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From flooding to finance: NHS ambulance-assisted evacuations of care home residents in Norfolk and Suffolk, UK

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Abstract

Focusing on the counties of Norfolk and Suffolk (UK), this investigation examines the effect of coastal and fluvial flooding on the use of ambulance service vehicles in the assisted evacuation of care home residents and quantifies the cost of this service to the NHS under flood conditions. This was completed using GIS Network Analyst functions to identify the impacts of flood probability (high: 1 in 30, medium: 1 in 30 to 1 in 100, and low: 1 in 100 to 1 in 1000) and target ambulance response-times (7, 18, 120, and 180 min) on ambulance service area, road network accessibility, the number of vulnerable care homes and their accessibility, the appropriateness of pre-identified evacuation routes, and the drive-time based evacuation cost to the National Health Service (NHS). The results indicate that approximately 68 care homes and 2,320 residents in Norfolk and Suffolk are at risk of inundation, and care home accessibility, in addition to ambulance service area, decreases with shorter ambulance response-times and lower flood probabilities. Additionally, the use of pre-identified evacuation routes, by the ambulance service, promotes efficient navigation between ambulance stations, care homes, and rest centres, but can unfavourably cause network clustering if unmanaged. In association with these routes, an estimated cost of evacuation based on ambulance drive-time was calculated at £34,000–£42,000 depending on flood probability. The importance of this research is highlighted by the current lack of identified flood evacuation and accessibility maps for emergency responder use, and the associated lack of evacuation cost estimations to be used by the government and NHS to budget for aid assistance during these natural disasters. Therefore, the application of this approach at a national level in the flood emergency planning process would be beneficial to promote strategic efficiency and financial preparedness of ambulance services for the purpose of ambulance-assisted flood evacuations.

KEYWORDS

coastal, economic assessment, emergency response and evacuation, fluvial

1 | INTRODUCTION

As a Category 1 lead planning authority of Local Resilience Forums, governed by the UK Civil Contingencies Act 2004, the ambulance service is a vital emergency responder in the rescue component of the emergency planning process, responsible for the provision of relief (prior to inundation) and rescue (during inundation) of vulnerable populations, via assisted emergency evacuations during flood events (Coles, Yu, Wilby, Green, & Herring, 2017; DEFRA, 2014; Green et al., 2017; Lumbroso & Vinet, 2012). This vulnerable population is identified through social vulnerability principles associated with the Social Flood Vulnerability Index (SFVI), which were consequently mapped by 2002 as a part of the 77 Catchment Flood Management Plans produced by the Environment Agency (Anderson, 1995; Blaikie, Cannon, Davis, & Wisner, 2014; Cutter, Boruff, & Shirley, 2003; Cutter, Mitchell, & Scott, 2000; DEFRA and Environment Agency, 2002; Tapsell, Penning-Rowsell, Tunstall, & Wilson, 2002), as individuals that lack self-reliance and exhibit chronic medical conditions, such as care home residents, of which approximately 75% are severely disabled, 78% have abnormal mental capacity, and 100% require 24-hr personal care (Aday, 1994; Bowman, Whistler, & Ellerby, 2004; Fernandez, Byard, Lin, Benson, & Barbera, 2002; Gordon et al., 2013; NHS England, 2015). These individuals frequently utilise ambulance transportation due to their requirement of continuous medical monitoring (but not necessarily medical treatment), which consequently promotes the 'worst-case' scenario generalisation that ambulance vehicles are also likely to be frequently utilised for flood evacuation purposes (Renne, 2018; Renne, Sanchez, Jenkins, & Peterson, 2009; Rich & Callahan, 2008). Although the provision of ambulance services in flood emergency plans promotes the safeguarding of society by evacuation, to minimise injury and fatality (Alexander, 2005; Chang, Tseng, & Chen, 2007; Lumbroso & Vinet, 2012; McEntire & Myers, 2004), for improved efficiency, the plans require greater details of accessibility, area coverage, evacuation routes, and financial expenses (Lumbroso, Stone, & Vinet, 2011; Lumbroso & Vinet, 2012). This corresponds with the in-situ dependence of ambulance response on the static identification of floodable pathways and at-risk individuals and facilities, in addition to the dynamic aspects of flood hazard evolution, evacuee behaviour and strategic, tactical and operational variables associated with responder coordination and interactions, which are co-occurring on the ground (DEFRA, 2014; Leknes, Aartun, Andersson, Christiansen, & Granberg, 2017; Powell, Jaillet, & Odoni, 1995; Shahabi & Wilson, 2018).

The efficiency of ambulance-assisted emergency evacuations becomes impaired as road network flooding significantly decreases the ability of ambulance navigation, and therefore restricts road and vulnerable population accessibility (Albano, Sole, Adamowski, & Mancusi, 2014; Coles et al., 2017; Green et al., 2017; Lhomme, Serre, Diab, & Laganier, 2013; Yin, Yu, Yin, Liu, & He, 2016). This has been identified in previous research as road network disruptions associated with flooding have been evidenced to result in the complication of transport routes due to necessary diversions, single access transport routes as roads become impassable, the inaccessibility of critical road connections that connect largely populated areas, and the inaccessibility of areas that become islands with no navigational routes (Albano et al., 2014; Balijepalli & Oppong, 2014; Coles et al., 2017; Gil & Steinbach, 2008; Green et al., 2017; Sakakibara, Kajitani, & Okada, 2004). At present, this information of inaccessibility is not included in flood emergency plans with enough detail to be of sufficient use to emergency responders (Lumbroso et al., 2011; Lumbroso & Vinet, 2012), as was apparent during the 2007 flooding of England and Wales in which a lack of maps detailing the vulnerability of road network infrastructure to inundation greatly delayed the transportation of emergency response vehicles (Lumbroso et al., 2011; Pitt, 2008). Therefore, in an effort to bridge this accessibility identification gap, factors of the road, area, and site accessibility will be incorporated into this investigation.

Global advances in this research examine the influence of flooding on emergency responder accessibility by attributing ambulance service area (area that an ambulance can assist) and response-time (recommended response timeframes, e.g., 8 and 10 min for 'Red 1', time-critical incidents, based on the former UK legislated response-time targets) to road network inundation, via a GIS approach of combining flood extent, integrated transport network (ITN) data and a routing algorithm (Coles et al., 2017; Elboshy et al., 2018; Green et al., 2017; Yin, Yu, Lin, & Wilby, 2017). The concurring trends identified within these studies involve the understanding that responder timeframes restrict the distance that an ambulance can travel, thereby limiting service area and therefore accessibility (Albano et al., 2014; Coles et al., 2017; Green et al., 2017). However, this has not yet been replicated to correspond with updated UK target ambulance response-times of 7 min (for life-threatening cases), 18 min (for emergency cases), 120 min (for urgent, uncomplicated cases), and 180 min (for less urgent cases) (NHS England, 2017), or in reference to ambulance-assisted evacuations of vulnerable populations.

For successful evacuations to take place, arguably the most crucial factor is the identification of 'optimal' (most efficient) transportation routes to be used by the ambulance service to access large service areas in short timeframes (Cabinet Office, 2014). However, currently the UK predominantly lacks specific evacuation transport routes, although there are exceptions to this statement such as the implemented signage of 12 evacuation routes from coastal flooding in Lincolnshire county (Lumbroso et al., 2011; Powell, 2015; Vásconez & Kehrli, 2010). Advances in the field of emergency evacuation/transport route planning have produced three approaches that can identify 'optimal' evacuation routes by incorporating flood risk mapping and modelling, and GIS-assisted road network routing paths (Cabinet Office, 2014; Kim, George, & Shekhar, 2007; Shekhar et al., 2012). This includes simulation methods, which model the flow of evacuee traffic based on dynamic traveller behaviour and traffic conditions, however, these variables are uncertain (Pel, Bliemer, & Hoogendoorn, 2012); Heuristic methods, which are popular model routes based on shortest travel time and road capacity constraints, however, this requires extensive data and computational intensity for large area simulations (Di Mauro & Lumbroso, 2008; Kim et al., 2007; Lu, George, & Shekhar, 2005; Lu, Huang, & Shekhar, 2003; Lumbroso & Davison, 2018; Shekhar et al., 2012; Tagg, Kolen, Leenders, Chen, & Powell, 2013; Tuydes & Ziliaskopoulos, 2006); Linear programming methods, which model lowest-cost (shortest distance) paths between facilities, although this causes traffic congestion (Cova & Johnson, 2003; Talarico, Meisel, & Sörensen, 2015; Yamada, 1996). In this instance, transportation routes are created between ambulance stations, care homes, and rest centres. These designated rest centres, predominantly consisting of schools and community centres, are established by Local Resilience Forums to provide temporary flood shelter, and are suitable short-term refuge sites for care home residents that do not require medical treatment (Cabinet Office, 2013).

Globally, there is minimal research investigating ambulance-assisted evacuations during flooding and there is no current research that quantifies the cost of this service solely to the NHS (or other medical organisations) (Mustafa, 2003; Penning-Rowsell & Wilson, 2006; Pfurtscheller & Schwarze, 2008; Rosenthal & t'Hart, 2012). Instead, research mostly quantifies the cumulative cost of flood impacts to all emergency services and volunteer organisations for all assistance, including evacuation and rescue, food and shelter provision, and flood control and clean-up operations (Pfurtscheller & Schwarze, 2008). For example, the quantification of economic impacts of flooding from the summer 2007 and winter 2013 to 2014 floods in England and Wales determine the cost of emergency services (combined police, fire and rescue, and ambulance services) in terms of the cost of attendance and assistance involving staff overtime, provision of emergency supplies, resources and medical attention, and assistance of evacuation and rescue (Environment Agency, 2010, 2016). However, by specifically focusing on the impact of flooding on the NHS, practical benefits of financial budgeting of ambulance-assisted evacuations for varying flood events arise. This is important as the NHS is currently facing severe financial pressures due to a lack of funding compared to rising demand (The King's Fund, 2017); resulting in a collective deficit of £2.5 billion for 2015–2016 and £791 million for 2016–2017 (NHS Improvement, 2017), and an ambulance sector deficit of £12 million in 2015–2016 and neutral in 2016–2017 despite a £250 million ambulance service funding increase since 2011–2012 (Anandaciva, 2017; National Audit Office, 2017; The King's Fund, 2017).

Consequently, via the utilisation of GIS software (ESRI ArcMap 10.6), this study aims to: (a) analyse the impact of coastal and fluvial flooding on the provision of ambulance-assisted evacuations, provided by the East of England Ambulance Service Trust (EEAST), of vulnerable care home residents in Norfolk and Suffolk, and: (b) quantify the associated financial impact on the NHS based on an hourly drive-time cost of the ambulance service. This is conducted on a worst-case scenario basis, in association with the 'Precautionary Principle,' and consequently includes the following assumptions:

- Fluvial and coastal flooding occurs at the same time
- All flooded roads are inaccessible
- All at-risk care homes are at full resident capacity and each resident requires ambulance-assisted evacuation to rest centres
- One ambulance is assigned per care home and undertakes repeat journeys
- A static transport model is implemented to route between ambulance stations, care homes and rest centres

2 | METHODS

2.1 | Study site

The study was undertaken in the East Anglia region of the UK which consists of two counties including Norfolk and Suffolk (Figure 1). The exposure to flood risk in Norfolk and Suffolk is the resultant of topography and its geographical location. This includes a combination of low-lying land with a 225 km coastline, with variable levels of flood protection, and a large number and extent of river courses, including the tidal River Waveney and River Orwell.

Flood hazards associated with fluvial flood risk in Norfolk and Suffolk involve extreme rainfall events (e.g., April–July 2012), typically caused by a southerly jet stream track forcing Atlantic low atmospheric pressure

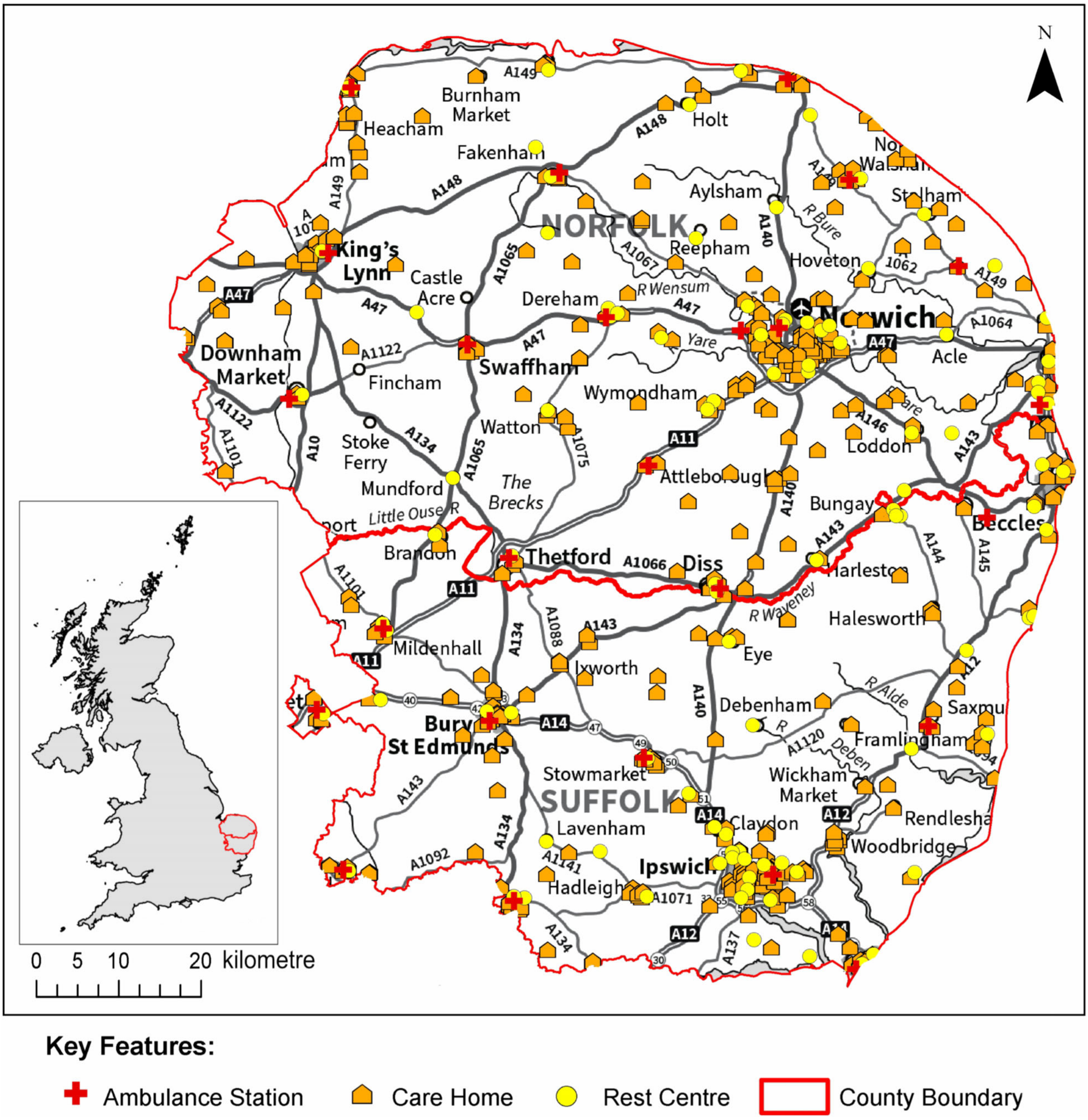

FIGURE 1 Location of all ambulance stations, care homes, and rest centres in Norfolk and Suffolk (EDINA Digimap, 2017a; Office for National Statistics, 2011)

weather systems (Flint, 2015; Met Office, 2012). Comparatively, hazards of coastal flooding in the East of England involve North Sea storm surges (e.g., December 2013 and January–February 1953), caused by Atlantic low atmospheric pressure systems, strong wind speeds and high tide, approaching the UK (Norfolk Resilience Forum, 2015; Spencer, Brooks, Evans, Tempest, & Möller, 2015; Suffolk Resilience Forum, 2015). The 2013 storm surge breached coastal defences and resulted in inland water levels of 2.9–1.8 m between Norfolk and Suffolk, exceeding that of the 1953 North Sea Storm Surge (Spencer et al., 2015).

In total, it is estimated that there are 80,200 properties (42,200 in Norfolk and 38,000 in Suffolk) at risk of fluvial and coastal flooding. The demographic composition of the population in Norfolk and Suffolk is characterised by a large number elderly individuals aged 65$^+$ years (185,000 and 145,000 persons, respectively), which accounts for approximately 20% of the county populations (Norfolk Resilience Forum, 2015; Office for National Statistics, 2018; Suffolk Flood Risk Management Partnership, 2016). With some of these individuals eligible for care home residency with 24-hr support from the approximate

360 Norfolk care homes and 190 Suffolk care homes, in combination with some care home properties at risk of flooding, this population is considered to be extremely vulnerable to flood risks (carehome.co.uk, 2018; Office for National Statistics, 2018).

2.2 | Data sourcing and processing

'Probability of Flooding from River and Sea' datasets were obtained from the Environment Agency (2015a). Despite the historical tendency for East Coast coastal and fluvial flooding to occur independently, the concurrent river and sea flood scenarios represent the effects of 'tide-locking', where high-tide prevents river-flow drainage, and 'backwater', where high water levels at the river mouth propagate upstream and exacerbate river discharge, which is possible to occur in regions such as the Broads river catchment which contains a low topographic gradient and tidal rivers (Environment Agency, 2009; Ikeuchi et al., 2017; Pasquier, He, Hooton, Goulden, & Hiscock, 2018). This spatial dataset, consisting of 50 m × 50 m grid cells, presents the chance of coastal and fluvial flooding in terms of high (greater than 1 in 30 year; Annual Exceedance Probability [AEP] of 3.33%), medium (between 1 in 30 year and 1 in 100 year; AEP between 3.33% and 1%), and low (between 1 in 100 year and 1 in 1000 year; AEP between 1% and 0.1%) flood risk probability, while taking into account the presence of current flood defences (Environment Agency, 2015b).

The locations of key infrastructure in Norfolk and Suffolk were acquired from a variety of sources. For example, ambulance station locations were sourced from the EEAST, care home locations and resident capacity were obtained from carehome.co.uk (2018), and suitable rest centre locations were provided by the Norfolk and Suffolk Councils and LRFs. An overview of Norfolk and Suffolk's flood-related infrastructure and major road network is provided in Figure 1. Ordnance Survey Integrated Transport Layer (ITN) (EDINA Digimap, 2017b) that contains navigation-grade routing information was used to calculate ambulance response-times, accessibility, and evacuation routes, using functions available within ArcGIS Network Analyst toolkit.

Upon analysis, flooded areas under various AEPs were used to identify care homes and numbers of vulnerable residents that are situated within corresponding flood risk zones, hence likely to require assistance in the evacuation process. In conjunction, network analysis was undertaken using the ITN. Initially, this analysis involved estimating the service area of each ambulance station for the legislated response-time targets by generating non-overlapping polygons of accessible areas and defining the areal geometry, for both the time-based travel impedance and the fluvial and coastal flood risk polygon barrier impedance (Esri, 2017a). This analysis provided an identification of care homes that are excluded from the ambulance service areas, due to the impedance of time or flooding, and so are determined to be inaccessible to the emergency service.

Finally, network analysis was again undertaken to generate evacuation routes and the estimated time of route navigation for each at-risk care home. This was completed using the 'closest-facility' analysis to create transport routes between ambulance stations, care homes, and rest centres, based on the shortest time of travelling between destinations (Esri, 2017b). Flood roads are used as barriers in the analysis, following the methods described in Coles et al. (2017) and Green et al. (2017).

In this study, we relate the financial cost of increased emergency evacuation activities during flooding directly with the increases of ambulance vehicle travel time due to flooded roads, based on the average cost to the Ambulance Trust to run a 12-hr Ambulance shift (approximately £1,040, including all staff, vehicles and support costs) (EEAST, 2017a). Using the estimated route durations between facilities and the estimated cost of the ambulance service per minute provided by the EEAST, an estimated total cost of evacuation to the NHS was calculated. This was calculated in stages, the first being the single route from the ambulance station to the care home and the second being the repeated journeys between the care homes and rest centres, to account for each care home occupant. This produced an overall estimation of the cost of ambulance-assisted evacuations of vulnerable care home residents based on the 'worst-case' scenario that care homes are at maximum capacity, each resident requires assisted evacuation, and one ambulance is assigned to evacuate one care home. This allows the total journey time associated with evacuation to be translated into monetary values in the baseline no-flood and flood scenarios.

3 | RESULTS

3.1 | Quantification of care homes and residents likely to require assisted evacuation

The inclusion of coastal and fluvial flood extent data of high-, medium- and low-risk flood events indicates care homes on affected land. It is evident that 68 out of 550 care homes in the region are located on lands that are at risks of being flooded despite the presence of flood defences (Figure 2), and these care homes hold a maximum resident capacity of 2,320 people.

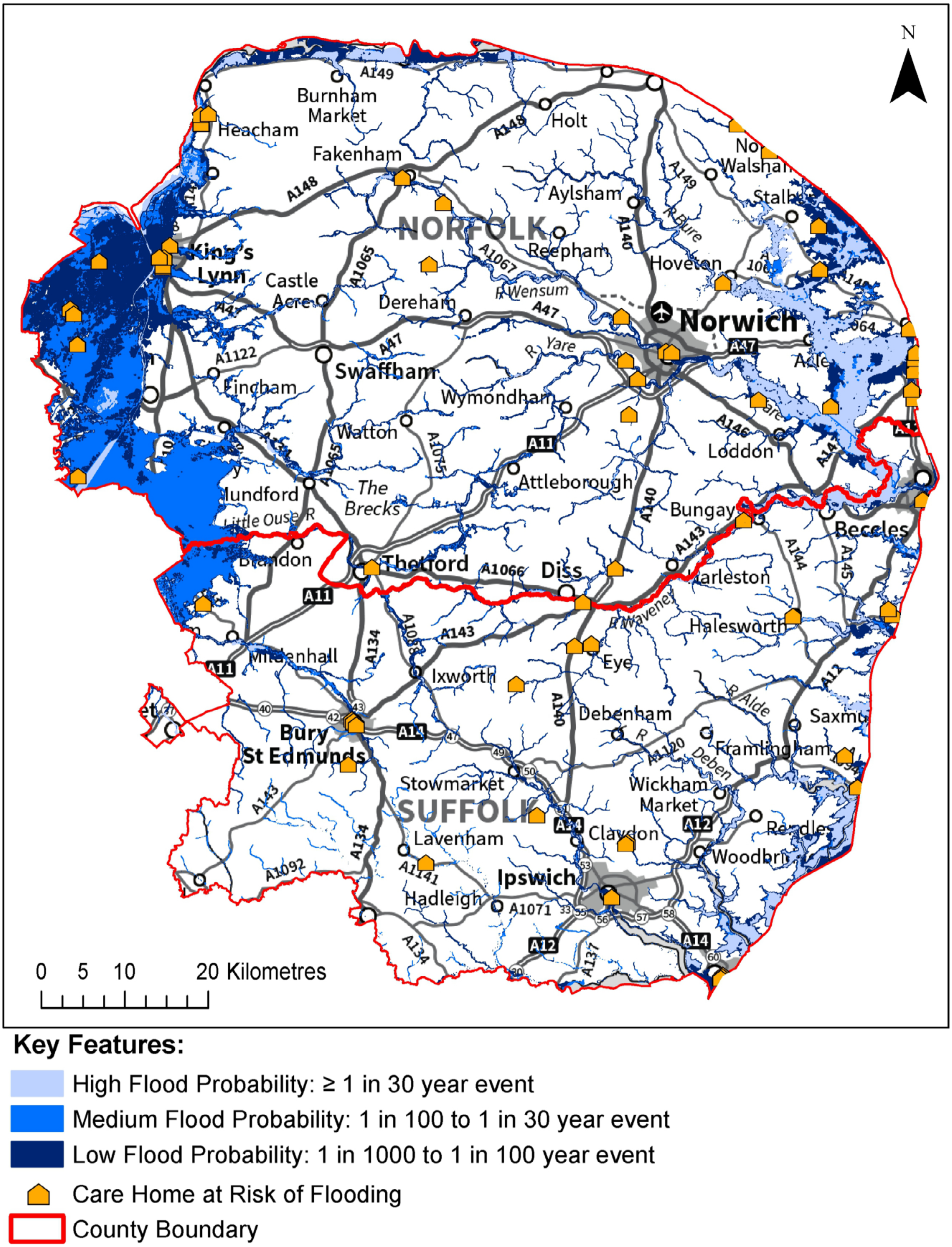

FIGURE 2 Areal extent of the probability of flooding from rivers and sea (accounting for the presence and condition of flood defences) for varying flood probabilities, and associated care homes at risk of flooding (EDINA Digimap, 2017a, 2017b; Environment Agency, 2015a, 2015b)

The spatial distribution of these impacted care homes indicates that the majority of vulnerable population are situated in Norfolk, where over 2 of 3 of the impacted care homes are located, in proportion to the land areas of the two counties. Moreover, the number of care homes at risks of coastal and fluvial flooding is similar. Specifically,

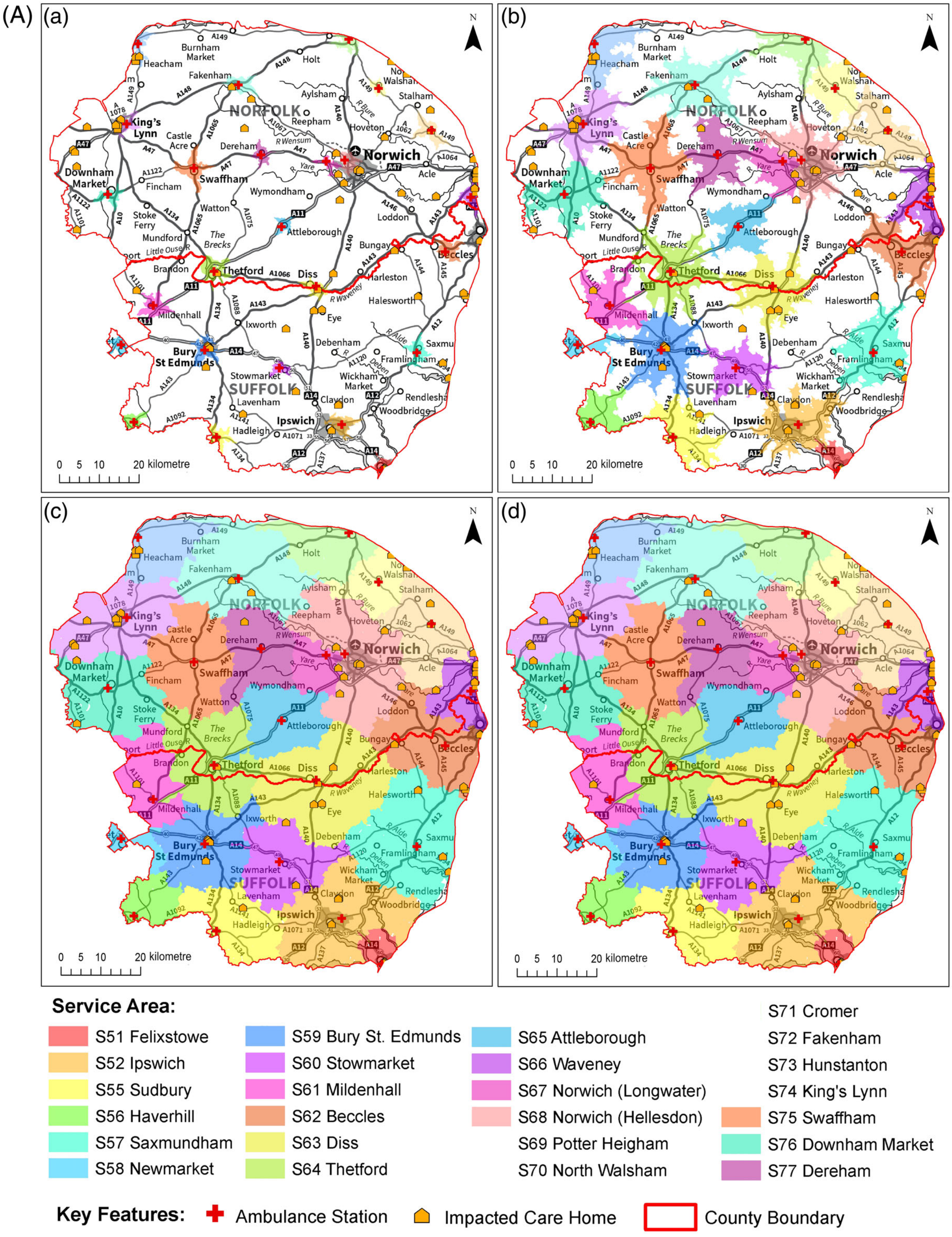

FIGURE 3 Service area and care home accessibility under baseline (A), high (B), medium (C) and low (D) flood probability scenarios for response times of: (a) 7 minutes, (b) 18 minutes, (c) 120 minutes, and (d) 180 minutes

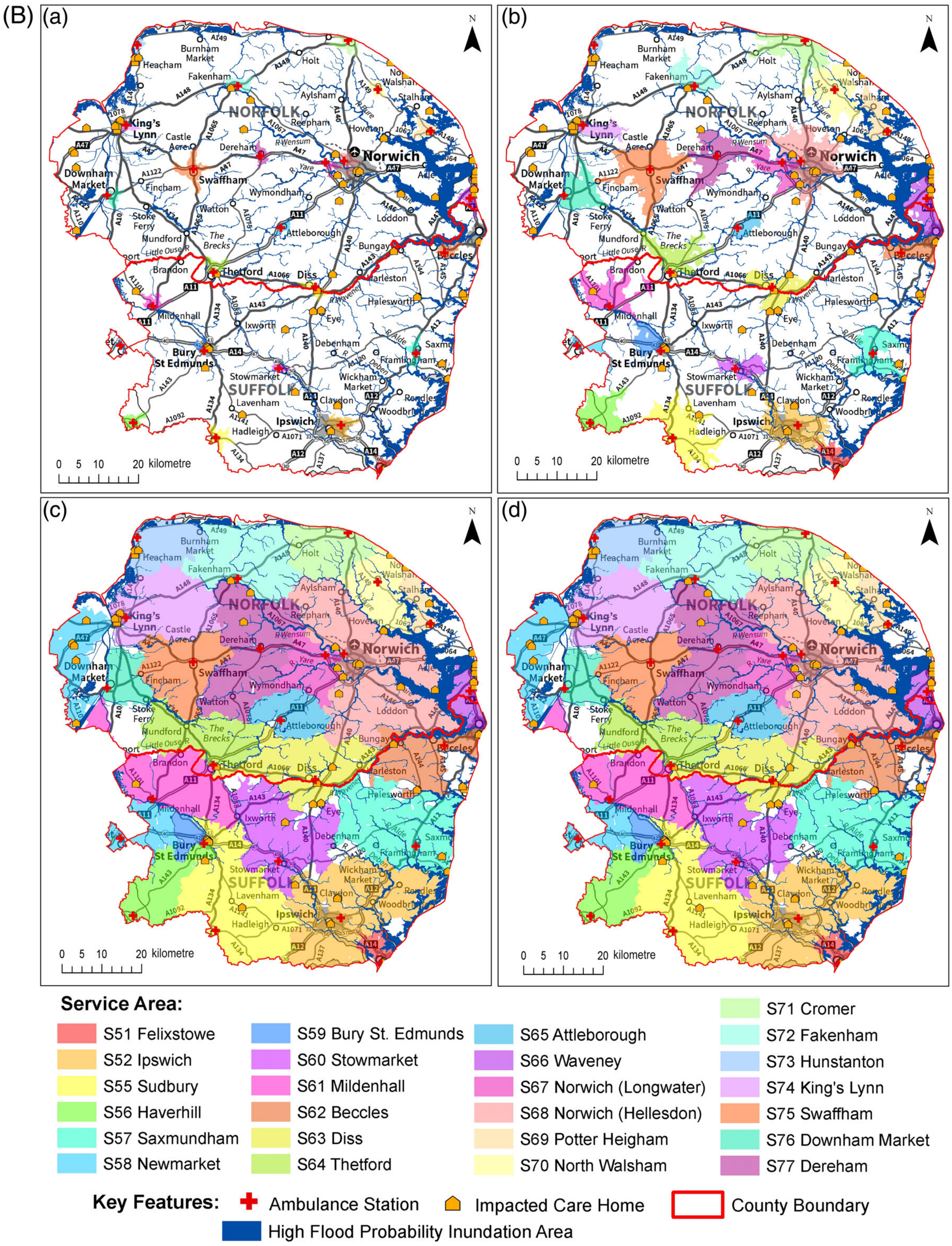

FIGURE 3 (Continued)

care homes affected by coastal flooding are mostly located in the council districts of King's Lynn and West Norfolk in the west and Great Yarmouth and Suffolk Coastal in the east, which corresponds with the tendency of older populations to reside in care homes close to the sea (Lievesley, Crosby, Bowman, & Midwinter, 2011). Comparatively, a similar number of the care homes are affected by fluvial flooding which is apparent in central locations, for example, surrounding the River Yare in Norwich and the River Orwell estuary in Ipswich.

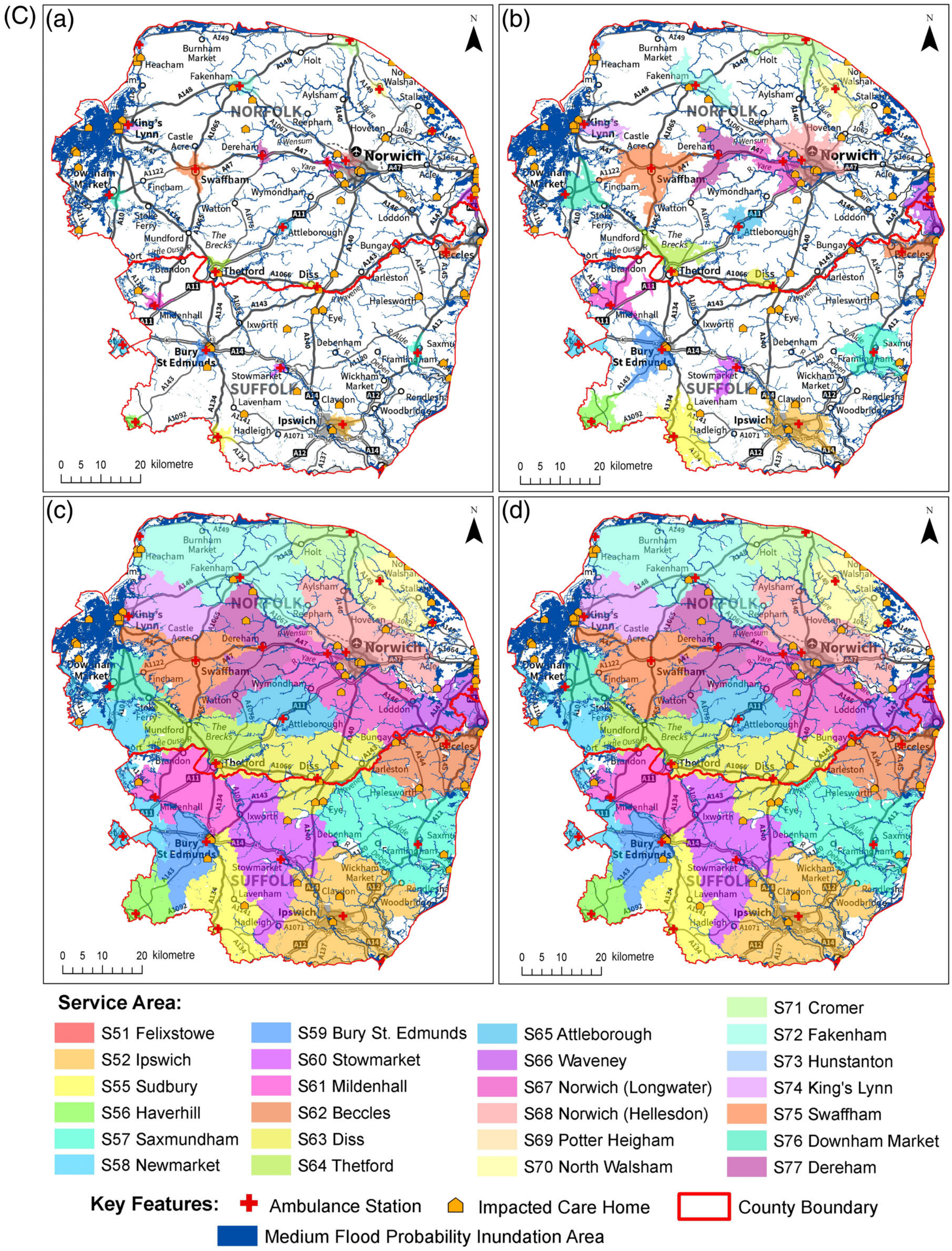

FIGURE 3 (Continued)

3.2 | Effect of current flood risk on ambulance service area coverage

The service area that an ambulance station can cover during emergencies, such as flood events is a function of the specific response-time target, flood magnitude, and spatial distribution, and the 'quality' (e.g., speed limit and level of congestion) of the integrated road network that a vehicle has to navigate. In static scenario-based analysis, such as that considered in this study, the service area is determined

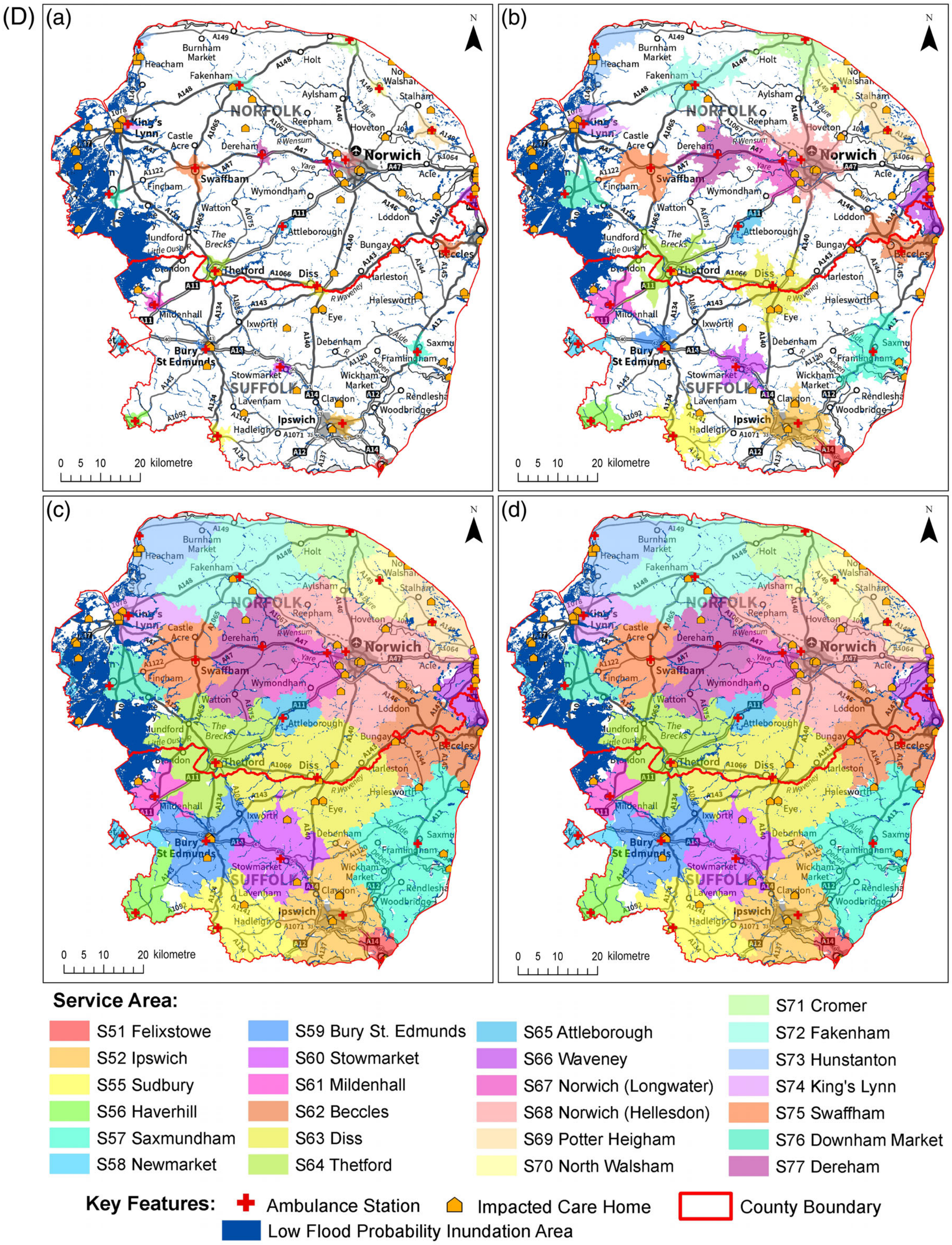

FIGURE 3 (Continued)

by the response-time and flood characteristics; although a dynamic analysis of an agent-based model would provide interactions between emergency responder vehicles and the flood water (Coles et al., 2017; Lumbroso et al., 2010). The areas and number of care homes that Ambulance Service can reach within the respective timeframes for each station under no-flood and flood conditions of various probabilities are shown in Figure 3 and summarised in Table 1.

Under the 'no-flood' scenario, results show that all 68 care homes can be reached within 120 min compared with only 26 in 7 min and 56 in 18 min, suggesting that in order for the majority of care homes to be accounted for in evacuation, the time allowance for reaching care homes lies between 18 and 120 min. That fact that a large proportion (62% and 18%) of care homes are not reachable within Ambulance Service's 7 and 18-min timeframes even under the normal condition is alarming as elderly individuals tends to generate more life-threatening Category A calls which requires immediate attention.

As more areas become inaccessible during flood conditions of all magnitudes, and within all response-time targets (Figure 3; Table 1), the number of accessible care homes increases drastically. For example, 5 care homes are not accessible within 180-min of ambulance travel time in a high-probability flood (Figure 3B), increasing to 16 when a low-probability event occurs (Figure 3D). Inaccessible care homes are predominantly located in the coastal locations of Great Yarmouth, King's Lynn and West Norfolk, although there are sporadic areas of inaccessibility throughout both Norfolk and Suffolk under all flood risk scenarios.

3.3 | Pre-identified evacuation routes

The generation of static, shortest-path evacuation routes indicates the clustering that is commonly associated with shortest-path route modelling (Figure 4) (Holme, 2003). This is primarily visible towards the eastern coast where the majority of the evacuation routes lie. Although, as the flood probability decreases, creating additional and larger flood risk zones, the distribution of the evacuation route clusters increases towards the western (landward) side of the counties. For example, under a high flood probability (Figure 4a), route clustering occurs as the Waveney station ambulances tend to 11 proximal care homes, of which the residents from six facilities are routed to the same rest centre; comparatively under a low flood probability (Figure 4c) there are a wider distribution of smaller clusters within evacuation routes, such as those in Felixstowe, Waveney, Norwich-Hellesdon, and King's Lynn. This reflects the variable magnitude of the available water sources as the greater availability from the sea produces significantly larger inundation extents and evacuations in the coastal regions whilst the lesser water availability from rivers produces multiple smaller inundation extents and evacuations inland (Hatono et al., 2014).

Clustering aside, the evacuation routes do account for every vulnerable care home, as evidenced in Figure 4b, and provide definite paths between the ambulance stations, care homes, and rest centres, promoting rapid and efficient evacuations. These road network visualisations highlight the most direct course of navigation for emergency responders due to the use of the shortest-path approach.

TABLE 1 Ambulance service area and accessibility statistics based on flood risk and response times

Flood probability	Response time (min)	Area coverage (km^2)	Inaccessible area (%)	Number of accessible care homes	Number of inaccessible care homes
None	7	466	95.0	26	42
	18	3,950	57.4	56	12
	120	9,211	0.7	68	0
	180	9,212	0.7	68	0
Medium	7	342	96.3	24	44
	18	2070	77.7	38	30
	120	8,264	10.9	60	8
	180	8,353	10.0	60	8
High	7	387	95.8	18	50
	18	2,693	71.0	51	17
	120	8,390	9.6	63	5
	180	8,407	9.4	63	5
Low	7	319	96.6	11	57
	18	1853	80.0	25	43
	120	8,167	12.0	51	17
	180	8,208	11.5	52	16

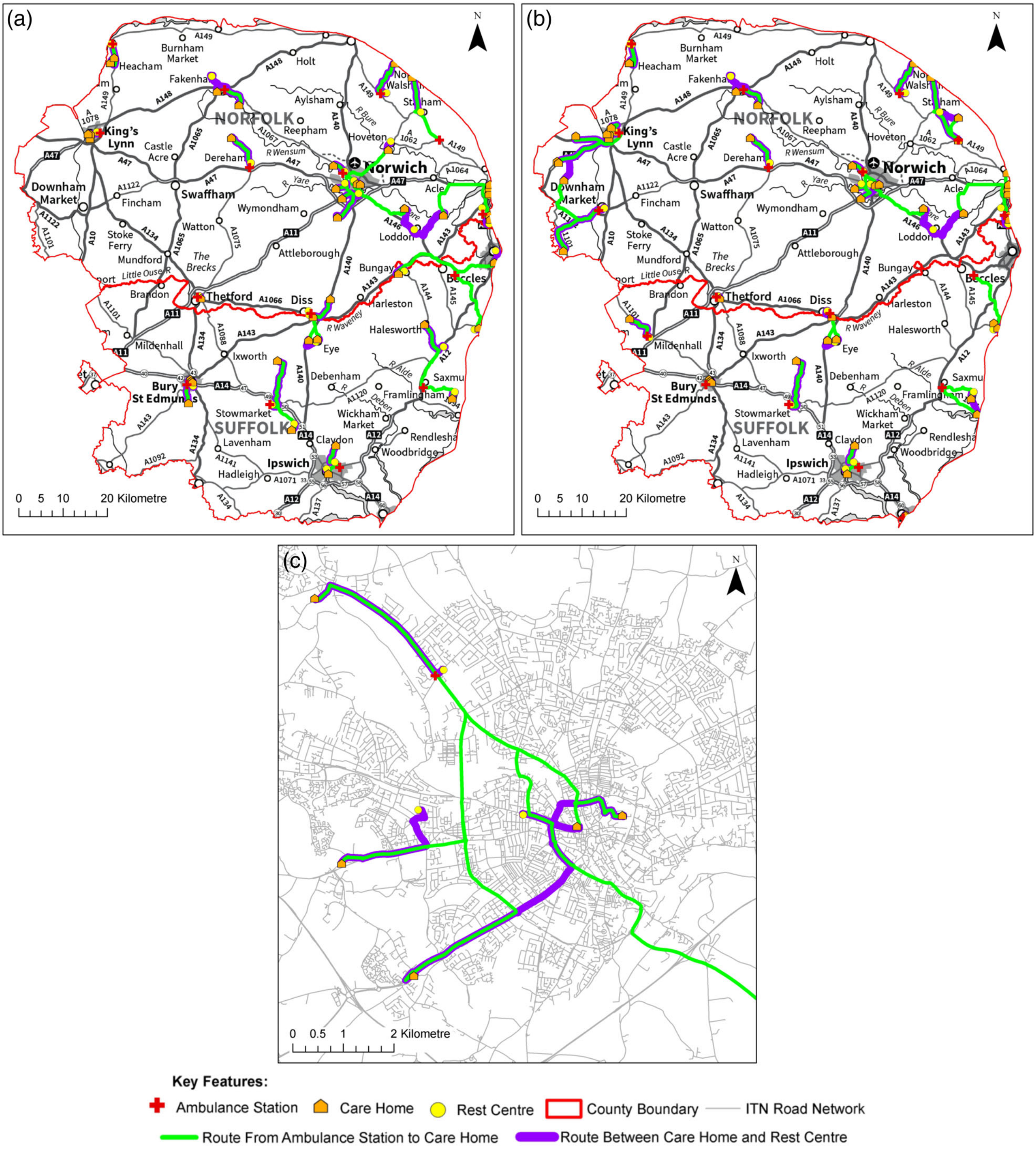

FIGURE 4 Shortest-path evacuation routes for evacuating vulnerable care home residents during times of (a) high-probability, (b) medium-probability (Norwich), and (c) low-probability flood events

3.4 | The financial impact of ambulance-assisted evacuations to the NHS

The estimated financial cost of ambulance assisted evacuations to the NHS was calculated based on the ambulance service cost per minute of £1.44, provided by the EEAST. This was used to generate financial outcomes based on the Precautionary Principle of preparing for uncertainty by predicting and preparing for worst-case scenarios (UNESCO, 2005). In this investigation, the worst-case outcome represents the use of a single ambulance travelling from its station to the closest vulnerable care home and undertaking repeat journeys between the care home and designated rest centre to transport each resident.

From this calculation, a relationship between increasing financial impact on the NHS and decreasing flood

TABLE 2 Summary costs of ambulance-assisted evacuations to the NHS based on the drive-time associated with the closest-facility evacuation routes, specifically for low flood probability events

Low flood probability scenario: Summary							
Ambulance Station	**Journey 1 drive-time (min)**	**Number of care homes to assist**	**Maximum resident capacity**	**Journey 2 drive-time (min)**	**Number of allocated rest centres**	**Evacuation drive-time (min)**	**Cumulative cost to NHS (£)**
S51 Felixstowe	9	6	204	222	1	231	333
S52 Ipswich	17	2	34	504	2	521	750
S57 Saxmundham	30	2	90	1,217	1	1,247	1,796
S59 Bury St. Edmunds	4	1	65	380	1	384	552
S60 Stowmarket	25	1	21	1,003	1	1,028	1,480
S61 Mildenhall	9	1	6	112	1	121	174
S62 Beccles	43	2	44	220	1	263	379
S63 Diss	25	3	152	1,427	3	1,452	2091
S64 Thetford	5	2	96	849	1	854	1,230
S66 Waveney	105	12	319	3,910	5	4,016	5,783
S68 Norwich (Hellesdon)	64	6	210	2,391	4	2,455	3,536
S69 potter Heigham	36	3	55	1,372	1	1,408	2028
S70 North Walsham	16	1	14	501	1	517	744
S72 Fakenham	18	2	61	2,119	1	2,137	3,077
S73 Hunstanton	9	1	26	465	1	474	683
S74 King's Lynn	95	8	313	5,703	1	5,798	8,349
S76 Downham Market	52	2	79	4,795	2	4,847	6,980
S77 Dereham	15	1	64	1,722	1	1,737	2,501
Total		56	1853		29	29,490	42,466

Note: Journey 1: Cumulative drive-time between ambulance stations to care homes. Journey 2: Cumulative drive-time to evacuate each care home resident to the closes rest centre, based on return journeys. Evacuation drive-time: Cumulative evacuation time (sum of Journey 1 and 2) used to determine the cost to the NHS.

probability is highlighted. The cost of evacuations increases from approximately £35,770 for high flood probabilities to £40,110 for medium flood probabilities, to £42,470 for low flood probabilities (Table 2). Although these estimations are considered the worst-case outcomes, the financial cost per person (pp) is surprisingly low. For example, for each flood probability investigated, average individual costs include £21 pp for high probability floods, £23 pp for medium probability floods and £24 pp for low probability floods.

The increasing cost of evacuation is directly linked to increasing vehicular travel times associated with lower flood probabilities, as evidenced by a 4,653 min increase of evacuation time between high and low flood probabilities. This is a result of low flood probabilities posing greater flood consequences, thereby increasing areas and care homes at risk of inundation, and so increasing the number of ambulance journeys and residents to evacuate (Environment Agency, 2005).

4 | DISCUSSION

4.1 | Modelled ambulance response to reaching vulnerable people

Although the majority of the 68 at-risk care homes are within reach of ambulance assistance by 180 min for all flood scenarios, there are still multiple care homes and residents that remain unaided due to the determinants of service area and accessibility. In terms of ambulance service area determinants, the geographical distribution of the stations influences service area coverage. Currently, the EEAST owns 85 ambulance stations and 387 emergency ambulances, and assuming that these ambulances are equally dispersed between stations, Norfolk and Suffolk possess 25 ambulance stations and approximately 113 ambulances to provide assistance at an average of approximately 20 patient evacuations each (in relation to the approximate 2,320 at-risk residents) (EEAST, 2017b). The even distribution of these stations (Figure 1) promotes wide-spread service area coverage per response-time which would not occur under an aggregated distribution (Chen et al., 2014).

Ambulance service area (Figure 3) is a dynamic function of strategic, tactical, and operational variables (Leknes et al., 2017). Strategic issues of ambulance station location impacts service area in regards to response-time as many ambulance stations are located in cities and towns; therefore, access to urban areas is possible under a short 7 min response-time while access to remote rural areas requires a longer response-time (Leknes et al., 2017; Van Barneveld, Bhulai, & Van der Mei, 2016). Tactical issues include the location and fleet size of ambulances per station, which tends to be greater within towns and cities where a larger population may require the service (Leknes et al., 2017), resulting in greater ambulance attendances in urban areas and fewer ambulances and coverage available to support larger service areas in rural regions (Gendreau, Laporte, & Semet, 2006). Finally, operational issues involve ambulance reallocation during emergency events, to increase service area coverage by reducing the response-time required to reach an incident, via re-routing available ambulances or dispatching available ambulances from nearby stations (Leknes et al., 2017; Van Barneveld et al., 2016). However, due to the uncertainties and dynamism surrounding these issues, the numbers of ambulances per station were not incorporated into this investigation.

Ambulance accessibility determinants can be separated into spatial and temporal factors. The spatially concentrated nature of fluvial and coastal flooding to nearby watercourses and coastlines (Figure 2) reduces the potential of widespread disruption, however, these inundated areas of land influence the navigation of ambulances along the road network by creating impassable barriers related to the flood hazards of water depth and flow velocity, which are predominantly estimated via the use of topographic data, hydraulic models, floodplain information systems and expert judgement (DEFRA, 2006; Green et al., 2017; Kramer, Terheiden, & Wieprecht, 2016; Teo, Liew, Falconer, & Lin, 2013). For cars, water depth is the primary hazard that affects the stability and functioning of vehicles as driving through water depths of 10 cm causes risk of control loss, engine failure, and submerged hazards, while 30 cm of flowing water (approximately 6 m/s) causes vehicle instability by floating, sliding, and toppling due to buoyancy effects (Automobile Association, 2015; Martínez-Gomariz, Gómez, Russo, & Djordjević, 2018; Smith, Modra, Tucker, & Cox, 2017; Teo et al., 2013). Theoretically an ambulance is capable of fording through 60-cm deep water due to its greater size, weight, and power (providing higher engine air inlets and electrical systems, and greater vehicle stability); although in practice this is restricted to approximately <25 cm to prevent submergence associated ambulance malfunctioning and to avoid other vehicles that may float into the road and restrict ambulance access (Green et al., 2016; Green et al., 2017; Kramer et al., 2016). This inundation disrupts the transport path of ambulance vehicles as road closures and diversions prevent the use of shortest-path transport routes, resulting in reduced care home access (Albano et al., 2014).

Temporal aspects restricting ambulance accessibility to care homes include the predicted inundation time and the estimated evacuation procedure time (Hubbard, Stewart, & Fan, 2014). It is recommended that evacuations take place within 12 hr of flooding, while the road network is fully accessible, to allow time for the evacuation procedure and the withdrawal of the emergency responders, and prevent rescue operations of individuals regarded as inaccessible (Esm, OAM, & Davies, 2010; Norfolk Resilience Forum, 2017). For example, Table 2 indicates that the best case of no flood and 180 min ambulance response-time has low inaccessibility (0.7% area and 0 care homes); while the worst case of low probability flooding and 7 min ambulance response-time has high inaccessibility (96% area and 57 care homes). As traffic congestion may cause evacuations to over-run into the inundation, it is important to prioritise the evacuation of most vulnerable care home residents from most at-risk care homes to prevent flood rescue operations (Cho & Yoon, 2015; Noh, Chiu, Zheng, Hickman, & Mirchandani, 2009).

4.2 | Suitability of pre-identified evacuation routes

The production of shortest-path evacuation routes clusters ‘optimal’ ambulance stations and rest centres to the vulnerable care home locations (Figure 4), such as the six care homes routed to the same ambulance station (Waveney) and rest centre (Marina Leisure Centre) under the low flood probability scenario. This traffic congestion reflects the requirement of longer ambulance response-times to reach a destination, as multiple vehicles within close proximity are routed to the same shortest-path facilities, thereby increasing the network load and road traffic, and increasing transport times (Boyan & Littman, 1994; Cova & Johnson, 2003; Danila, Yu, March, & Bassler, 2006; Kim et al., 2007; Panahi & Delavar, 2008). Traffic congestion can be alleviated by devoting the shortest-path evacuation routes exclusively for the use of emergency vehicles to evacuate the most vulnerable individuals with the highest flood risk while ensuring that the general public do not contribute to vehicle congestion, and evacuating low-risk care homes with ambulances from distant stations to rest centres that are more spatially distributed (Cabinet Office, 2013).

In the event that the shortest-path evacuation routes must be used for all ambulances, care homes, and rest centres, then alternative implementations of traffic relief may include counterflow and contraflow lanes, staggering evacuations based on risk factor, staggering vehicle departure times and controlling traffic flow via traffic signal control (Cabinet Office, 2013; Panahi & Delavar, 2008; Yuan, Han, Chin, & Hwang, 2006).

When comparing the suitability of static, shortest-path, evacuation routing compared to dynamic evacuation routing, the static routing approach may produce ‘optimal’ transport pathways, however, evacuations are dynamic processes (Jotshi, Gong, & Batta, 2009). This dynamism occurs due to real-time changes in the environment and evacuee behaviour (Shahabi & Wilson, 2018), and includes predictable changes, such as road works, temporal, and spatial flood extent, and self-evacuee traffic on specific roads (Powell et al., 1995; Shahabi & Wilson, 2018), and unpredictable factors, such as the occurrence of road traffic accidents and chaotic traffic trying to navigate around disturbances (Hsueh, Chen, & Chou, 2008; Lujak & Giordani, 2017). Based on these influences, it may be beneficial to produce agile evacuation routes capable of re-routing vehicles around possible congestion and other dynamic disturbances, such as those simulated by Lumbroso and Davison (2018); these account for dynamic interactions of people, buildings, and vehicles with flood depth and velocity (and flood event evolution) in the analysis of evacuation behaviours (Jotshi et al., 2009; Lujak & Giordani, 2017; Powell et al., 1995; Tagg et al., 2013). However, the inclusion of these uncertain, predictable and unpredictable, environmental, and socio-behavioural influences may produce evacuation routes that are longer and more indirect than necessary (Pel et al., 2012). Therefore, the best approach for evacuation routing may be for ambulance services to directly or indirectly follow static shortest-pathways, providing the knowledge of standardised fastest routes and the flexibility of route deviation if necessary. However, such assumptions may not hold for individual circumstances and could be tested using agent-based modelling (Dawson, Peppe, & Wang, 2011) which can incorporate detailed consideration of behavioural and environmental influences at the local scale.

The identification of pre-flood, shortest-path routes between ambulance stations, care homes, and rest centres, benefits the ambulance service as it can increase the efficiency of the evacuation process, although this depends on whether or not the routes are prone to flooding during the inundation period (Khalid & Yusof, 2018). The evacuation routes produced in this investigation (Figure 4) are based on the completion of evacuations prior to road network inundation and emergency responder withdrawal (Norfolk Resilience Forum, 2017). This is to allow the procedure to be carried out under conditions that guarantee access to all vulnerable care homes within 180 min (as in Figure 4), rather than conducting rescue missions of inaccessible ‘island’ locations during flood events (as in Figure 4) (Jonkman, Maaskant, Boyd, & Levitan, 2009). For example, during the 2005 New Orleans flooding associated with Hurricane Katrina, 1.1 million people evacuated to safety prior to the flooding, whilst of the remaining population, 62,000 people were rescued, and 480 of the 746 fatalities were recovered from their place of residence or nursing homes (Jonkman et al., 2009). Having said this, static and dynamic routing analysis can increase the efficiency of rescue operations by identifying impassable flooded pathways and routing around flood hotspots, although, accessibility of care homes cannot be guaranteed during this period and a longer ambulance response-time is required due to the indirect navigation around the flood risks (Pidd, De Silva, & Eglese, 1996). In relation to the link between the ambulance service response-time and shortest-path evacuation routes, the routes increase ambulance service efficiency by promoting the most rapid transportation path between facilities, allowing a rapid access of people and evacuation procedure in minimal timeframes (Derekenaris et al., 2001).

4.3 | Justification of estimated ambulance-assisted evacuation costs

With no previous research conducted on the quantification of the financial impact of ambulance-assisted evacuations on the NHS, the most reliable approach quantifies the cost per minute of the ambulance service based on the use of shortest-path evacuation routes.

This assumes that the shortest-path route (between ambulance stations, care homes, and rest centres) is most likely to be navigated to ensure that maximum vulnerable residents are accessed within the legislated responder timeframes. The quantification of ambulance-assisted evacuation cost to the NHS utilises a statistic provided by the EEAST which states that the cost of a 12-hr ambulance shift to the Trust is £1,040 (£1.44 per min), which represents the cost of the whole ambulance service as it incorporates staff wages, vehicle costs, and support costs. This time-based statistic was utilised over published NHS incident-based statistics, such as the £264 average cost per ambulance attendance in 2015–2016 (National Audit Office, 2017), due to the increased accuracy of encompassing the cost of all aspects of the service compared to the average cost of call-out events, such as road traffic accidents, which are significantly more costly than any assistance provided during evacuations. Although in this investigation, the cost of the ambulance-service was solely based on time as distance-driven rather than in combination with the (unknown) ambulance load and unload times, thereby providing a baseline evacuation cost and underestimate of total evacuation cost.

The primary difficulty when trying to compare the estimated cost of evacuation calculated in this investigation to other national and international flood events is the lack of data in the form of government assessments and external research studies into the assisted-evacuation costs caused by natural hazards, which for example Austria lacks entirely (Pfurtscheller & Schwarze, 2008). This is resultant of the multi-agency approach to flood risk management in which assistance is provided by multiple voluntary and non-voluntary organisations, making individual service cost assessments complex (Pfurtscheller & Schwarze, 2008). Additionally, it is considered to be inappropriate to compare flood emergency costs on an international basis due to differences in geographic structure (Morselt, Engelsman, & Lobbes, 2007). For example, the evacuation of 2,500 people in Nyngan, Australia equated to $1.5 million (Joy, 1993), averaging $600 per person; comparatively, this investigation identifies that (on average between flood probabilities) the evacuation of 1,727 people equated to an average of £39,446, which is approximately £22 per person. This difference in cost is mostly due to the larger land surface area of Australia than the counties of Norfolk and Suffolk, resulting in longer transport routes and the requirement of helicopter assistance (Joy, 1993).

The purpose of establishing the cost of evacuation on a worst-case/highest-cost basis, via the assignment of one ambulance per care home and undertaking of repeat journeys, is to ensure financial and strategic preparedness for extreme flood events. Within the Public Health Sector it is beneficial to base risk management on the precautionary principle, which incorporates a preventative approach to promote protection against uncertain risks, to ensure preparedness for all consequences (Crichton, Ramsay, & Kelly, 2009; Fischbacher-Smith & Calman, 2010; Smith & Toft, 1998; Somers & Svara, 2009). In association, by calculating the worst-case outcome, the NHS, local councils, and government may incorporate this financial impact into the financial budgeting and investment of the sectors and agencies that are pivotal to the flood evacuation procedure, in addition to the promotion of strategically prioritising the channelling of resources to the most at-risk areas and populations, to ensure the preparedness of the ambulance services for all probabilities of flood events. Ideally, this would minimise the financial constraints on the health service for assisted-evacuations and prevent the negative impacts associated with a lack of funding, such as limited service and service quality, and lack of required resources (Achour, Pascale, Soetanto, & Price, 2015).

4.4 | Limitations

This investigation possesses two key limitations. First, this research contains sensitivities and uncertainties associated with the use of worst-case scenario assumptions in which the occupants of each care home are transported by a single ambulance making multiple journeys, rather than the inclusion of a specific number of different vehicle types. For example, the assumption of maximum occupancy rates of facilities within the defended flood extent regions is used to reflect the annually increasing 89.4% facility occupancy in the UK, however, this provides an over-estimation of associated evacuation costs in accordance with the precautionary principle (Evans, 2018). Similarly, the assumption that the vehicles most suitable to transport care home residents, who are generalised to vary in physical and mental capabilities, are the 387 emergency ambulances (incorporated in this study) that provide single patient care during transportation, also provide an over-estimation of evacuation costs (Black & Davies, 2005; EEAST, 2017b, 2017c). In reality, the vulnerability and transport needs of the occupants are non-uniform and so a variety of vehicles would be utilised including the 175 non-emergency ambulances that provide transportation for multiple individuals who require assistance but not treatment, and adapted minibuses (Renne et al., 2009; EEAST, 2017b, 2017c). Unfortunately, due to uncertain in situ variables, including the ambulance fleet size per station, number of vehicles used for the evacuation procedure, non-emergency ambulance capacity, and the number of residents that would use the service over privately owned vehicles, the only appropriate vehicle inclusion into this investigation was the incorporation of an unspecified number of emergency ambulances.

Second, although rest centres are frequently utilised in the refuge of vulnerable people, including the elderly, disabled, and those with limited mobility (Kipling, Newton, & Ormerod, 2011; Stepanov & Smith, 2009), they may not be suitable facilities for all care home residents. For example, it has been evidenced that the post-evacuation mortality of 'patient evacuees' increases by approximately 10% after 1 month due to the physical and mental distress induced by relocation (Dosa et al., 2012; Willoughby et al., 2017). However, relocation to rest centres remains a recommended worst-case scenario safety measure when the risk of increased mortality associated with sheltering-in-place (via shortages of supplies, the loss of amenities, and facility inundation induced exposure) outweighs that associated with evacuation (Dosa et al., 2012; Dosa, Grossman, Wetle, & Mor, 2007; Haynes et al., 2009; Willoughby et al., 2017). Furthermore, residents with severe medical conditions or the terminally ill require evacuation to other care facilities, such as hospitals to prevent the disruption of medical treatment and health deterioration (Hyer, Brown, Christensen, & Thomas, 2009). This was not included in this investigation because, at present, NHS hospitals lack the accommodation space for evacuees due to the bed-shortage crisis (British Medical Association, 2017). The shortage of hospital bed spaces is caused by the current strains, such as staffing shortages, resulting in the bed-blocking (delayed discharge) of hospital patients, leading to the bed shortage (Gaughan, Gravelle, & Siciliani, 2017). Furthermore, when nationally generalising, the ratio of care home beds to hospital beds is 4:1 in England (Bowman & Meyer, 2017), and although it is likely that only a small portion of the residents would require hospital aid, under mass evacuation scenarios this can become a significant number of people that may not all be able to receive accommodation.

4.5 | Applications and opportunities for further research

Limitations aside, the approach of this investigation could be incorporated into the emergency flood planning process and undertaken at a national level to increase organisational and financial preparedness to flood events. The primary application of this investigation is the production of more detailed flood maps and evacuation maps for use of the emergency services, to promote the efficient assistance of vulnerable people in times of need. A secondary application of this investigation is the promotion of informed NHS financial budgeting to ensure that there is always available funding should a mass ambulance-assisted evacuation of vulnerable people be required.

Further research may incorporate aspects of climate and population projections to determine future emergency response, the number of vulnerable people, and evacuation costs. For example, climate projections based on the UKCP09 medium emissions scenario (SRES A1B) estimate global mean surface temperature increase of 1.7–4.4°C, and mean sea level rise of 21–48 cm (global) and 13–60 cm (UK) by 2,100 (Edwards, 2017; Lowe et al., 2009), in addition to East of England winter precipitation increase of 14% by 2080 (DEFRA, 2009). By 2080, this will increase Norfolk and Suffolk annual flood frequency probability by 4,135% and the UK flood-risk residing population by 41% (Oven et al., 2012; Sayers, Horritt, Penning-Rowsell, & McKenzie, 2015). Additionally, population projections predict that in the UK between 2006 and 2033 individuals aged 65+ will increase by 7% and individuals aged 85+ will increase by 2.4% (Oven et al., 2012). This will increase the number of vulnerable individuals that may require assisted evacuation. In association, this approach can be expanded to consider the evacuation of the wider population by including other socially vulnerable populations, such as children, and individuals with ill-health and non-affluent background, via the use of SFVI maps which encompass additional factors such as the level of unemployment, non-car ownership and non-home ownership (Cutter et al., 2003; Pitt, 2008).

Another further research opportunity involves the production of an agent-based model to assess the duration of the simulated evacuation procedures, which according to Tagg et al. (2013), comprises of the length of time for evacuees to join the traffic network, travel to a refuge site, and exit the traffic network, in addition to influences of social behaviour, traffic congestion, road network capacity, vehicle loading, and unloading times. Evacuation time information is imperative for emergency planners to determine the time at which flood warning and evacuation orders are to be issued to ensure enough time prior to the flood onset for evacuees to travel to refuge (Lumbroso & Davison, 2018; Tagg et al., 2013). This time basis corresponds with the identified evacuation routes in Lincolnshire which are implemented to minimise evacuation durations (Powell, 2015).

5 | CONCLUSION

This investigation has examined the influences that coastal and fluvial flooding pose on the use of ambulance service vehicles in the assisted evacuation of vulnerable care home residents in Norfolk and Suffolk and attempts to quantify the cost of use of this service to the NHS. This was undertaken using GIS to analyse the impacts that a high-, medium-, and low-flood risk probability pose on ambulance response-time and service area, number of care homes requiring evacuation, care home accessibility, suitability of pre-identified evacuation routes between ambulance stations, care homes and rest centres, and the drive-time-based cost of ambulance-assisted evacuations to the NHS.

The results revealed that flooding may render many care homes inaccessible within ambulance emergency target response time and it is necessary to evacuate these residents prior to flood events. The use of shortest-path evacuation routes between ambulance stations, care homes, and rest centres identified the most efficient routes for the ambulance service to take to promote rapid evacuations, however, if precautions are not taken, this could also result in network clustering. Based upon the use of these evacuation routes, the estimation of a baseline worst case financial impact of this service on the NHS was calculated for flooding with various probabilities.

With further development this approach could be applied at a national level in the flood emergency planning process. This would allow the government and the NHS to be better prepared strategically, for the assisted mass evacuations of vulnerable populations, and financially, allowing an informed budgeting of emergency funds for the purpose of ambulance evacuations. Furthermore, with the inclusion of climate change data, it is possible to account for the future changes of flood impacts and determine developments that will be necessary to promote the efficiency of emergency responders, evacuations routes, and emergency financing in the years to come.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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REFERENCES

Achour, N., Pascale, F., Soetanto, R., & Price, A. D. (2015). Healthcare emergency planning and management to major hazards in the UK. *International Journal of Emergency Management*, *11*(1), 1–19.

Aday, L. A. (1994). Health status of vulnerable populations. *Annual Review of Public Health*, *15*(1), 487–509.

Albano, R., Sole, A., Adamowski, J., & Mancusi, L. (2014). A GIS-based model to estimate flood consequences and the degree of accessibility and operability of strategic emergency response structures in urban areas. *Natural Hazards and Earth System Sciences*, *14*(11), 2847–2865.

Alexander, D. (2005). Towards the development of a standard in emergency planning. *Disaster Prevention and Management*, *14* (2), 158–175.

Anandaciva, S. (2017) Nine things we learnt about provider finances in 2016/17, The King's Fund. Retrieved from https://www.kingsfund.org.uk/publications/nine-things-NHS-providerfinances-2016-17.

Anderson, M. B. (1995). *Vulnerability to disaster and sustainable development: A general framework for assessing vulnerability. Disaster prevention for sustainable development: Economic and policy issues* (pp. 41–59). Washington, DC: World Bank.

Automobile Association (2015) Flood Water Dangers. Retrieved from http://www.theaa.com/motoring_advice/seasonal/flood-water-dangers.html.

Balijepalli, C., & Oppong, O. (2014). Measuring vulnerability of road network considering the extent of serviceability of critical road links in urban areas. *Journal of Transport Geography*, *39*, 145–155.

Black, J. J., & Davies, G. D. (2005). International EMS systems: United Kingdom. *Resuscitation*, *64*(1), 21–29.

Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (2014). *At risk: Natural hazards, People's vulnerability and disasters*. New York: Routledge.

Bowman, C., & Meyer, J. (2017). Care home leadership: Action is needed. *Age and Ageing*, *46*(4), 534–535.

Bowman, C., Whistler, J., & Ellerby, M. (2004). A national census of care home residents. *Age and Ageing*, *33*(6), 561–566.

Boyan, J. A., & Littman, M. L. (1994). Packet routing in dynamically changing networks: A reinforcement learning approach. In J. D. Cowan, G. Tesauro, & J. Alspector (Eds.), *Advances in neural information processing systems* (Vol. 6, pp. 671–678). USA: Morgan Kaufmann.

British Medical Association. (2017). *State of the health system beds in the NHS: England*. London: British Medical Association.

Cabinet Office. (2013). *Emergency response and recovery: Non statutory guidance accompanying the civil contingencies act 2004*. London: Cabinet Office.

Cabinet Office. (2014). *Evacuation and shelter guidance: Non-statutory guidance to complement emergency preparedness and emergency response and recovery*. London: Cabinet Office.

carehome.co.uk (2018) Care Homes. Retrieved from https://www.carehome.co.uk/care_search_results.cfm/searchcounty/ 2017].

Chang, M. S., Tseng, Y. L., & Chen, J. W. (2007). A scenario planning approach for the flood emergency logistics preparation problem under uncertainty. *Transportation Research Part E: Logistics and Transportation Review*, *43*(6), 737–754.

Chen, A. Y., Yu, T. Y., Lu, T. Y., Chuang, W. L., Lai, J. S., Yeh, C. H., … Sun, W. Z. (2014). Ambulance service area considering disaster-induced disturbance on the transportation infrastructure. *Journal of Testing and Evaluation*, *43*(2), 1–11.

Cho, J. and Yoon, Y. (2015) *GIS-Based Analysis on Vulnerability of Ambulance Response Coverage to Traffic Condition: A Case Study of Seoul*. 2015 IEEE 18th International Conference on Intelligent Transportation Systems (ITSC), 1402–1407.

Coles, D., Yu, D., Wilby, R. L., Green, D., & Herring, Z. (2017). Beyond 'flood hotspots': Modelling emergency service accessibility during flooding in York, UK. *Journal of Hydrology*, *546*, 419–436.

Cova, T. J., & Johnson, J. P. (2003). A network flow model for lane-based evacuation routing. *Transportation Research Part A: Policy and Practice*, *37*(7), 579–604.

Crichton, M. T., Ramsay, C. G., & Kelly, T. (2009). Enhancing organizational resilience through emergency planning: Learnings from cross-sectoral lessons. *Journal of Contingencies and Crisis Management*, *17*(1), 24–37.

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly*, *84*(2), 242–261.

Cutter, S. L., Mitchell, J. T., & Scott, M. S. (2000). Revealing the vulnerability of people and places: A case study of Georgetown County, South Carolina. *Annals of the Association of American Geographers*, *90*(4), 713–737.

Danila, B., Yu, Y., March, J. A., & Bassler, K. E. (2006). Optimal transport on complex networks. *Physical Review E*, *74*(7), 46–106.

Dawson, R. J., Peppe, R., & Wang, M. (2011). An agent based model for risk-based flood incident management. *Natural Hazards*, *59* (1), 167–189.

DEFRA (2006) *Flood and Coastal Defence R&D Programme. R&D Outputs: Flood Risks To People—Phase 2. FD2321/TR1 The Flood Risks to People Methodology*. London: Department for Environment, Food and Rural Affairs (DEFRA), Environment Agency.

DEFRA (2009). *Adapting to climate change: UKclimate projections*. London: Department for Environment, Food and Rural Affairs (DEFRA).

DEFRA (2014). *The National Flood Emergency Framework for England*. London: Department for Environment, Food and Rural Affairs (DEFRA).

Department of the Environment, Food and Rural Affairs and Environment Agency (2002). *Catchment flood management plans, development of a modelling and decision support framework (MDSF): MDSF procedures and technical annexes, reports EX4495 and EX4497*. Oxford: HR Wallingford.

Derekenaris, G., Garofalakis, J., Makris, C., Prentzas, J., Sioutas, S., & Tsakalidis, A. (2001). Integrating GIS, GPS and GSM technologies for the effective management of ambulances. *Computers, Environment and Urban Systems*, *25*(3), 267–278.

Di Mauro, M., & Lumbroso, D. (2008). *Hydrodynamic and loss of life modelling for the 1953 Canvey Island flood. Proceeding the international conference FLOODrisk* (p. 2008). Oxford: UK.

Dosa, D., Hyer, K., Thomas, K., Swaminathan, S., Feng, Z., Brown, L., & Mor, V. (2012). To evacuate or shelter in place: Implications of universal hurricane evacuation policies on nursing home residents. *Journal of the American Medical Directors Association*, *13*(2), 190.e1–190.e7.

Dosa, D. M., Grossman, N., Wetle, T., & Mor, V. (2007). To evacuate or not to evacuate: Lessons learned from Louisiana nursing home administrators following hurricanes Katrina and Rita. *Journal of the American Medical Directors Association*, *8*(3), 142–149.

East of England Ambulance Service Trust (2017a) Freedom of Information Request Officer for the East of England Ambulance Service NHS Trust. eoeasnt.foi@nhs.net. Obtained under the Freedom of Information request [20 Dec 2017]. East of England Ambulance Service Trust (nda) About us. Retrieved from https://www.eastamb.nhs.uk/about-us/.

East of England Ambulance Service Trust (2017b) Patient transport service. Retrieved from https://www.eastamb.nhs.uk/your-service/patient-transport.htm.

East of England Ambulance Service Trust (2017c) Your Service. Retrieved from https://www.eastamb.nhs.uk/your-service/.

EDINA Digimap (2017a) MiniScale [TIFF geospatial data], Scale 1: 1 000 000, Tiles: Norfolk and Suffolk, Updated: January 2017, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, http://digimap.edina.ac.uk, Downloaded: 8th June 2017.

EDINA Digimap (2017b) ITN—Integrated Transport Network [GML2 geospatial data], Scale 1:1250, Tiles: Norfolk and Suffolk, Updated: May 2017, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, http://digimap.edina.ac.uk, Downloaded: 8th May 2017.

Edwards, T. (2017). *Future of the sea: Current and future impacts of sea level rise on the UK. Government Office for Science*. London: Government Office for Science.

Elboshy, B., Kanae, S., Gamaleldin, M., Ayad, H., Osaragi, T., & Elbarki, W. (2018). A framework for pluvial flood risk assessment in Alexandria considering the coping capacity. *Environment Systems and Decisions*, *39*(1), 77–94.

Environment Agency (2005) R&D Technical Summary W5-024/TS. Retrieved from http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/SCHO0505BJDV-EP_pdf.sflb.ashx.

Environment Agency (2009). *Broadland Rivers catchment flood management plan*. Peterborough: Environment Agency.

Environment Agency (2010). *The costs of the summer 2007 floods in England*. Bristol: Environment Agency.

Environment Agency (2015a) Risk of Flooding from Rivers and Sea. Retrieved from https://data.gov.uk/dataset/risk-of-flooding-from-rivers-and-sea1.

Environment Agency (2015b) Risk of Flooding from Rivers and Sea: product description. Retrieved from https://parallel.co.uk/rofrs/resources/RoFRS_Product_Description_vs1.5.pdf.

Environment Agency (2016). *The costs and impacts of the winter 2013 to 2014 floods*. Bristol: Environment Agency.

Esm, S. O., OAM, P. C., & Davies, B. (2010). Timeline modelling of flood evacuation operations. *Procedia Engineering*, *3*, 175–187.

Esri (2017a) Service area analysis. Retrieved from http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/service-area.htm.

Esri (2017b) Closest facility analysis. Retrieved from http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/closest-facility.htm.

Evans, J. (2018). *UKhealthcare property 2018*. London: Knight Frank.

Fernandez, L. S., Byard, D., Lin, C. C., Benson, S., & Barbera, J. A. (2002). Frail elderly as disaster victims: Emergency management strategies. *Prehospital and Disaster Medicine*, *17*(2), 67–74.

Fischbacher-Smith, D., & Calman, K. (2010). A precautionary tale—the role of the precautionary principle in policy making for public health. In P. Bennett, K. Calman, S. Curtis, & D. Fischbacher-Smith (Eds.), *Risk communication and public health* (pp. 197–209). New York: Oxford University Press.

Flint, E. (2015). *Our environment: A summary of environmental factors influencing health and wellbeing in Suffolk*. Ipswich: Suffolk County Council.

Gaughan, J., Gravelle, H., & Siciliani, L. (2017). Delayed discharges and hospital type: Evidence from the English NHS. *Fiscal Studies*, *38*(3), 495–519.

Gendreau, M., Laporte, G., & Semet, F. (2006). The maximal expected coverage relocation problem for emergency vehicles. *Journal of the Operational Research Society*, *57*(1), 22–28.

Gil, J., & Steinbach, P. (2008). From flood risk to indirect flood impact: Evaluation of street network performance for effective management. *Response and Repair. WIT Transactions on Ecology and the Environment*, *118*, 335–344.

Gordon, A. L., Franklin, M., Bradshaw, L., Logan, P., Elliott, R., & Gladman, J. R. (2013). Health status of UKcare home residents: A cohort study. *Age and Ageing*, *43*(1), 97–103.

Green, D., Yu, D., Pattison, I., Wilby, R., Bosher, L., Patel, R., … Yang, L. (2017). City-scale accessibility of emergency responders operating during flood events. *Natural Hazards and Earth System Sciences*, *17*(1), 1–16.

Green, D., Yu, D., Pattison, I., Wilby, R. L., Bosher, L. S., Patel, R., … Yang, L. (2016). Flood impacts on emergency responders operating at a city-scale. *Natural Hazards and Earth System Sciences Discussions*, *17*, 1–16.

Hatono, M., Noda, K., Kim, H., Baimoung, S., Yoshimura, K., Oki, K., & Oki, T. (2014). Conversion of surface water coverage to water volume using satellite data. *Hydrological Research Letters*, *8*(1), 15–19.

Haynes, K., Coates, L., Leigh, R., Handmer, J., Whittaker, J., Gissing, A., … Opper, S. (2009). 'Shelter-in-place' vs. evacuation in flash floods. *Environmental Hazards*, *8*(4), 291–303.

Holme, P. (2003). Congestion and centrality in traffic flow on complex networks. *Advances in Complex Systems*, *6*(02), 163–176.

Hsueh, C. F., Chen, H. K., & Chou, H. W. (2008). Dynamic vehicle routing for relief logistics in natural disasters. In T. Caric & H. Gold (Eds.), *Vehicle routing problem* (pp. 71–85). Croatia: InTech.

Hubbard, S., Stewart, K., & Fan, J. (2014). Modeling spatiotemporal patterns of building vulnerability and content evacuations before a riverine flood disaster. *Applied Geography*, *52*, 172–181.

Hyer, K., Brown, L. M., Christensen, J. J., & Thomas, K. S. (2009). Weathering the storm: Challenges to nurses providing care to nursing home residents during hurricanes. *Applied Nursing Research*, *22*(4), e9–e14.

Ikeuchi, H., Hirabayashi, Y., Yamazaki, D., Muis, S., Ward, P. J., Winsemius, H. C., … Kanae, S. (2017). Compound simulation of fluvial floods and storm surges in a global coupled river-coast flood model: Model development and its application to 2007 cyclone Sidr in Bangladesh. *Journal of Advances in Modeling Earth Systems*, *9*(4), 1847–1862.

Jonkman, S. N., Maaskant, B., Boyd, E., & Levitan, M. L. (2009). Loss of life caused by the flooding of New Orleans after hurricane Katrina: Analysis of the relationship between flood characteristics and mortality. *Risk Analysis*, *29*(5), 676–698.

Jotshi, A., Gong, Q., & Batta, R. (2009). Dispatching and routing of emergency vehicles in disaster mitigation using data fusion. *Socio-Economic Planning Sciences*, *43*(1), 1–24.

Joy, C. S. (1993). The cost of flood damage in Nyngan. *Climatic Change*, *25*(3–4), 335–351.

Khalid, M. N. A., & Yusof, U. K. (2018). Dynamic crowd evacuation approach for the emergency route planning problem: Application to case studies. *Safety Science*, *102*, 263–274.

Kim, S., George, B., & Shekhar, S. (2007). Evacuation route planning: Scalable heuristics. *15th Annual ACM International Symposium on Advances in Geographic Information Systems*, (20).

Kipling, J., Newton, R., & Ormerod, M. (2011). Accessing emergency rest centres in the UK–lessons learnt. *International Journal of Disaster Resilience in the Built Environment*, *2*(1), 47–58.

Kramer, M., Terheiden, K., & Wieprecht, S. (2016). Safety criteria for the trafficability of inundated roads in urban floodings. *International Journal of Disaster Risk Reduction*, *17*, 77–84.

Leknes, H., Aartun, E. S., Andersson, H., Christiansen, M., & Granberg, T. A. (2017). Strategic ambulance location for heterogeneous regions. *European Journal of Operational Research*, *260*(1), 122–133.

Lhomme, S., Serre, D., Diab, Y., & Laganier, R. (2013). Analyzing resilience of urban networks: A preliminary step towards more flood resilient cities. *Natural Hazards and Earth System Sciences*, *13*(2), 221–230.

Lievesley, N., Crosby, G., Bowman, C., & Midwinter, E. (2011). *The changing role of care homes*. London: Bupa and Centre for Policy on Ageing.

Lowe, J. A., Howard, T. P., Pardaens, A., Tinker, J., Holt, J., Wakelin, S., … Bradley, S. (2009). *UK climate projections science report: Marine and coastal projections*. Exeter: Met Office Hadley Centre.

Lu, Q., George, B., & Shekhar, S. (2005). Capacity constrained routing algorithms for evacuation planning: A summary of results. In C. B. Medeiros, M. Egenhofer, & E. Bertino (Eds.), *Advances in spatial and temporal databases* (pp. 291–307). Berlin: Springer.

Lu, Q., Huang, Y., & Shekhar, S. (2003). Evacuation planning: A capacity constrained routing approach. In H. Chen, R. Miranda, D. D. Zeng, C. Demchak, & T. Madhusudan (Eds.), *Intelligence and security informatics* (pp. 111–125). Berlin: Springer.

Lujak, M., & Giordani, S. (2017). Centrality measures for evacuation: Finding agile evacuation routes. *Future Generation Computer Systems*, *83*, 401–412.

Lumbroso, D., & Davison, M. (2018). Use of an agent-based model and Monte Carlo analysis to estimate the effectiveness of emergency management interventions to reduce loss of life during extreme floods. *Journal of Flood Risk Management*, *11*, S419–S433.

Lumbroso, D., Johnstone, W., De Bruijn, K., Di Mauro, M., Lence, B., & Tagg, A. (2010). *Modelling mass evacuations to improve the emergency planning for floods in the UK, The Netherlands and North America*. Birmingham, UK: Proceedings of the international conference on emergency preparedness (InterCEPt): the challenges of mass evacuation.

Lumbroso, D., Stone, K., & Vinet, F. (2011). An assessment of flood emergency plans in England and Wales, France and The Netherlands. *Natural Hazards*, *58*(1), 341–363.

Lumbroso, D., & Vinet, F. (2012). Tools to improve the production of emergency plans for floods: Are they being used by the people that need them? *Journal of Contingencies and Crisis Management*, *20*(3), 149–165.

Martínez-Gomariz, E., Gómez, M., Russo, B., & Djordjević, S. (2018). Stability criteria for flooded vehicles: A state-of-the-art review. *Journal of Flood Risk Management*, *11*, S817–S826.

McEntire, D. A., & Myers, A. (2004). Preparing communities for disasters: Issues and processes for government readiness. *Disaster Prevention and Management: An International Journal*, *13* (2), 140–152.

Met Office (2012) Record rainfall—April to July 2012. Retrieved from https://www.metoffice.gov.uk/weather/learn-about/past-uk-weather-events

Morselt, T., Engelsman, G. J., & Lobbes, E. (2007). *Estimating cost functions for evacuation, emergency services and cleanup in case of floods*. Netherlands: Rebelgroup.

Mustafa, D. (2003). Reinforcing vulnerability? Disaster relief, recovery, and response to the 2001 flood in Rawalpindi, Pakistan. *Global Environmental Change Part B: Environmental Hazards*, *5*(3–4), 71–82.

National Audit Office. (2017). *NHS ambulance service*. London: National Audit Office.

NHS England. (2015). *NHS England emergency preparedness, resilience and response (EPRR) planning for the shelter and evacuation of people in healthcare settings*. Leeds: NHS England EPRR.

NHS England (2017) New Ambulance Standards—easy read document. Retrieved from https://www.england.nhs.uk/publication/new-ambulance-standards-easy-read-document/.

NHS Improvement (2017) Quarterly performance of the NHS provider sector: quarter 4 2016/17. Retrieved from https://improvement.nhs.uk/resources/quarterly-performance-nhsprovider-sector-quarter-4-1617/.

Noh, H., Chiu, Y. C., Zheng, H., Hickman, M., & Mirchandani, P. (2009). Approach to modeling demand and supply for a short-notice evacuation. *Transportation Research Record*, *2091*, 91–99.

Norfolk Resilience Forum. (2015). *Norfolk strategic flood plan 2015*. Norwich: Norfolk County Council.

Norfolk Resilience Forum. (2017). *Norfolk emergency response guidance 2016*. Norwich: Norfolk City Council.

Office for National Statistics (2011) Census: Digitised Boundary Data (England and Wales) [Target Geography: InFuse United Kingdom, 2011]. UK Data Service Census Support. Retrieved from https://borders.ukdataservice.ac.uk/.

Office for National Statistics (2018) Table 3 2011 Census: Usual resident population by five-year age group and sex, local authorities in the United Kingdom. Retrieved from https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/2011censuspopulationandhouseholdestimatesfortheunitedkingdom.

Oven, K. J., Curtis, S. E., Reaney, S., Riva, M., Stewart, M. G., Ohlemüller, R., … Holden, R. (2012). Climate change and health and social care: Defining future hazard, vulnerability and risk for infrastructure systems supporting older people's health care in England. *Applied Geography*, *33*, 16–24.

Panahi, S., & Delavar, M. R. (2008). A GIS-based dynamic shortest path determination in emergency vehicles. *World Applied Sciences Journal*, *3*(1), 88–94.

Pasquier, U., He, Y., Hooton, S., Goulden, M., & Hiscock, K. M. (2018). An integrated 1D–2D hydraulic modelling approach to assess the sensitivity of a coastal region to compound flooding hazard under climate change. *Natural Hazards*, *98*(3), 915–937.

Pel, A. J., Bliemer, M. C., & Hoogendoorn, S. P. (2012). A review on travel behaviour modelling in dynamic traffic simulation models for evacuations. *Transportation*, *39*(1), 97–123.

Penning-Rowsell, E., & Wilson, T. (2006). Gauging the impact of natural hazards: The pattern and cost of emergency response during flood events. *Transactions of the Institute of British Geographers*, *31*(2), 99–115.

Pfurtscheller, C., & Schwarze, R. (2008). Estimating the costs of emergency services during flood events. In *Proceedings of the 4th international symposium on flood defence*. Toronto: Institute for Catastrophic Loss Reduction.

Pidd, M., De Silva, F. N., & Eglese, R. W. (1996). A simulation model for emergency evacuation. *European Journal of Operational Research*, *90*(3), 413–419.

Pitt, M. (2008). *The Pitt review: Learning lessons from the 2007 floods*. London: Cabinet Office.

Powell, D. (2015). *Emergency evacuation route signage. A report to flood and drainage management scrutiny committee*. Lincoln: Lincolnshire County Council.

Powell, W. B., Jaillet, P., & Odoni, A. (1995). Stochastic and dynamic networks and routing. *Handbooks in Operations Research and Management Science*, *8*, 141–295.

Renne, J. L. (2018). Emergency evacuation planning policy for carless and vulnerable populations in the United States and United Kingdom. *International Journal of Disaster Risk Reduction*, *31*, 1254–1261.

Renne, J. L., Sanchez, T. W., Jenkins, P., & Peterson, R. (2009). Challenge of evacuating the carless in five major US cities: Identifying the key issues. *Transportation Research Record*, *2119*(1), 36–44.

Rich, T., & Callahan, M. (2008). *Mass Evacuation Model: AHRQ Publication No. AHRQ 08 0102-1-EF*. Prepared for

Agency for Healthcare Research and Quality. Maryland: Abt Associates.

Rosenthal, U., & t'Hart, P. (Eds.). (2012). *Flood response and crisis management in Western Europe: A comparative analysis*. the Netherlands: Springer Science & Business Media.

Sakakibara, H., Kajitani, Y., & Okada, N. (2004). Road network robustness for avoiding functional isolation in disasters. *Journal of Transportation Engineering*, *130*(5), 560–567.

Sayers, P. B., Horritt, M., Penning-Rowsell, E., & McKenzie, A. (2015). *Climate change risk assessment 2017: Projections of future flood risk in the UK*. Research Undertaken by Sayers and Partners on Behalf of the Committee on Climate Change. London: Committee on Climate Change.

Shahabi, K., & Wilson, J. P. (2018). Scalable evacuation routing in a dynamic environment. *Computers, Environment and Urban Systems*, *67*, 29–40.

Shekhar, S., Yang, K., Gunturi, V. M., Manikonda, L., Oliver, D., Zhou, X., … Lu, Q. (2012). Experiences with evacuation route planning algorithms. *International Journal of Geographical Information Science*, *26*(12), 2253–2265.

Smith, D., & Toft, B. (1998). Editorial: Issues in public sector risk management. *Public Money and Management*, *18*(4), 41–50.

Smith, G. P., Modra, B. D., Tucker, T. A., & Cox, R. J. (2017). *Vehicle stability testing for flood flows*. New South Wales, Australia: Water Research Laboratory.

Somers, S., & Svara, J. H. (2009). Assessing and managing environmental risk: Connecting local government management with emergency management. *Public Administration Review*, *69*(2), 181–193.

Spencer, T., Brooks, S. M., Evans, B. R., Tempest, J. A., & Möller, I. (2015). Southern North Sea storm surge event of December 5, 2013: Water levels, waves and coastal impacts. *EarthScience Reviews*, *146*, 20–145.

Stepanov, A., & Smith, J. M. (2009). Multi-objective evacuation routing in transportation networks. *European Journal of Operational Research*, *198*(2), 435–446.

Suffolk Flood Risk Management Partnership. (2016). *Suffolk flood risk management strategy 2016*. Ipswich: Suffolk City Council.

Suffolk Resilience Forum. (2015). *Suffolk flood plan*. Ipswich: Suffolk Resilience Forum.

Tagg, A. F., Kolen, B., Leenders, J., Chen, H., & Powell, D. (2013). *The use of traffic modelling to inform a flood evacuation policy for Lincolnshire and Norfolk*. Taylor & Francis Group, London: Comprehensive Flood Risk Management.

Talarico, L., Meisel, F., & Sörensen, K. (2015). Ambulance routing for disaster response with patient groups. *Computers & Operations Research*, *56*, 120–133.

Tapsell, S. M., Penning-Rowsell, E. C., Tunstall, S. M., & Wilson, T. L. (2002). Vulnerability to flooding: Health and social dimensions. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, *360*(1796), 1511–1525.

Teo, F.Y., Liew, Y.S., Falconer, R.A., & Lin, B. (2013). Estimation of Flood Hazard Risk Relating to Vehicles. *Proceedings of 35th IAHR World Congress*. China: IAHR.

The King's Fund. (2017). *Understanding NHS financial pressures: How are they affecting patient care?* London: The King's Fund.

Tuydes, H., & Ziliaskopoulos, A. (2006). Tabu-based heuristic approach for optimization of network evacuation contraflow. *Transportation Research Record*, *1964*(1), 157–168.

UNESCO (2005) The Precautionary Principle. Paris: UNESCO. US Geological Survey (2016) Floods: Recurrence intervals and 100-year floods. Retrieved from https://water.usgs.gov/edu/100yearflood.html

Van Barneveld, T. C., Bhulai, S., & Van der Mei, R. D. (2016). The effect of ambulance relocations on the performance of ambulance service providers. *European Journal of Operational Research*, *252*(1), 257–269.

Vásconez, K. C., & Kehrli, M. (2010). *Highway evacuations in selected metropolitan regions: Assessment of impediments*. Washington: Office of Transportation Operations.

Willoughby, M., Kipsaina, C., Ferrah, N., Blau, S., Bugeja, L., Ranson, D., & Ibrahim, J. E. (2017). Mortality in nursing homes following emergency evacuation: A systematic review. *Journal of the American Medical Directors Association*, *18*(8), 664–670.

Yamada, T. (1996). A network flow approach to a city emergency evacuation planning. *International Journal of Systems Science*, *27*(10), 931–936.

Yin, J., Yu, D., Lin, N., & Wilby, R. L. (2017). Evaluating the cascading impacts of sea level rise and coastal flooding on emergency response spatial accessibility in lower Manhattan, New York City. *Journal of Hydrology*, *555*, 648–658.

Yin, J., Yu, D., Yin, Z., Liu, M., & He, Q. (2016). Evaluating the impact and risk of pluvial flash flood on intra-urban road network: A case study in the city center of Shanghai, China. *Journal of Hydrology*, *537*, 138–145.

Yuan, F., Han, L., Chin, S. M., & Hwang, H. (2006). Proposed framework for simultaneous optimization of evacuation traffic destination and route assignment. *Transportation Research Record: Journal of the Transportation Research Board*, *1964*, 50–58.

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