Using a Vulnerability Index and Agent-Based Modelling to explore British Red Cross Emergency Flood Response

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Summary

This paper presents an updated and 'agentised' version of the Open Source Vulnerability Index (OS-VI), previously created by the authors (Garbutt et al., 2014), to assess changes in social vulnerability over the course of a flood emergency. The model provides a dynamic, place-based assessment of vulnerability and when combined with flood risk scenarios can provide NGOs and local authorities with valuable context and guidance when planning for or responding to flood emergencies. The paper also outlines the work and research goals of the BRC with an aim to increasing mutually beneficial academic research.

KEYWORDS: Vulnerability, Demographics, Agent-Based Modelling, Vulnerability Index, NGO, Emergency, Aid, Open Source, Flood Risk

1. Introduction

Flooding represents the primary natural hazard for much of the UK. The British Red Cross (BRC) is regularly called upon to provide emergency flood response, including relief distribution, evacuation management, ambulance support and rest center management following a flood.

Spatial vulnerability assessments are routinely used by non-governmental organisations (NGOs) and emergency services to examine levels of vulnerability across a given area to understand better the potential impact of an emergency and to plan appropriate response procedures. Most such assessments consider vulnerability from a static point of view. These indices usually present vulnerability as a snapshot in space and time and are rarely capable of capturing the short-term, dynamic nature of vulnerability during an emergency.

This paper presents an updated and 'agentised' version of the Open Source Vulnerability Index (OS-VI), previously created by the authors (Garbutt *et al*., 2015), to assess changes in social vulnerability over the course of a flood emergency within the English county of Norfolk under three flood scenarios. The model provides a dynamic, place-based assessment of vulnerability and when combined with flood risk scenarios can provide NGOs and local authorities with valuable context and guidance when planning for or responding to flood

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emergencies. The paper also outlines the work and research goals of the BRC with an aim to increasing mutually beneficial NGO-academic cooperation and research.

The research aims to examine questions such as: is it possible to model accurately the dynamic drivers of vulnerability? What is the appropriate level of abstraction, aggregation and time frame when modelling vulnerability? Can we identify thresholds within response impact and vulnerability?

2. Vulnerability & Emergency Response

Collectively, vulnerability in the UK appears to be increasing (Lewis & Lewis, 2014). With an ageing society and increased disparity between wealth and healthcare (Appleby, 2013; OECD, 2015), modern society includes groups whose vulnerability can greatly increase their level of risk during times of crisis. The elderly proportion of the UK population is increasing and it is estimated that one-third of people born today will live to 100 (ONS, 2014). However, it is likely that they will also live with long term chronic health problems and comorbidities and may have reduced pensions, state support and be increasingly isolated (AgeUK, 2014; Humphrey et al., 2012).

The identification of vulnerability is an important part of NGO work and relief distribution. Pinpointing where those most likely to be affected by an emergency are located as well as how they are likely to be impacted and their needs helps responders to effectively plan service provision.

During an emergency, such as a flood, the efficient distribution of relief is essential to reducing risk and saving lives. Emergencies are complex, constantly developing situations, with response capacity and overall knowledge changing minute by minute. There is a strong spatial dimension to emergency response and management planning work, yet there is a lack of emergency response models that utilise geographical data and aid planning and assessment (Hashemi & Alesheikh, 2013). Further, there is a lack of grounded and applied work that coordinates with emergency responders (Menth, 2016). This research aims to produce a carefully designed emergency exploration and planning support tool to address this gap, facilitate decision making and further the progress of ABM within emergency response management.

3. The British Red Cross

The 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. Much of the work undertaken by the BRC in the UK focuses on providing valuable short-term support to vulnerable people following, for example, a hospital stay or a crisis such as a flood. In the future, the BRC anticipates having to offer 24/7 response capability and to adapt its service provision to accommodate the projected changes in population, particularly the increasing elderly population (Adamson, 2014). The BRC needs to be able to adequately plan and justify its future service development and provision through, for example, effective testing of emergency response plans and the targeting of communities where needs may change in the future and thus where services are likely to be needed and located.

To this end, the BRC, as well as the Third Sector and government/council-led social care providers more widely, require knowledge of the UK population's demographics, the geographical composition of vulnerability, as well as how a population is likely to act during certain events, for example a flood. Emergency simulation and planning is one of the best ways for an organisation like the BRC to examine these issues and ensure that it can adequately respond to future events (Stanganelli, 2008). Computer modelling is an effective method of visualising scenarios, testing strategies and identifying the resources, equipment and timescales required to adequately respond to an emergency (Stanganelli, 2008). It is also a considerably cheaper and less-restrictive method of simulation compared to real-world exercises and emergency simulations that are a mainstay of emergency response organisations (Taniguchi et al., 2010; Coburn & Spence, 2002). However, such work requires careful design, resources and time that such organisations more often than not lack (Tang & Wen, 2009) and so it is necessary for academics to work with the organisation.

The BRC is concerned with "what if" research questions that examine complex situations and test the potential impacts of strategy decisions to learn from the outcomes of such simulations and guide future work. The potential operative utilisation of tools such as vulnerability indices and ABM to simulate an evolving emergency could provide responders with the knowledge needed to adapt and improve real-life response strategies and improve response preparedness, as well as capacity and capability management.

4. Modelling Vulnerability & Response Efforts

This research updates, improves and 'agentises' the previously designed Open Source Vulnerability Index (OS-VI) (Garbutt *et al.,* 2015). Data pertaining to demographics (age, sex, population location and density, employment, household finances, health and disability etc.) obtained from, for example, the UK Census and Neighbourhood Statistics Service is combined with accessibility data produced by the Department of Transport, open source digital maps supplied by the Ordnance Survey (OS) and Office for National Statistics (ONS) and flood data produced by the Environment Agency to synthesise a population for the model. Vulnerability levels are dynamically represented at the LSOA level and are influenced by: demographics; economics and wellbeing; the presence of flood waters; accessibility; resource allocation; and the actions, decisions and response strategies of NGO agents (see figure 1).

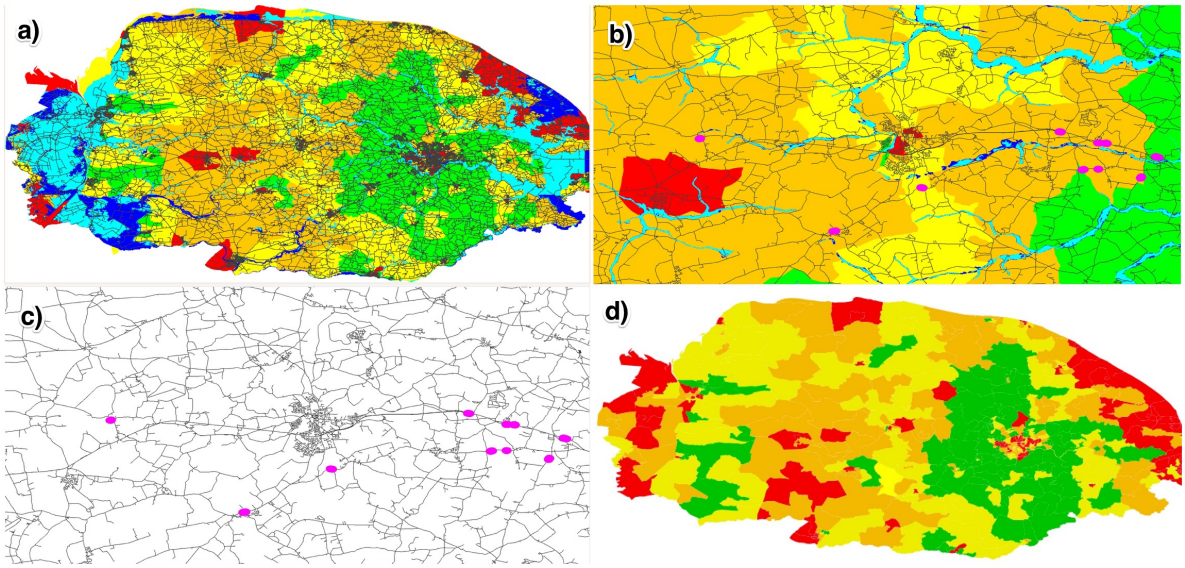

Figure 1 Model visualisations. a) Original OS-VI with flood map and road network overlay; b) Detail of OS-VI with Agents; c) Detail of road network with Agents; d) example OS-VI output after

The model is designed to visualize the movements, decisions, actions and interactions of multiple classes of responder agents (see figure 2) as well as the changes in vulnerability of those affected. The actions of responder agents are guided by response strategies dictated by users. Agents are endowed with a knowledge of where those affected are located, where flood zones are located and a set of rules governing their actions (*e.g.* if the agent runs out of resources, it heads back to base; if the agent encounters flood waters, it finds an alternate route *etc.*). Responder agents are used to test the feasibility and success of different relief distribution and response strategies. For example, during pre-event scenarios, leaflet and sandbag distribution strategies will be put in place whereby resources are distributed to those areas within the flood zones. Similarly, during post-event scenarios, water and cleaning supplies distribution strategies are put in place.

A participatory modelling approach is utilised whereby BRC staff and volunteers are included in all aspects of the model design to ensure that their domain knowledge is integrated and that the model addresses the most pressing BRC interests.

Several constraints were placed upon the research to maximise the use of the resultant model by the BRC and others: all secondary data used must be from the public domain and free to use; where possible open source software should be utilised; and all work, including all products, reports, briefings and external materials, must abide by the BRC's Fundamental Principles[§].

[§] More information can be found at: https://goo.gl/kl3NuX

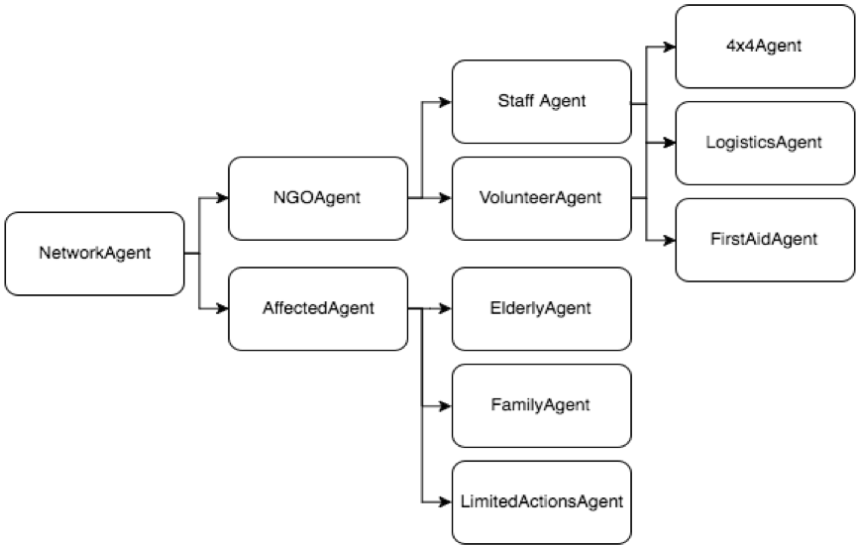

Figure 2 Schematic demonstrating agent class structure.

5. Future Work

The methods used to create both the Index and the model are scalable and adaptable and the use of open data encourages use by NGOs and supports coordination and information sharing, potentially improving local knowledge and reducing vulnerability (Trujillo et al. 2000). In addition, the modular setup of the model allows it to be extended with different management structures, hazards, or processes. The BRC regularly works across boundaries and with other NGOs and future work will address this scale effect by examining service locality, catchment zones and mutual aid.

The major contribution of this work is the novel synthesis of demographics analysis, vulnerability mapping and geospatial simulation to produce a dynamic model of vulnerability. The project contributes to the growing understanding of vulnerability and response management within the NGO sector by providing information, analysis and findings specifically geared towards their needs. It is hoped that NGO responders and others will use the model to examine vulnerability, and test response strategies and capacity and capability breakpoints before deployment.

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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.

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