A Spatiotemporal Population Subgroup Model of Radiation Exposure

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Summary

Understanding the whereabouts of vulnerable population subgroups during emergencies can improve the targeting and implementation of countermeasures, including evacuation and sheltering. This paper uses spatiotemporal population density modelling and atmospheric dispersal modelling to estimate the radiation exposure of a specific population at different times of day, during the start of a hypothetical radiation accident scenario in Exeter, UK. The model outputs are analysed by GIS to discern spatiotemporal trends in population exposure, and to identify the times of day when population subgroups may be most at risk.

KEYWORDS: Spatiotemporal population modelling, Public health, Radiation protection, Risk.

1. Introduction

The UK began the world's first civil nuclear energy production programme in 1956 and has a successful legacy of power generation. Nuclear energy currently contributes toward 18.5% of the UK electricity portfolio and a new phase of reactors is anticipated, following publication of the Nuclear Industrial Strategy (Bolton, 2013, HM Goverment, 2013).

Emergency preparedness is an important feature of nuclear installation (NI) management. All UK NIs are required to have off-site emergency planning to comply with Radiation (Emergency Preparedness and Public Information) Regulations (REPPIR). REPPIR includes the testing of hypothetical scenarios to inform understanding of potential outcomes and to improve decision-making. Nuclear and radiation emergencies are low-likelihood but extremely high impact events which have long-term public health implications. Demographic studies of historical accidents, including Fukushima Daiichi (2011), Chernobyl (1986), Three Mile Island (1979) and Idaho National Engineering Laboratory SL-1 (1961) have been used to advise preparedness. Fortunately, the UK has not experienced an accident of equivalent scale to these accidents. This paper tests a hypothetical scenario which includes accurate spatial and temporal population profiles, to understand how the timing of the start of an accident may cause differential exposure to vulnerable population subgroups.

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2. Methodology and Data

Gridded spatiotemporal population density modelling was combined with atmospheric dispersal modelling by GIS analysis. SurfaceBuilder was implemented to model spatiotemporal population density (Smith, 2013). Using this model, an adaptive kernel density algorithm was applied to redistribute population subgroups from individual postcode-based origin centroids, to destination centroids, and onto a transport network. The proportion and distance of the redistribution was determined by centroid density, catchment size, and time; and was dasymetrically constrained to prevent inappropriate relocation. It is important to include different population subgroups, due to age and gender differences in daytime spatiotemporal activity patterns, which can result in differential exposure. There are also some physiological differences between body mass, respiration and susceptibility to the effects of radiation exposure, across age and gender subgroups (Shore, 2014, Simon and Linet, 2014). Spatiotemporal distribution profiles were constructed for six new age groups and two new genders with 2011 data. An example of population data sources, scales, subgroups and temporal profiles within this case study is shown by **Figure 1.**

Origin Population (term-time): Residence type by age, by output area (LC1105, ONS). Usual resident population (KS101) **Origin Population (out-of-term-time):** Sex by single year of age OTT (OT1117, ONS).	Scale: Grid reference linked postcode.	Subgroups: Male and female, all age groups.	
Workplace: Workplace population by industry (WP605, ONS).	Scale: Workplace Zone to grid reference-linked postcode	Subgroups: Workplace: Male and female, 16-64WORK and 65+. Fifteen different industries.	Temporal profiles: Workplace: “Hours worked in the labour market” ONS. Working time patterns in the UK, ONS; HETUS.

Figure 1: A residential and workplace population example of data sources, scales, subgroups and temporal profiles.

However, the model also includes 2011 education, healthcare, retail, tourism, and leisure data to provide a comprehensive insight into the spatiotemporal whereabouts of different population subgroups during day-time. **Figure 2** shows the distribution of some of these activities, compared to the residential population distribution.

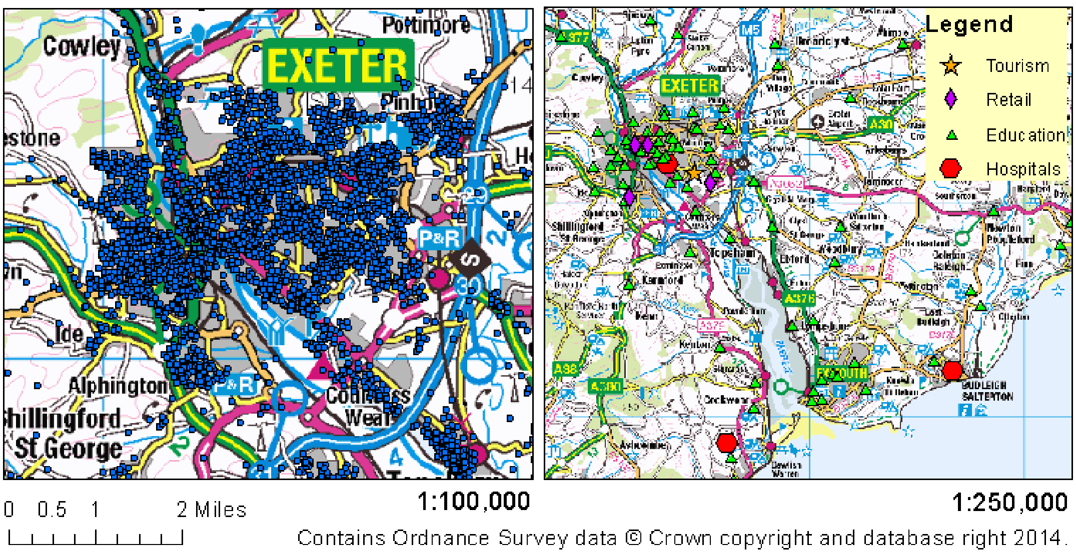

Figure 2: The original spatial distribution of residential population data (left) and activities (right).

The Numeric Atmospheric Modelling Environment (NAME) is a Lagrangian model which uses Monte-Carlo random walk techniques to represent and predict turbulent atmospheric transport, and the deposition of airborne substances in the atmosphere within a stochastic framework. NAME was applied to model the dispersal of 0.47PBq of Cs-134 a source term of ≈1% of Chernobyl for this isotope. Archive MESUM5 meteorological data used to generate dispersal for an hours' time slice from 08:00 to 09:00 on Monday 28th March 2011. This slice is being used to represent the start of an incident, to investigate exposure differentials for different populations. Regional weather was dry with hazy sunshine and a peak temperature of 19^{o}C, providing good conditions for dry deposition, which can be a source of external exposure in urban environments. However washout of atmospheric particles and gases may be a more significant exposure mechanism (IAEA, 1994). Dry deposition is also affected by deposition surface, but this is beyond the scope of this paper.

Atmospheric plume dispersal model and spatiotemporal population model data layers were combined using GIS to assess exposure likelihood, by concentration (Bq/m^2) for each grid cell of residential population density at 08:00 and 20:00.

3. Results

A study area of 15km^2 centered upon the City of Exeter (X: 286000, Y: 079500) was selected. Exeter is a location without a nuclear installation (NI), and is therefore a suitable analogue site. The city includes national and international rail, road and air transport infrastructure, and has a residential population of approximately 117,770 individuals (ONS, 2014).
Figure 3 3 shows some modelling results from the study area. Both images include NAME output for the dispersal of an atmospheric plume of Cs-134 from 08:00 to 09:00 on 28th March 2011. This has been combined with two different outputs of population distribution model, for assessment of radiation exposure.

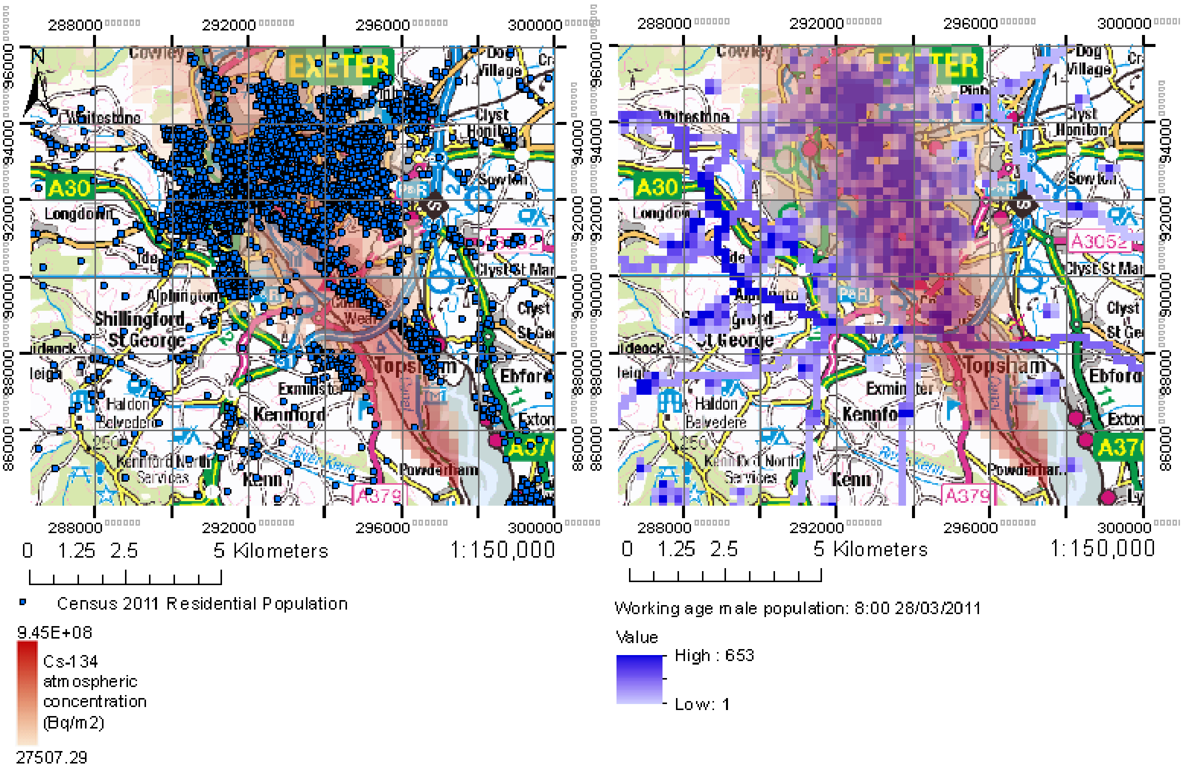

Figure 3: GIS analysis of NAME Cs-134 plume dispersal has been combined with a) Census total residential population centroid distribution; and b) SurfaceBuilder spatiotemporal population density surface output for a working-age male population subgroup, at 08:00 on 28th March 2011.

Figure 4 shows the difference between male and female spatiotemporal distribution for the working age population subgroup, at 22.00 on 28th March 2011. It is evident that fewer females are present within the city centre at the time. Combining this information with the plume model output, significantly more males of working age are likely to be exposed than females of working age within this scenario. This may be due to more females working in occupations that do not require evening-shift working patterns in this region.

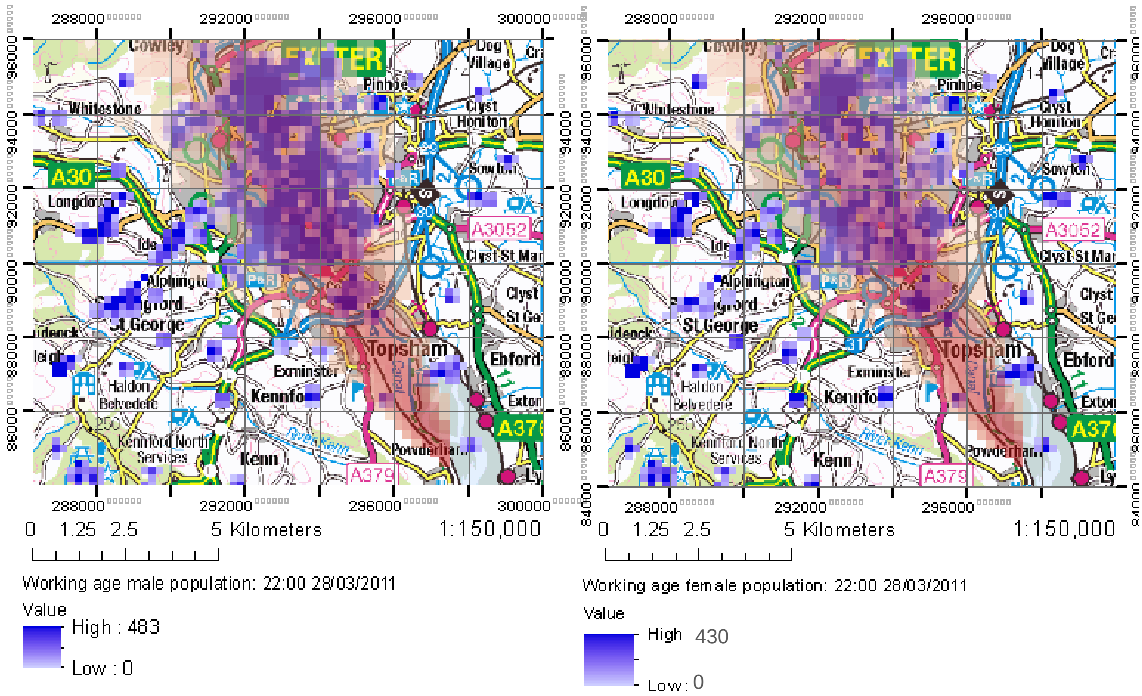

Figure 4: Comparison of male and female working age population distributions with equivalent NAME model output, at 22.00 on 28th March 2011.

Comparing the temporal profiles of the male and female working-age population subgroups confirms that more males than females should be anticipated within the city at 22.00 on a working weekday, and that therefore males are potentially more vulnerable to the effects of radiation exposure at the start of an incident, within this specific application.

4. Discussion and Conclusions

The inclusion of spatiotemporal population density modelling offers improvements upon the traditional chloropleth map, by revealing spatial population subgroup change through time. Whilst the hypothetical scenario of differential male and female exposure to radiation is interesting, the key purpose of this study is to demonstrate that spatiotemporal radiation plume dispersal modelling and population density modelling can be combined to offer new insights into the likelihood of subgroup exposure to radiation and its cumulative effects; providing substantial improvement to existing comparative study methodologies across different times, spaces, ages and genders, for any location where appropriate data is available.

Whilst this study provides a methodology for assessment of exposure at the start of a radiation emergency, there is still a need for a model which estimates the deterministic and stochastic health effects of radiation exposure to different populations in space and time.

5. Acknowledgements

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Data: OS 1:150,000 Scale Raster [WMS map service], Coverage: Exeter, Ordnance Survey/EDINA supplied service © Crown Copyright 2014. NAME modelling output and MESUM5 archive weather datasets © Copyright/database rights Met Office and Public Health England 2003-2014, Census Output Area Boundaries and Workplace Zones © Crown copyright 2011.

6. Biography

Becky Martin is a PhD researcher in Geography at the University of Southampton. Her research interests include spatiotemporal demography, public health and radiation protection.

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