24/7 Population modelling for enhanced assessment of exposure to natural hazards

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1. Introduction

Accurate spatio-temporal population estimates free from arbitrary administrative boundaries are required to make enhanced assessments of population exposure to natural hazards (Aubrecht *et al.*, 2012). Variability in vulnerable populations exposed to natural hazards, such as temporal density changes, needs to be recognised to make improvements in emergency planning in order to develop effective procedures (Cutter and Finch, 2008). Major natural hazard incidents have been highlighted by the UK government as one of the highest priority risks (HM Government, 2010).

The calculation of exposed population is not straightforward as populations are not static and shift dramatically with time (McPherson and Brown, 2004). Census datasets traditionally only provide residential 'night-time' population counts. This paper highlights the significant improvements that might be achieved in assessment of populations exposed to natural hazards through application of spatio-temporal models developed by the "Pop24/7" project (Martin *et al.*, 2009). This is exemplified through an application to flooding in the UK.

2. Methodology

Population data is modelled onto a variable grid. A 200 metre cell size has been chosen for this study. Population is redistributed from origin centroid locations derived from the 2001 UK census to destination locations such as shops, schools and workplaces according to a specified catchment area, spatial extent and associated time profile (Figure 1). A population capacity is assigned to each receiving destination such as the number of staff and students at a school. The time profile derived from ancillary datasets contains the temporal signal governing the proportion of a site's capacity occupied at a given time. A mask is applied to constrain the modelled population distribution preventing placement in uninhabitable areas such as water and to weight the population to likely locations such as the transport network. The population is modelled for seven age subgroups in order to assess variation in exposure between subgroups.

The modelled population density grids are combined with Environment Agency flood map data (July, 2012) to evaluate the effect that enhanced time-specific population estimates might have on exposure estimates with a 2006 mid-year estimate baseline population. The most likely scenario under the 'zone three' (high probability) extent (Figure 2) is employed: this models inundation caused by fluvial and tidal flooding with a 1% (1:100 years) and 0.5% (1:200 years) annual probability of exceedance respectively.

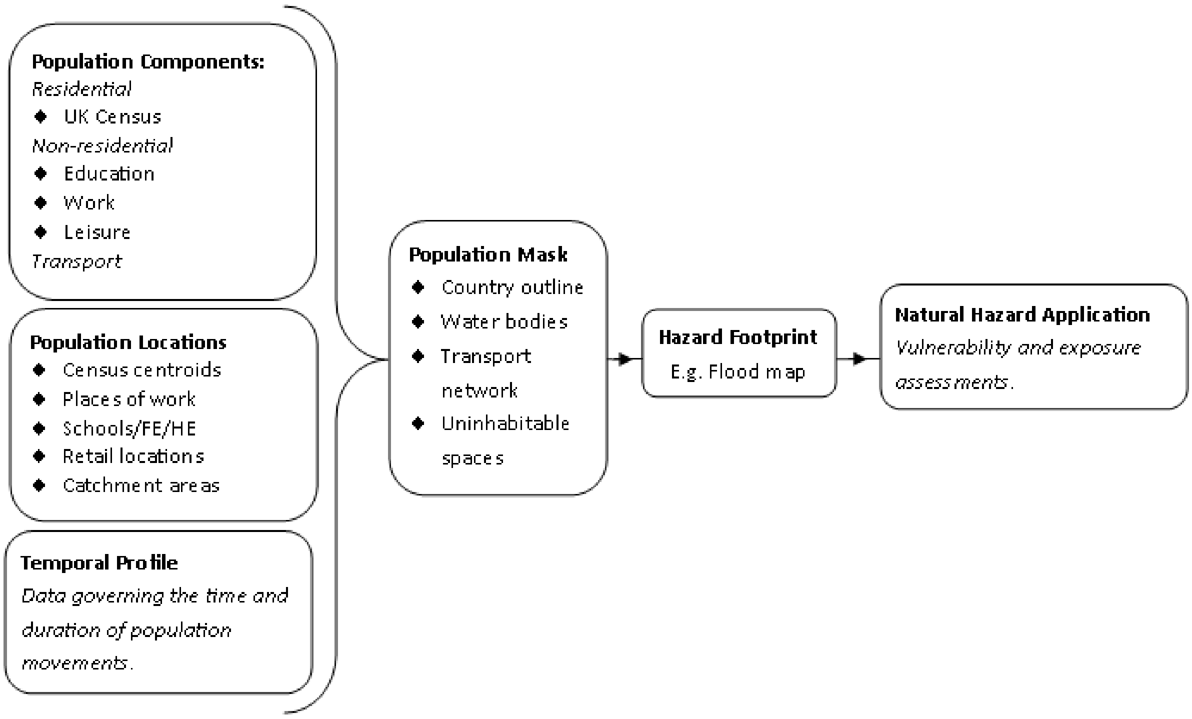

Figure 1 Overview of analytical operations to assess natural hazard exposure.

The modelling framework allows for consideration of population density variation over a range of temporal scales e.g. hourly, daily or seasonally. Datasets and temporal profiles can be amended accordingly to reflect this level of detail. Here, the population on a typical working weekday during school term time is modelled and population exposure estimates within the potential flood extent are calculated for different times of the day.

3. Example application: Flooding in the Solent region, UK.

A 25 × 25 km application study area is centred on Southampton (Figure 2). The narrow funnel-like channel is vulnerable to storm surges driven by low pressure systems, or north sea surges that propagate through the English Channel (Wadey *et al.*, 2012). When combined with high spring tides these events pose a heightened flood risk and exert pressure on existing defences. This region and accompanying low lying areas contain major coastal transportation links, population centres and commercial and military ports.

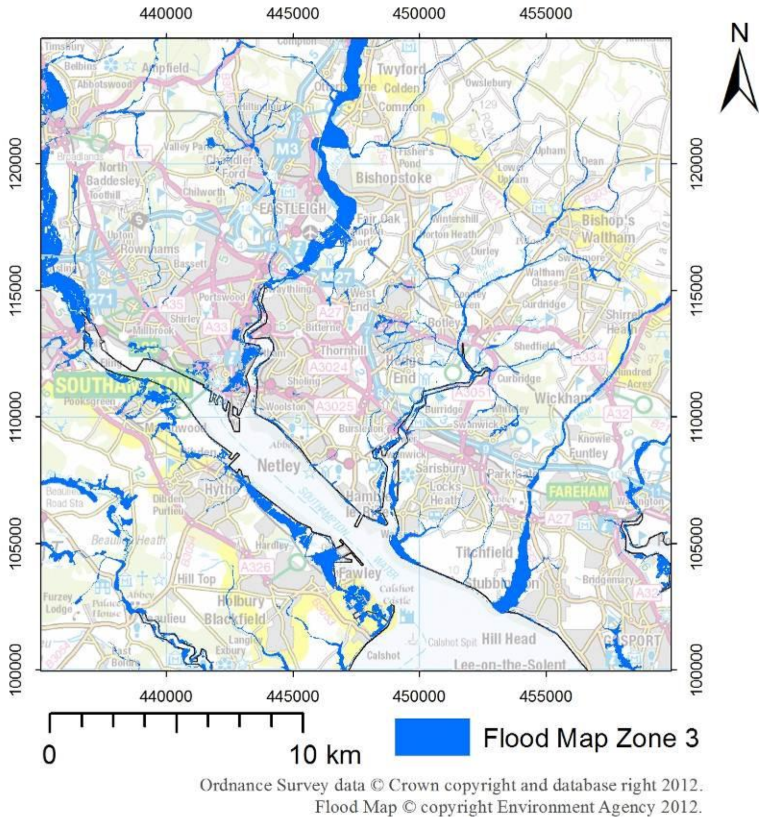

Figure 2 Application study area centred on Southampton (UK) showing potential flood inundation.

4. Results and Discussion

Figure 3a shows total population for rasterised 2001 census output areas and the population modelled in 200 m grid cells for three different times of day. A large daily variation in population occurs. During the working day (Figure 3c), population becomes highly concentrated in specific areas such as the city centre and schools as employees and students travel to and temporally reside at places of work and study. Population also increases in the non-residential areas of the city centre due to people travelling to engage in other activities as Southampton is a major retail and transportation hub. The 08:00 model differs from the 20:00 model with more people in the transportation network at 08:00 – mostly on their way to work or school (Figures 3b and d).

The modelled outputs contrast starkly with the coarse, static 'night-time' population density coverage provided by the 2001 census output areas The difference between the maximum cell values in the census and modelled outputs highlights the concentrated nature of population density during the working day, which is missed by traditional census maps. The modelled outputs also provide a more realistic distribution with zero population in uninhabited areas.

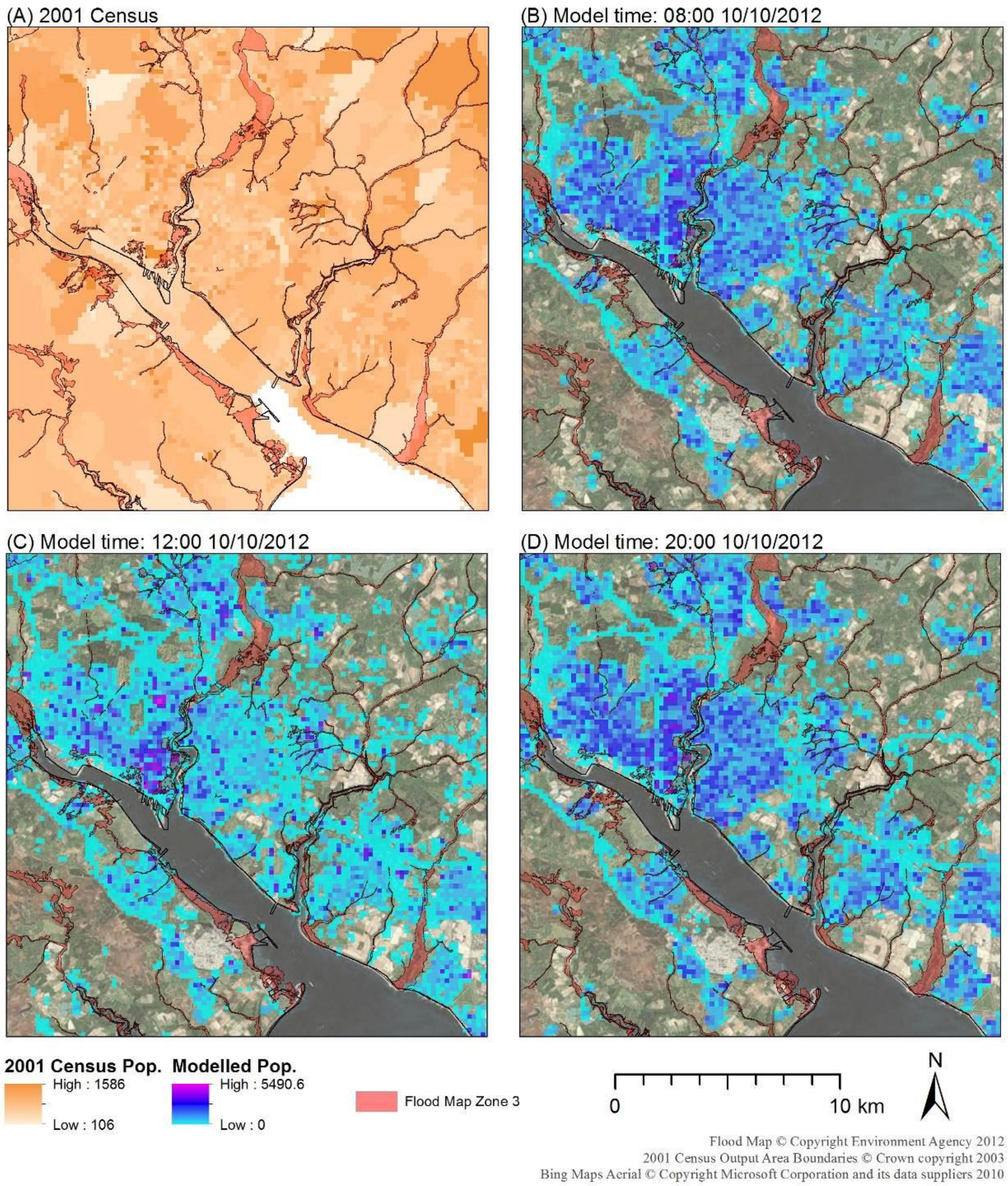

Figure 3(A) Rasterised 2001 census output area total population counts. **(B)-(D)** Spatio-temporal model ouputs showing total population for three time slices, together with Environment Agency flood map data. All maps at 200 metre resolution.

Within the study area approximately 78 km^2 is at risk of tidal or fluvial flood inundations under the zone three scenario. There are spatial (Figure 3) and temporal (Figure 4) shifts in populations potentially exposed during the day. Preliminary analysis suggests that the total population exposed peaks towards the end of the typical working day (Figure 4a). However, differentiating the flood risk components (Figure 4b) highlights an interesting phenomenon within the Southampton study area demonstrating the importance of spatio-temporal population estimates. Throughout the day exposure to fluvial flood risk closely resembles the reciprocal of tidal exposure with a symmetry approximately centred during standard working hours. This pattern is attributable to the region's coastal concentration of industry and commercial activity. As employees migrate to the coastal regions during the day their tidal flood exposure increases; when they return home to residential locations further inland in the evening fluvial flood risk dominates.

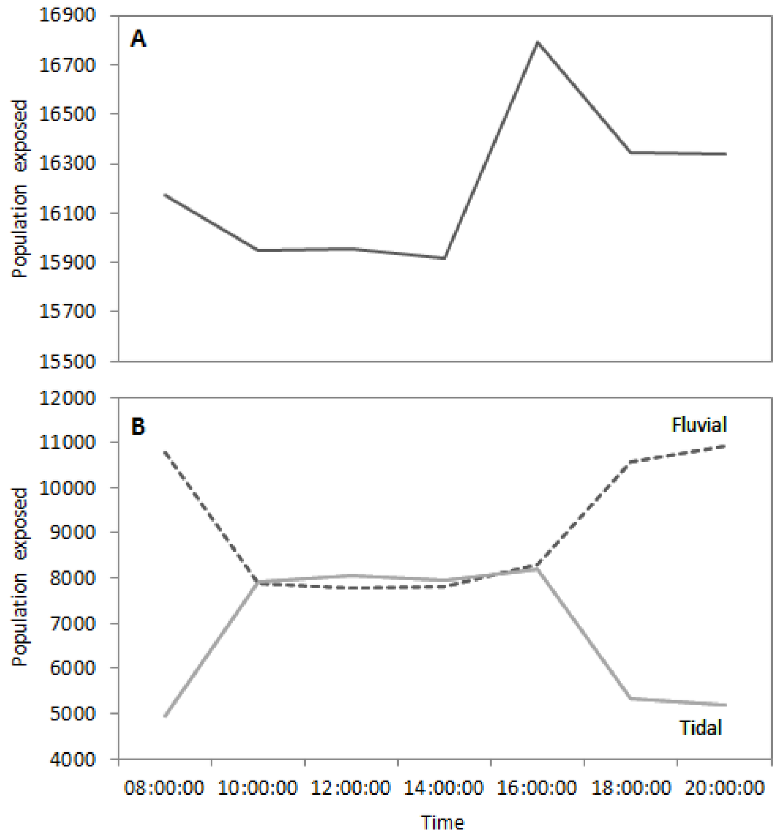

Figure 4(A) Estimated total population exposure by time of day for flood map zone three. **(B)** Estimated population exposure to the fluvial (1:100 year) and tidal (1:200 year) composite components of the zone three flood risk.

Figure 5 shows the percentage age group composition for the total population exposed at 12:00 and 20:00. The reversal in exposure between tidal and fluvial flooding is most notable within the working aged population, where there is a large decrease in tidal exposure in the evening.

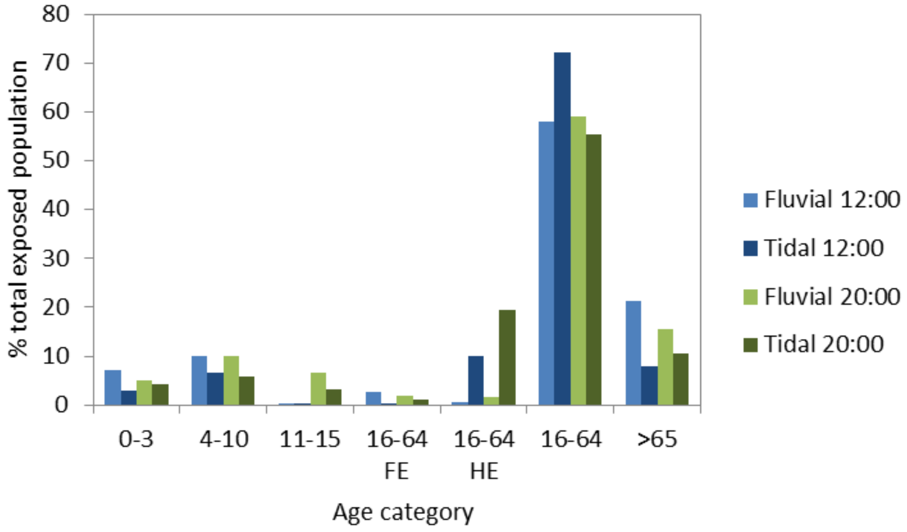

Figure 5 Age composition of population potentially exposed to fluvial and tidal flooding during the working day (midday) and evening (20:00).

5. Conclusions and Future Work

This paper demonstrates the enhanced insights and improvements in the accuracy of exposure estimates to hazards to be gained by employing spatio-temporal population models. The potential usefulness of such models for flood risk management has been demonstrated. Pending further dataset development and validation this technique has direct application to natural hazard scenarios both within the UK and globally.

6. Acknowledgements

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Biography

Alan Smith is an ESRC doctoral researcher in Geography and Environment at the University of Southampton. His research interests include spatio-temporal population modelling and the study of natural hazards.

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