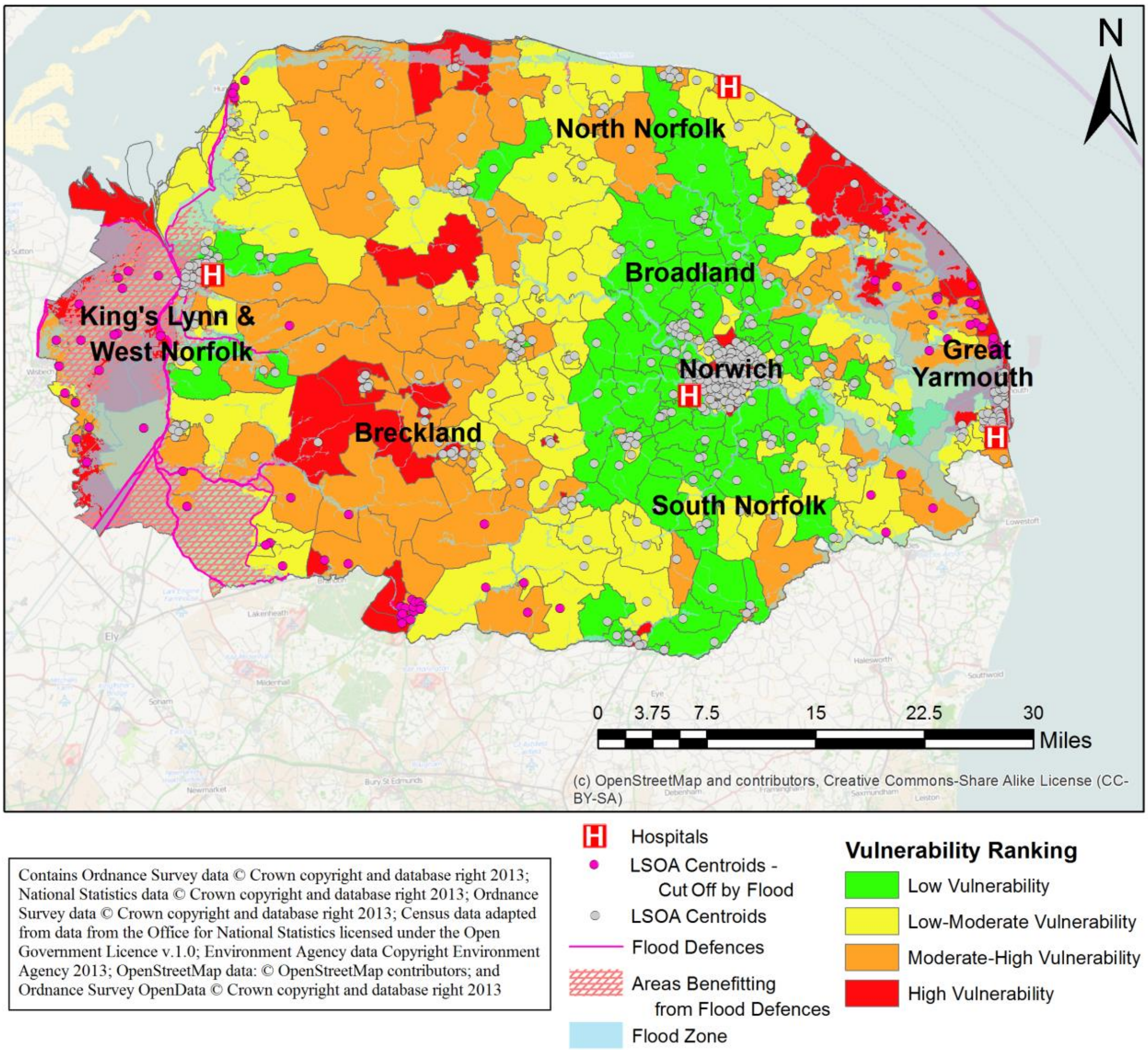


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Figure 3 Vulnerability Index under FZ3 'extreme flood' scenario featuring flood data overlay.

5. Discussion

The results presented above demonstrate the potential cascading impact of a flood hazard as it impacts an already vulnerable population: exacerbating pre-existing vulnerabilities, limiting capabilities and restricting accessibility and access to key services. The OS-VI and its use here to examine the potential impact of flooding was found to be a useful supplementary tool for the BRC, with the measurement and visualisation of vulnerability and potential hazard impact providing context and aiding response service planning and capability assessment.

To ensure its use by the BRC, open data and software was used exclusively to reduce organizational expenditure and provide quality data that can be freely disseminated. The demographic data used was deemed the best available at the scale and resolution required and the GIS software used, QGIS, was also deemed appropriate for the analysis required. One limitation noted was the assumption that, under each flood scenario, all roads within the flood zone would be impassable and thus roads and key services within each zone were restricted. This was due to the lack of flood depth information within the available flood data. Future work would use topographical data and digital elevation models to calculate flood depth and improve the accessibility metrics within the indices.

It was also noted that the discrete county boundary used to restrict analysis to within the county of

Norfolk likely led to limitations within accessibility routing as key services outside of the study zone may have been a viable option if the restriction was not in place. At a county level the analysis remains valid, but for organisations like the BRC who regularly work across boundaries, future work will address this scale effect by examining service locality and the catchment zones of neighbouring services that are utilised by populations within the study zone.

6. Conclusion

The approach presented here utilises vulnerability indices built upon quality open data to examine the potential impact of flooding on social vulnerability. The original OS-VI takes into account a broad range of social and economic indicators to highlight hotspots of social vulnerability. The addition of varying hazard scenarios allows for the examination of how vulnerability changes during an emergency. The indices produced can be extended to the national level whilst retaining the relatively small LSOA resolution. The methods used are scalable and adaptable and the use of open data allows all parties involved to easily coordinate and share information, potentially improving local knowledge and reducing vulnerability (Trujillo *et al*. 2000). The OS-VI and its use here to examine flood risk represents the first step in imagining a dynamic and customisable disaster risk platform that can be updated as new data is made available and adapted and utilised by the BRC and others to identify pockets of vulnerable communities and improve emergency response.

7. Biography

Kurtis Garbutt is a postgraduate research engineer at the Centre for Urban Sustainability & Resilience at University College London. Kurtis received a full EPSRC scholarship to work with the British Red Cross on development of a GIS tool to support the work of NGOs and improve understanding of urban resilience.

Claire Ellul is a lecturer and course tutor at UCL. Claire’s research focuses on spatial data management and infrastructures, in particular the creation, maintenance and use of metadata, as well as big data performance optimization and the use of topology in GIS, in particular 3D GIS.

Taku Fujiyama is a lecturer and leader of the Resilience Research Group at UCL. Taku’s research focuses on the resilience of infrastructure, primarily transport systems, as well as the understanding of user behaviour of transport environments, particularly amongst the most vulnerable, and the design and operation of railway infrastructure.

8. Acknowledgements

This work was supported by the Economic and Social Research Council and represents part of an EngD project currently being undertaken at University College London. The authors thank Andrew Braye and the Mapping Team at the British Red Cross for guidance. Portions of this study have been presented in an article currently under review by the journal *Environmental Hazards: Human and Policy Dimensions*. Data was provided by Ordnance Survey under ©Crown copyright and database right 2014; Office for National Statistics licensed under the Open Government Licence v.1.0; Environment Agency under Copyright Environment Agency 2014; and OpenStreetMap under ©OpenStreetMap contributors.

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