Percival, S, Gaterell, M and Teeuw, R

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Urban Neighbourhood Flood Vulnerability and Risk Assessments at Different Diurnal Levels.

Percival Sarah[1], Gaterell Mark[1] & Teeuw Richard[2]

[1] School of Civil Engineering & Surveying, University of Portsmouth, UK
sarah.percival@port.ac.uk & mark.gaterell@port.ac.uk
[2] Centre for Applied Geoscience, School of Earth and Environmental Sciences, University of Portsmouth, UK. richard.teeuw@port.ac.uk

Abstract

Diurnal changes within communities can significantly alter the level of impacts during a flood, yet these essential daily variations are not currently catered for within flood risk assessments. This paper develops a flood vulnerability and risk model that captures crucial features of flood vulnerability; integrating physical and socio-economic vulnerability data, combined with a flood hazard analysis, to give overall flood risk at neighbourhood scale, at two different times of day, for floods of different magnitudes. The flood vulnerability and risk model, the resulting diurnal coastal flood vulnerability and risk indexes and corresponding maps for the ward of Hilsea, (Portsmouth, UK), presented within this paper, highlight three previously unidentified neighbourhoods in particular in the north-west of the Hilsea ward, that have the highest levels of risk during both time zones and for flood events of different magnitude. Critically, these neighbourhoods lie further inland and not directly on the Hilsea coastline, yet by analysing at this resolution (including diurnal impacts), substantial levels of underlying vulnerability were identified within these areas.

Keywords: integrated flood risk; mapping of hazard and risk; risk analysis; vulnerability

Introduction

Recent flood disasters in the UK (2007, 2013-2014 storm surges, 2015 and 2017) have reminded us of society's increasing vulnerability, as flooding has far-reaching, short and long-term consequences for those concerned, including death, damage, and disruption. The Committee on Climate Change (2016) stated that future flood research needs to focus and prioritise efforts on the understanding of potential impacts to communities, businesses and infrastructure. Current levels of flood risk management in the UK are considered insufficient (Committee on Climate Change 2016), and in the context of sustainability, new and proactive approaches for the management of flood hazards are needed, that engage with a much wider set of tools and knowledge (Wilkinson *et al*. 2015; Bracken *et al*. 2016).

Currently 5.2 million people in England and Wales are deemed to be at risk of flooding (National Flood Forum 2016). Yet within those at-risk areas, people and places will suffer differently according to their degrees of vulnerability (Birkmann *et al*. 2013), i.e. the physical and socio-economic characteristics or wider deprivation in those areas (Maantay and Maroko 2009; Wilson *et al.* 2014). Understanding and identifying vulnerability at the right scale prior to undertaking new flood management approaches is vital in order to establish potential impacts within communities. While risk and vulnerability can be seen as continuous, impacts are a materialisation ('this is happening now'/ 'real event') of these underlying conditions (Renn 1992; Adam and Van Loon 2000; Beck 2000; Cardona *et al*. 2012; Birkmann *et al*. 2013).

While vulnerability analyses have evolved significantly, there is still no consensus within the risk science community about vulnerability or its factors. Therefore, development of a theoretical framework to structure the analysis is essential. Research presented in this paper, based on a case study of Portsmouth, UK, aims to assess and map coastal flood risk (CoFR) for urban communities at neighbourhood scale, for floods of different magnitudes, diurnally. In the methodology presented, the original risk, hazard and vulnerability relationship (Wisner *et al.* 2004; Cancado *et al*. 2008) has been developed to further analyse vulnerability, by combining three components (physical vulnerability, socio-economic vulnerability and resilience) into one measurement (Equation 1). The resulting tool captures the most relevant features of diurnal flood vulnerability (both pre and post impact), assisting our understanding of the reality of vulnerability at the level of detail necessary to truly deliver effective local solutions and embed resilience.

Equation 1

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability (Physical Vulnerability + Socio-economic Vulnerability + Resilience)}$$

Within this research hazard refers to the possible future occurrence of natural events that could have serious adverse effects on vulnerable elements (Birkmann 2006; Ramieri *et al*. 2011; Cardona *et al*. 2012; IPCC 2014). The concept of risk combines the probability of hazard occurrence with the likely impacts or consequences that are associated with that event (vulnerability) (Ramieri *et al*. 2011; IPCC 2014). Vulnerability therefore relates to the predisposition, lack of capacities, exposure, susceptibilities, weaknesses, or fragilities that would favor the adverse effects from hazardous events (Birkmann 2006; Cutter 2006; UNISDR 2009; Kaźmierczak and Cavan 2011; Menoni *et al.* 2012) i.e. vulnerability is more dynamic than traditional approaches suggest (Birkmann *et al.* 2013). It encompasses a broad range of factors including socio-economic characteristics of the population and the physical characteristics of the built environment, as well as a community's ability to cope and recover from a flood and the associated impacts (resilience). The combination of these factors can increase the significance of potential impacts for those at risk (England and Knox 2015). Any risk assessment should therefore incorporate the interaction between the nature of the hazard and the inherent characteristics of the area/community at risk (Green, Parker and Tunstall 2000; Cancado *et al.* 2008).

A fundamental problem with current flood risk forecasting and the implementation of comprehensive safety/management measures has been the lack of detailed information regarding diurnal and seasonal variations (Bush and Cerveny 2013). The time of day when the flood occurs is a variable that can seriously affect degrees of flood vulnerability and the levels of flood impact i.e. turning an event into a disaster. On average, more people are killed by flooding than by any other single severe weather hazard including tornados and hurricanes, and most of these deaths have occurred at night (NOAA 2015). Generally people are unaware of disasters occurring at night as most are sleeping. People become aware of the situation perhaps 'too late', when it has become very dangerous, increasing risk to life. It is therefore best to evacuate the inundating/inundated area immediately and go to shelter on safer or higher ground (Miltner 2017; Earth Networks 2017). However, leaving any flooded area can be fraught with dangers that are both immediate and continue when water levels have stopped rising (Miltner 2017; Earth Networks 2017). Six inches of swiftly moving water can knock most people off of their feet (NOAA 2015; Miltner 2017) and driving must be done with extreme caution (Public Health England 2015). Loss of vehicle control can onset very quickly, especially when water levels build. Vehicles can hydroplane, stall or even come to a complete standstill, trapping those inside and sweeping them away, possibly leading to drowning (Public Health England 2015; NOAA 2015; Earth Networks 2017). It is also ill-advised to either drive or walk through standing water with poor visibility (Public Health England 2015). Depths of floodwater are not always obvious and roads/pathways can be seriously compromised or blocked due to heavy invisible debris (NOAA 2015). Floodwater can also hide downed power lines or sharp debris/objects, and can be heavily contaminated with either sewage or other hazardous substances, all leading to possible increases in risk of harm, general infection or diarrheal/sickness diseases (Public health England 2015; NOAA 2015; Earth Networks 2017; Miltner 2017). All of these dangers highlight that contact with either moving or standing floodwater should be minimised.

Floods at night time present a real danger as darkness can lead to disorientation and inability to observe any flood dangers present i.e. deep water, contaminated flood water, flooded drains, missing manhole covers, dangerous submerged large/sharp objects, or fast moving objects (Newry, Mourne and Down District Council 2016; NOAA 2015; Public Health England 2016). Thus flood forecasting and warning systems are vital for safe evacuation practices. Yet despite our flood forecasting and warning systems and carefully managed search and rescue teams, these systems are not perfect and problems still arise, resulting in tragedies or being caught in very dangerous situations, particularly at night e.g. 9th January 2018 California, USA floods, 2013/14 UK storm surges and recently 22nd April 2018 Southampton, UK flash floods. In the UK as a result of the 1953 North Sea storm surge (which occurred mainly during the night) that resulted in 307 deaths in England, 19 in Scotland and 1800 in the Netherlands; the Storm Tides Warning Service was established by the Met Office to accurately forecast development and movement of storm surges up to two-five days ahead (Met Office 2014). The flood alert and warning service was established more recently and is freely available to the English public, sending an alert/warning anywhere between 2 hours and 2 days prior to the flood (Environment Agency 2014; 2018). However, this warning service is not available in all areas, requires prior sign up via governmental links, and the alert and warning codes provide little detail unless further investigation is made, firmly placing the responsibility with the homeowner (BBC 2007; Environment Agency 2014; 2018). Furthermore these services have led to unnecessary residential evacuations (Yarmouth 2007 and 2017) i.e. no flood transpired, leading to mistrust in the warnings. Unfortunately though, the greatest issue is that residents can refuse to leave their homes. In January 2017 in Great Yarmouth, UK, 60% of residents chose not to leave their dwellings, despite door-to-door severe flood warnings issued to around 6000 properties (BBC 2017; Norfolk Constabulary 2017). Additionally, in areas of the UK such as Portsmouth, where risk is very high but severe or catastrophic coastal flooding events have either never occurred or not for some time, there is a high probability of limited individual flood preparation and severe impacts, due to lack of knowledge or even complacency. Potentially leading to further problems and risk to emergency service personnel when rescue is required.

Meterological events cannot be changed, but the severity of impacts arising from a flood event as a result of weather extremes, can be mitigated. As floods at different times of day can result in different levels of impact, it is key to pinpoint neighbourhoods where these perils may arise in order to improve our evacuation and mitigation strategies and target where our resources are needed. To better spotlight these at risk areas, the remainder of this paper discusses how we can understand diurnal variations in flood risk and presents a methodology that analyses it at the appropriate scale, establishing its local context. This research uniquely assesses and pinpoints diurnal flood risk, providing a significant advance on existing approaches to considering the impact of flooding to communities when undertaking flood risk management. Finally, the implications, uncertainties and opportunities to improve this methodology are discussed.

Methodology

Study Area – Portsmouth, UK

The study area chosen to pilot this methodology was the island city of Portsmouth, UK (Figure 1). Flood risk issues confronting Portsmouth reflect many of those being faced by other UK communities and indeed globally. The city and unitary authority of Portsmouth covers a total area of 40 km^2 split between the mainland and Portsea Island, with the primary source of flood risk from the sea (Atkins 2007; Portsmouth City Council 2011a, b, c; Wadey *et al*. 2012). Physically, Portsmouth's topography ranges from sea level to approx. 125 m above Ordnance datum (mAOD), however on the island and most of the mainland very few areas are higher than 10 mAOD (Atkins, 2011). Portsmouth is a densely populated (just over 197,000) and urbanised city, the majority of which reside on Portsea Island (Figure 1) (Environment Agency, 2010). This city is extensively developed (over 87%) with future plans for an additional 14,700 homes to be built before 2026 (Environment Agency, 2010). Furthermore, 47% of the city land area is designated within Environment Agency (EA) Flood Zones 2 and 3, with 0.1% and 0.5% chance of flooding, respectively (Atkins 2007, 2011). Coastal floods of this magnitude would inundate densely populated, expensive, and socially deprived neighbourhoods in Portsmouth (more than 15,000 properties), causing devastation and difficult evacuation. With these mounting pressures on flood risk management practices, successful flood risk identification and communication is vital in Portsmouth to reduce flood risk levels. Within Portsmouth, the ward of Hilsea was chosen to present this methodology for this paper (Figure 1), as Portsmouth City Council (2011a) has identified this area to be critical, due to potentially high risk to life from inundation and high capital costs for flood defences.

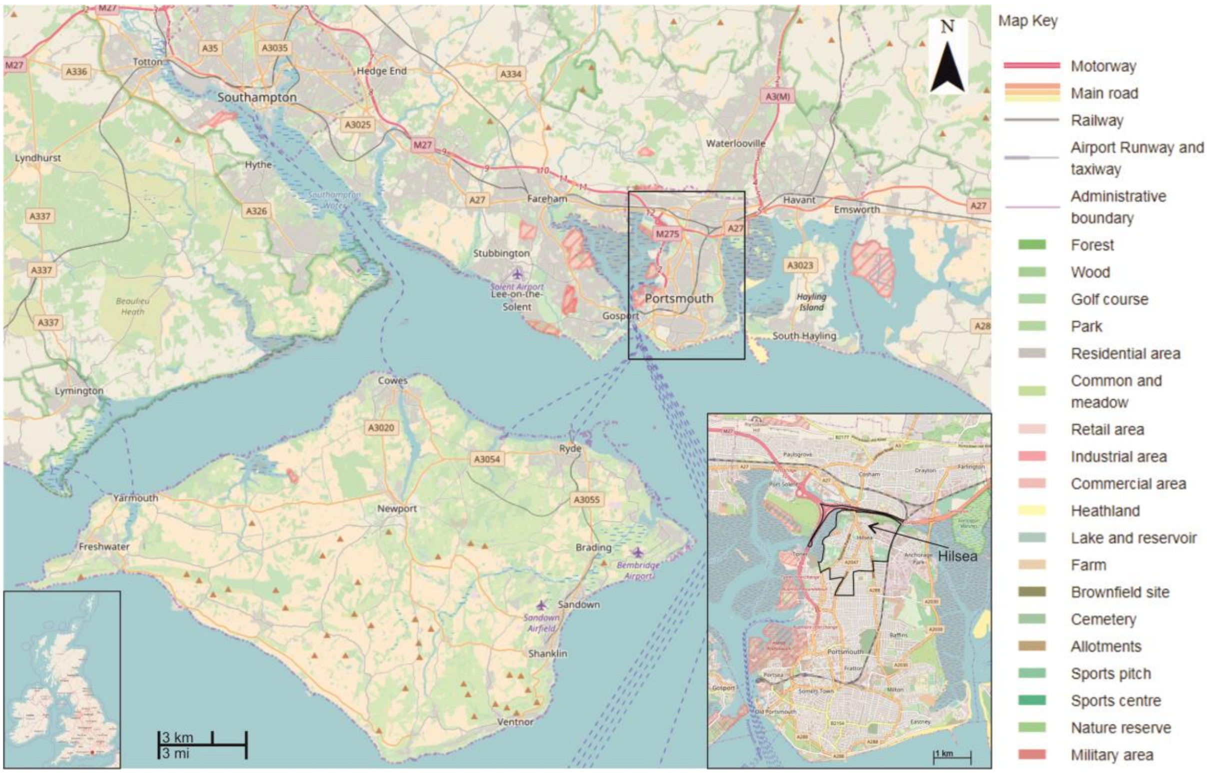

Figure 1. Location map of Hilsea and Portsmouth. Inset boxes shows the location of Hilsea within Portsmouth and Portsmouth within the UK. Map data © OpenStreetMap

Coastal Flood Vulnerability Factors

Pinpointing attributes of vulnerability and the ability to measure them in terms of data is a challenging task. Nevertheless, a number of datasets are available for the UK that can be used to represent different aspects and internal characteristics of geographical areas when considering coastal flooding. However, when incorporating many different data sources into one model, a standardisation of the data, to ensure uniformity in scales and units is required (Cutter *et al*. 2003; Tapsell *et al*. 2010; Menoni *et al*. 2012). An index approach was therefore adopted for this study, as indexing is one of the most simplistic systems and commonly used when assessing flood vulnerability (e.g. Chang *et al*. 2004; Connor and Hiroki 2005; Sullivan and Meigh 2005; Lindley *et al*. 2011; Balica *et al*. 2012) to natural and climate induced processes and hazards (erosion, flooding, sea-level rise etc.) (Ramieri *et al*. 2011). This approach enabled all the different vulnerability factors to be combined into their respective Coastal Flood Vulnerability components (physical vulnerability, socio-economic vulnerability and resilience), within one framework.

The final hazard and vulnerability indices were created and combined in equation 1, to create a Coastal Flood Risk index. Resulting in a simple numerical basis for ranking neighbourhoods in terms of their potential for impact and change, diurnally. These results are also displayed on maps to highlight specific regions assisting the identification of factors that might contribute to the vulnerability of those areas. To achieve this the first methodological step included the identification of key factors to represent the significant driving processes influencing coastal flood vulnerability. The second step involved the quantification of those key factors.

Vulnerability is composed of interacting elements where different processes or individual interactions increase or decrease it. For better understanding of this paper the different vulnerability components are further discussed, including the factors that compose each component. All the factors presented in this paper have been deduced through theoretical research (Cutter *et al*. 2003; Kaźmierczak and Cavan 2011; Lindley *et al*. 2011; Birkmann *et al*. 2013) where links have been derived from a theoretical framework, with proxies chosen based on those links (Balica *et al*. 2012; Damm 2010) i.e. all factors are chosen from a coastal flooding perspective. The factors used were screened for their suitability, definition (or theoretical structure) and their data availability. Figure 2 presents the vulnerability data variables included in the final flood risk model, the vulnerability factors they populate and the vulnerability component to which they are associated.

Physical Vulnerability

In recent years, natural hazards in metropolitan areas, such as floods, have shown that environment-compatible urbanisation has not occurred (Başaran-Uysal *et al*. 2014). Residential areas with an inadequate physical environment suffer the most in natural disasters (White *et al*. 2004; Wamsler 2006). Therefore in order to mitigate against hazards such as flooding, the degree of physical vulnerability in urbanised areas needs to be established (Başaran-Uysal *et al*. 2014). This is defined by the essential physical characteristics of the urban environment and the population density within the exposed area, i.e. the predisposition of a community that can either exacerbate or reduce the hazard's impact (Birkmann 2006; Kaźmierczak and Cavan 2011; Lindley *et al*. 2011; Menoni *et al.* 2012; Birkmann *et al*. 2013; Climate Just 2015), including buildings, roads, power stations, critical infrastructure, land, ecosystems, individuals, households etc. (Kaźmierczak and Cavan 2011; Cardona *et al*. 2012; Menoni *et al*. 2012). Topography is not included here as this is already considered (via a Digital Terrain Model (DTM)) within the Flood Zone 2 (1 in 1000 year event) and 3 (1 in 200 year event) data that populate the hazard analysis. A set of physical vulnerability factors (Figure 2) were created to guide data selection and manipulation, resulting in a physical vulnerability analysis in the form of a Coastal Flood Physical Vulnerability Index (CoFPVI); aided by remote sensing, image processing and GIS software. The Coastal Flood Physical Vulnerability (CoFPV) factors included *population density*, *green areas*, *essential buildings*, *utilities*, *transport*, *dwellings*, *tenure*, *commercial and industrial areas* and *vulnerable buildings day and night*.

Socio-economic Vulnerability

Social data have been identified as essential to vulnerability analyses (Gornitz 1991; Cutter *et al.* 2003; Boruff *et al.* 2005). The risk of a disaster occurs in the interaction zone of the human and the physical environment; yet socially created vulnerabilities are sometimes ignored due to quantification. Within this paper socio-economic vulnerability is understood as the social and economic elements susceptible within the system, influencing the probabilities of being harmed at times of hazardous events (Cardona 2011; Carreno 2007; Cardona *et al*. 2012). Socio-economic vulnerability focuses on demographic and socio-economic factors that either increase or decrease levels of impact of flooding on communities (Tierney *et al*. 2001; Heinz Carter 2002; Cutter *et al*. 2009). A set of socio-economic vulnerability factors were created to guide data selection and manipulation, resulting in a Coastal Flood Socio-economic Vulnerability Index (CoFSVI); aided by data variables from the National UK Census (2011) database and estate agents via GIS software. The Coastal Flood Socio-economic Vulnerability (CoFSV) factors (Figure 2) included *age*, *household structure*, *illness or disability*, *proficiency in English*, *economic*, *providers of unpaid care*, *occupation*, *communal establishment residents*, and *day* or *night population*.

Resilience

Resilience in communities is an important asset for buffering the effects of natural hazards and promoting social reorganisation (Adger 2005). Communities with knowledgeable, prepared and responsive institutions are more likely to prevent continuous flooding cycles transitioning to long-term social disasters. Flood resilience can be seen as a community/system's ability to either defy or alter itself so that flood damage is mitigated or minimised. Within this article resilience refers to the existing capacity of linked systems to absorb recurrent floods, so as to retain/adapt and mitigate/avoid harm, maintaining a significant/acceptable amount of processes, functioning and structure (Adger 2005; Balica 2012). This includes limitations in hazard response i.e. access to and mobilisation of resources, including pre-event risk reduction, in-time coping and post-event response measures (Birkmann *et al*. 2013). The essential resilience characteristics were identified through review, observation and evaluation. From this a set of Coastal Flood Resilience (CoFRe) factors were created to guide data selection, resulting in a Coastal Flood Resilience Index (CoFRe) aided by data from Ordnance Survey the National UK Census (2011) database, via GIS and remote sensing techniques. The CoFRe factors (Figure 2) included *socio-economic status*, *education*, *car ownership*, and *emergency facilities*.

Diurnal Factors

The repercussions of floods that occur at different times of day can vary significantly, yet assessments of flood vulnerability and risk diurnally are not currently undertaken. The final flood risk model (Figure 2) used to analyse diurnal flood vulnerability and risk for wards in Portsmouth, UK, highlights the different flood vulnerability factors that can be used to assess coastal flood risk from this new perspective. Taking into account how the areas in which we reside change diurnally, and how everyday circumstances can affect levels of vulnerability and ultimately levels of risk and impact, resulting in a more realistic understanding of why and where vulnerability and risk levels alter in communities.

To achieve the day and night time analysis for Coastal Flood Vulnerability and Risk, new parameters were created and applied to differentiate these time periods. The first diurnal factors are *Vulnerable Buildings Day* and *Vulnerable Buildings Night*, within the physical vulnerability analysis. Vulnerable buildings are identified by the Fire and Rescue Service (2013) as buildings they would primarily seek out; due to the vulnerable nature of the buildings and the residents/occupants of those buildings (Environment Agency per comms 2012; Hampshire Fire and Rescue per comms 2013). Examples include bungalows, schools, nurseries, care homes, mobile homes, day care, chemical works/factories, hospitals, prisons, children's homes, student halls of residence, social services homes, and hostels. Some of the vulnerable buildings listed above classed as vulnerable during the day are not vulnerable during the night and vice versa. The former is due to the building becoming empty at night i.e. schools, day care, nurseries etc. The latter is due to the resident type residing/sleeping in those buildings i.e. children's homes, social service homes, halls of residence etc. And finally, some vulnerable buildings are always vulnerable, due to the nature of the building (e.g. chemical works/factories), its activities (e.g. hospitals) or its residents (e.g. care homes). The other established diurnal factors are simply described as *Day Population and Night Population* within the socio-economic vulnerability component (there are no diurnal factors within the resilience assessment). *Day Population* relates to the residents predominantly present in their areas/homes during the day time. Large day populations increase vulnerability (Cardona *et al*. 2012) as they are situated within the flood pathway, and higher numbers need more assistance and evacuation. There are no datasets that tell us exactly how many people stay at home during the day. However, there are figures that represent those (aged between 16 and 74 years) working mainly at or from home, and the retired. It is also highly probable that the elderly (≥75 years) will be within their homes during the day as well. These datasets were combined to give an indication of a day population figure. This factor could also contain very young children (under 5 years), as it is likely they would be at home for the majority of the day under some form of care (parent, grandparent, carer, nanny etc.). However, this is not guaranteed due to childcare, nursery times, outings etc. During the holidays (not term time) this factor could also apply to children between 4-16 years, again however there is no guarantee they would be at home or close to the vicinity. People also tend to leave their houses during the day for shopping, commuting or other leisure activities, and these movements in population numbers are not considered here.

Night Population refers to the entire population residing in an area and should be at its maximum as most residents will be in their homes in order to sleep. Floods at night are more dangerous (Hampshire Fire and Rescue per comms 2013; NOAA 2015; Miltner 2017) and can result in higher amounts of fatalities (Met Office 2014). Therefore, large night populations increase vulnerability due to higher risk to life, larger numbers needing evacuation, and higher amounts of resources required (Category 1 Responders i.e. Ministry of Defence (MOD), emergency services, Environment Agency).

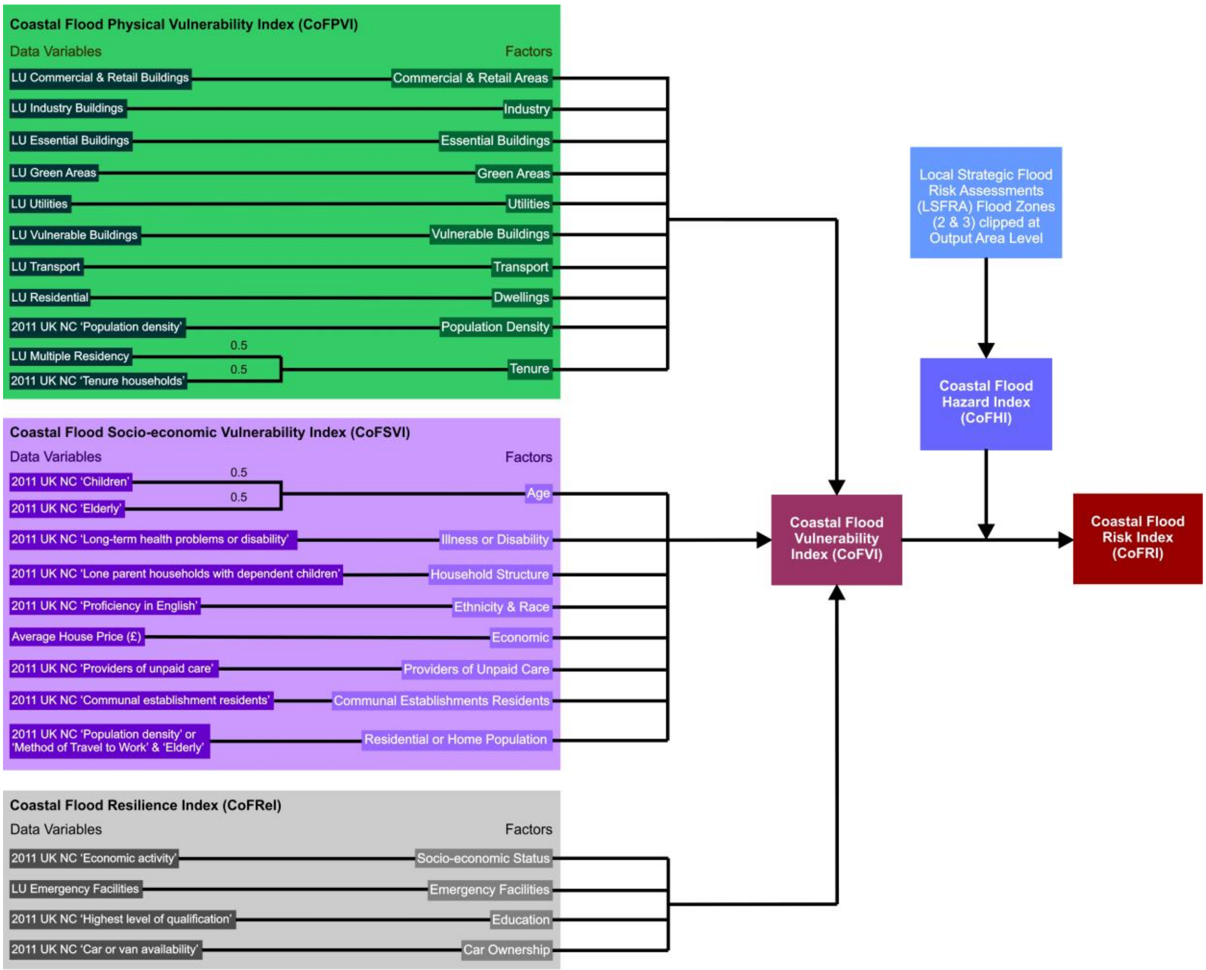

Figure 2. CoFRI and CoFVI model including data variables and vulnerability factors. NC: UK 2011 National Census. LU: Land Use

Results

Figures 3 and 4, display coastal flood vulnerability and risk levels in Hilsea at neighbourhood level (Output Area –the lowest geographical level UK National Census data are provided) from the flood risk model (Figure 2) designed to assess and map how impacts at street level vary diurnally, for floods of different magnitude. The results were produced where no judgement was made on the relative importance of the different factors used i.e. equal weights were applied to each factor (Briguglio 2004; Rygel *et al*. 2006; Lindley *et al*. 2011; Balica *et al*. 2013). Neighbourhoods within census wards from Portsmouth were used to test this model (the ward of Hilsea is shown as an example) producing three detailed key indices: a Coastal Flood Hazard Index (CoFHI), a Coastal Flood Vulnerability Index (CoFVI) and a Coastal Flood Risk Index (CoFRI). The vulnerability and hazard indexes were combined producing a subsequent analysis of risk for Portsmouth electoral wards, at neighbourhood level. The vulnerability and risk indexes for Hilsea are displayed at 7 intervals between 0 and

1; slight, very low, low, moderate, high, very high and acute. The indexes assign a numerical value (0-1) to coastal flood vulnerability and risk, allowing for numerical comparisons of vulnerability and risk levels between neighbourhoods within Hilsea. In order to produce vital and improved targeting of vulnerable and at-risk areas, crucial to prioritising interventions to improve resilience, reduce vulnerability and enhance recovery.

To create a diurnal equally weighted Coastal Flood Vulnerability Index (CoFVI) for Hilsea involved the combination of the Day CoFPVI, Day CoFSVI and CoFReI or the Night CoFPVI, Night CoFSVI and CoFReI in equations 2 and 3 (based on Sullivan and Meigh's (2005) CVI equation and equation 1). A working example of the vulnerability index development can be seen in equation 4. This presents the CoFVI value (using equation 2 and corrected to two decimal points) for neighbourhood 23 (identified in bold in Table 1 and Figure 3) during the daytime.

Equation 2

$$\text{Day CoFVI} = \frac{w_{cofpvid}\text{CoFPVId} + w_{cofsvid}\text{CoFSVId} + w_{coflri}\text{CoFReI}}{w_{cofpvid} + w_{cofsvid} + w_{cofrei}}$$

Where *Day CoFVI* – Coastal Flood Vulnerability Index Day *CoFPVId* – Coastal Flood Physical Vulnerability Index Day; *CoFSVId* – Coastal Flood Socio-economic Vulnerability Index Day; *CoFReI* – Coastal Flood Resilience Index; *Wcofpvid*, *Wcofsvid, Wcofrei* – weights of vulnerability components.

Equation 3

$$\text{Night CoFVI} = \frac{w_{cofpvin}\text{CoFPVIn} + w_{cofsvin}\text{CoFSVIn} + w_{coflri}\text{CoFReI}}{w_{cofpvin} + w_{cofsvin} + w_{cofrei}}$$

Where *Night CoFVI* – Coastal Flood Vulnerability Index Night; *CoFPVIn* – Coastal Flood Physical Vulnerability Index Night; *CoFSVIn* – Coastal Flood Socio-economic Vulnerability Index Night; *CoFReI* – Coastal Flood Resilience Index; *Wcofpvin, Wcofsvin, Wcofrei* – weights of vulnerability components.

Equation 4

Neighbourhood 23 Day CoFVI

$$0.6 = \frac{((0.33*0.57)+(0.33*0.42)+(0.33*0.81))}{(0.333+0.333+0.333)}$$

The vulnerability and hazard indexes were then combined producing a subsequent analysis of risk for Hilsea, diurnally, at neighbourhood level (Figure 4). This involved combining the *Day* and *Night* CoFVI results with the *Flood Zone 3 (FZ3)* and *Flood Zone 2 (FZ2)* CoFHI results of each neighbourhood in Hilsea in Equation 5. This resulted in four different CoFRI's for Hilsea – Day CoFRI (FZ3); Night CoFRI (FZ3); Day CoFRI (FZ2); and Night CoFRI (FZ2).

Equation 5

$$\text{Coastal Flood Risk (CoFRI)} = \text{CoFHI} * \text{CoFVI}$$

Where *CoFRI* – Coastal Flood Risk Index; *CoFHI* – Coastal Flood Hazard Index; *CoFVI* – Coastal Flood Vulnerability Index.

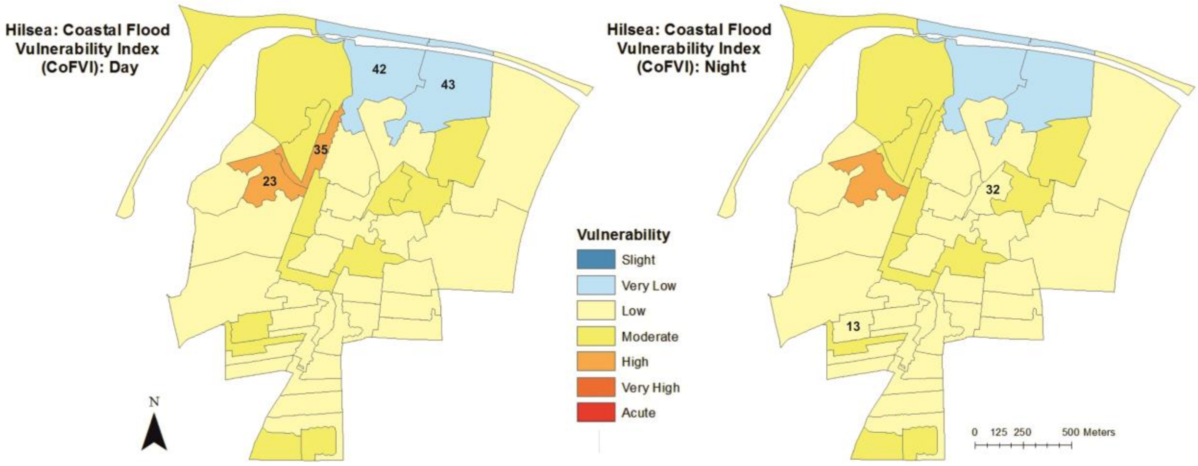

Figure 3. CoFVI for Hilsea ward at OA level - Day & Night. Numbers (Table 1) highlight certain neighbourhoods due to resulting vulnerability levels. ©Crown Copyright/database right supplied by Ordnance Survey and Contains National Statistics data © Crown copyright and database right [2017] (for ONS)

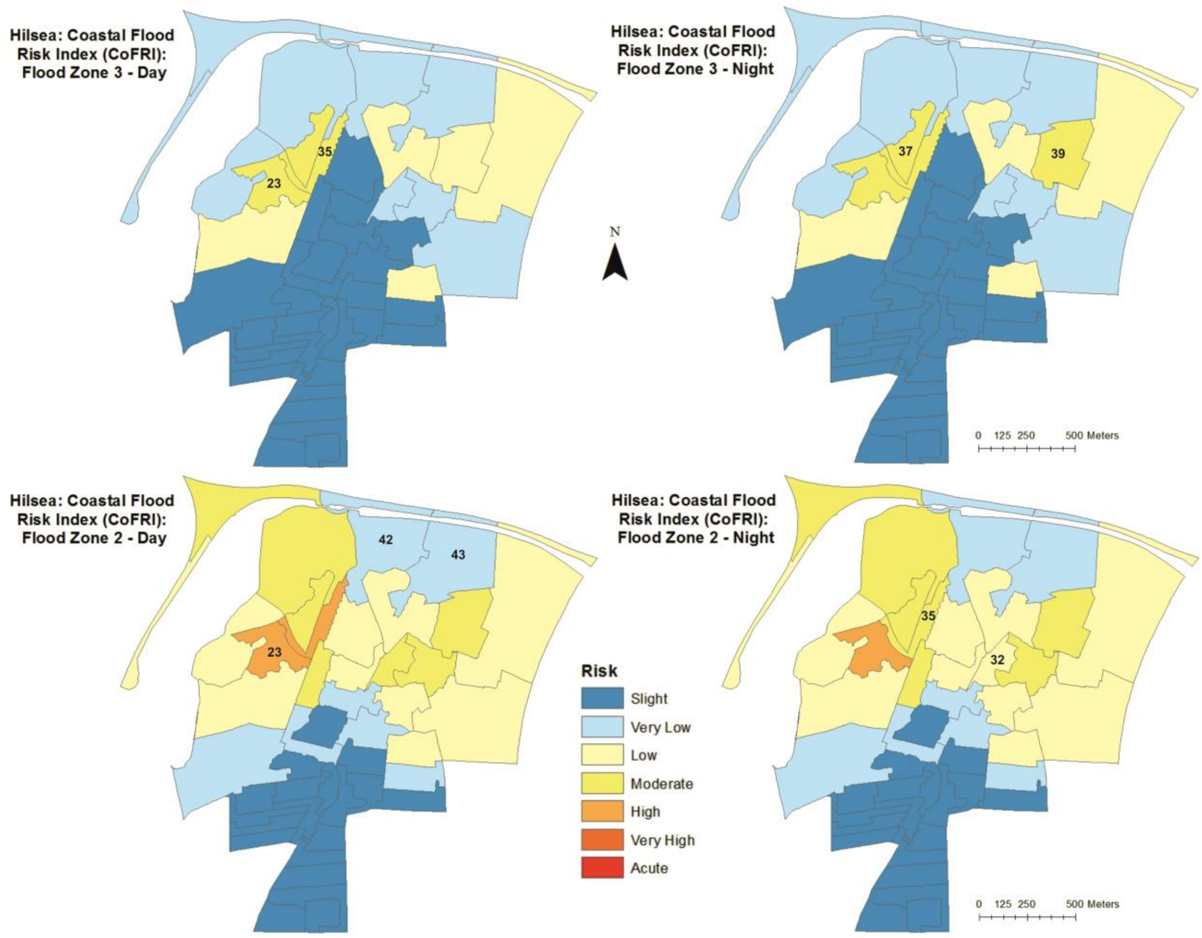

Figure 4. CoFRI for Hilsea ward at OA level – Flood Zone 3 and 2, Day & Night. Numbers (Table 2) highlight certain neighbourhoods due to resulting risk levels. ©Crown Copyright/database right supplied by Ordnance Survey and Contains National Statistics data © Crown copyright and database right [2017] (for ONS)

All Coastal Flood Vulnerability and Risk results for the ward of Hilsea are presented in Tables 1 and 2, and Figures 3, and 4. Numbers highlighted in bold in Tables 1 and 2 indicate neighbourhoods with notable vulnerability or risk levels (lowest or highest) and are also highlighted in Figures 3 and 4. Figure 3 and Table 1 show that during the day the majority of Hilsea's neighbourhoods have low or moderate vulnerability. Two particular neighbourhoods (42 and 43) have very low vulnerability and are situated on the northern coastline of the ward. Neighbourhoods 23 and 35 have the highest vulnerability levels within Hilsea; these are situated adjacent to each other at the north-west end of the ward, close to the coastline. These levels are due to very low resilience, and moderate physical and socio-economic vulnerability. Neighbourhood 23 has the highest amount of children, lone parent households with dependent children, dwellings and renters. It has very high day population numbers and many unemployed. It also has very few areas of green space, few main accessible transport links, and no essential buildings. Neighbourhood 35 has very high numbers of renters and multiple residency buildings, very little green spaces and hardly any accessible transport links, high numbers of unemployed and the highest number of households with no car availability in Hilsea.

The night analysis presents change for the Hilsea vulnerability results (Figure 3 and Table 2). Neighbourhood 23 still has high vulnerability, whereas neighbourhood 35's levels have lowered to moderate. The former neighbourhood (23) has the highest night population within Hilsea, increasing the night vulnerability level, resulting in neighbourhood 23 having the highest overall vulnerability level in Hilsea for both day and night time. Neighbourhood 35 compared to other neighbourhoods in the ward has a very low night population, hence decreasing its overall vulnerability level. Neighbourhood 32 also decreases in vulnerability from day to night time; this is due to a very low day population and a slight night population, compared to other neighbourhoods within Hilsea. Whereas neighbourhood 13 has a moderate day population but a low night population, again causing a drop in vulnerability levels.

For a Flood Zone 3 event during the day and night, the ward of Hilsea has three neighbourhoods that are most at risk – 23, 35 and 37 (Figure 4). These three neighbourhoods have higher levels of vulnerability for all three of the vulnerability component analyses (CoFPV, CoFSV & CoFRe). This combined with the chance of acute inundation coverage, resulted in moderate coastal flood risk. Neighbourhood 39 has moderate risk during the night time due to diurnal population changes compared to other Hilsea neighbourhoods. The risk levels for the centre and southern end of the ward are mostly slight, due to no flood water coverage predicted in these areas. However, all neighbourhoods surrounded by the coastline are at risk, yet that risk is very low. In fact the results show that neighbourhoods further inland were the most at risk rather than those along the coastline. This is due to high levels of underlying vulnerability combined with total flood water coverage.

For a Flood Zone 2 (1 in 1000 year) event, many neighbourhoods have substantial risk levels (Figure 4), due to potential spread of inundation. Within Hilsea risk levels range from slight to high, however the southern end has either slight or no risk, as the flood water again would not travel this far. This part of Hilsea is certainly the safest with regard to coastal flooding, which is advantageous as some of the neighbourhoods in this region had moderate vulnerability levels. For a Flood Zone 2 event, many more neighbourhoods (twenty four) have risk levels compared to a Flood Zone 3 event. This is due to more flood water inundating areas, and spreading further into the ward, affecting more neighbourhoods in the centre and further south.

Again the three neighbourhoods 23, 35 and 37 have the highest risk levels within Hilsea during both time zones for a flood event of this magnitude. However, neighbourhood 35 has moderate risk during the night time, due to distinct changes in day and night time populations. Although neighbourhoods 42 and 43 (situated on Hilsea's northern coastline) would be expected to be of high risk due to their proximity to the water and predicted almost full coverage by flood water (especially in 1 in 1000 year event), the risk levels are in fact very low, due to the very low levels of underlying vulnerability including very low numbers of children, elderly, sick, lone parents, non-English speakers, communal community residents, households without cars, multiple residency buildings, renters, commercial and industrial buildings.

Discussion

It is essential we assess and pinpoint flood risk in a way that provides as clear a picture as possible of the reality of local areas in order to understand and assess risk for future flood risk management activities. By understanding, evaluating and representing specific local contexts (socio-economic, physical, and resilient) diurnally, that shape the local flood risk problem within the flood risk management process (Maskrey *et al*. 2016), we can strive towards flood risk management practices that are successful and embed resilience into the community. To move towards this approach an appropriate vulnerability and risk analysis is needed, an example of which has been established within the paper.

The flood vulnerability and risk model presented (Figure 2) combines key components of vulnerability into one framework at the most efficacious level possible (neighbourhood scale), as this represents a level in which principle dimensions of vulnerability are founded and includes the 'physical', 'social', and 'resilient' composition of an area, diurnally. The resulting maps allow us to understand flood risk communities in a methodical and comprehensive way, identify potential fragilities and allow better targeting of new interventions to improve resilience and reduce vulnerability in the long term. The Coastal Flood Vulnerability and Risk analyses for Hilsea presented in this paper, provided new knowledge and understanding of which particular Hilsea regions are vulnerable at different times of day, and how this affects levels of risk. Critically it was in fact neighbourhoods further inland (rather than those directly on the coast as one might expect) that had the highest levels of flood risk in Hilsea, and this was due to the substantial levels of underlying vulnerability in those areas. For instance neighbourhood 23 has the highest levels of risk for both time zones, due to having acute or very high levels for the majority of its vulnerability factors. Some neighbourhoods in Hilsea have one or two vulnerability factors that are the highest in Hilsea, yet the remaining factors have either low or moderate vulnerability levels, resulting in that neighbourhood having low or moderate levels of risk. The results from this study highlight that only when many or the majority of a neighbourhood's vulnerability factors have significantly high levels of vulnerability, will a neighbourhood have a high level of risk. Additionally, if a factor also significantly shifts from day to night time i.e. population, this can result in a neighbourhood with a key change in risk level (neighbourhood 32 and 35). A critical point when planning emergency management strategies for Hilsea i.e. where are populations concentrated within an area during different times of the day. By analysing at this resolution, this methodology has identified key vulnerable and at risk areas within Hilsea that have been undetected by other assessments (notably the Local Strategic Flood Risk Assessment (Atkins 2007) and the UK River and Coastal Flood Disadvantage Index (Climate Just 2015)) that have influence on flood risk management decisions.

However, there are opportunities to further develop this methodology. Despite many vulnerability indices being created over time as a quick and consistent method for characterising relative vulnerability of different areas, the use of factors to represent reality in order to assist our urban/community comparisons, diurnally, can be subjective. There are many different definitions of vulnerability, and yet it is a concept that comprises a multitude of processes and aspects, the understanding of which helps with our understanding of risk and thus helps with our disaster risk reduction activities. Therefore, what one perceives as vulnerability, another may not. It is recommended that indices used for any natural hazards should be continuously developed as new knowledge is discovered or superior analytical processes created, assuring the best results for that time.

In this particular study, some of the differences between vulnerability levels for the Hilsea day and night analyses were very small (Tables 1 and 2), and these differences did not always transpire visually in the vulnerability and risk maps (Figures 3 and 4). There is an opportunity to further investigate this method to include other variables that clearly distinguish the difference between a day and night flood event; further establishing a distinction of vulnerability between the time zones. There is also an opportunity to develop the resilience component, which had the fewest factors (including no diurnal ones) and variables for analysis, due to its complexity. Three examples of factors that could be considered for this component are; *flood insurance, flood awareness* and *building adaptation measures*. Possessing flood insurance (i.e. Flood Re) would increase local resilience as dwellers would have the documentation necessary to assist with their personal and financial recovery from flood damage. Awareness and knowledge of floods would also improve resilience as residents would be prepared. Building flood adaptation measures (e.g. wet-proofing, dry proofing, raising floor levels, one way valves, specific building regulations etc.) would again increase community resilience, and is well established in European coastal communities that have high flood risk e.g. Dordrecht, Netherlands and Hafen City, Germany (Goltermann *et al*. 2008).

Conclusion

Being flooded is traumatic, and floods at night are predominantly more dangerous than during the day. Recent UK flood events have brought serious concerns about the effectiveness of current flood risk management (Committee on Climate Change 2016) and the levels of impacts to those that are most vulnerable. Added to this, is a general lack of flood awareness and care in communities, plus expected increases in frequency and intensity of future inundation events due to changing climatic conditions, further compounding the urgent need to measure and map flood vulnerability, highlighting areas of high risk, facilitating better mitigation and adaptation. To address this challenge, this paper has presented a methodology that can capture the relevant features of flood vulnerability, assisting our understanding of the reality of vulnerability (diurnally) at the level of detail necessary to truly deliver effective solutions (locally). The flood vulnerability and risk model presented has been tested on the city of Portsmouth, UK, with the results for one of Portsmouth's electoral wards (Hilsea) shown as an example. The resulting indexes and maps for Hilsea highlight areas with high levels of flood vulnerability and risk at different times of day; leading to previously unidentified communities requiring attention before and during a flood, thereby improving flood risk identification and future placement for flood risk management practices, increasing overall flood resilience. The results presented emphasise that in order to better support the development of future flood management policy and planning, integrated assessments of climatic change in flood risk areas are required, including the significant non-climatic aspects, such as time zones, physical (the land), socio-economic and resilience indicators, in order to understand the possible degree of impact for a community to this event. This model could be utilised by flood delegates (flood managers, emergency planners, and Local Resilience Forum members) to assist with future flood preparedness, effective flood risk management and communication, potentially and critically improving urban flood resilience in vulnerable communities.

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Word Count

5980

Figure Legends

Figure 1. Location map of Hilsea and Portsmouth. Inset boxes shows the location of Hilsea within Portsmouth and Portsmouth within the UK. Map data © OpenStreetMap

Figure 2. CoFRI and CoFVI model including data variables and vulnerability factors. NC: UK 2011 National Census. LU: Land Use

Figure 3. CoFVI for Hilsea ward at OA level - Day & Night. Numbers (Table 1) highlight certain neighbourhoods due to resulting vulnerability levels. ©Crown Copyright/database right supplied by Ordnance Survey and Contains National Statistics data © Crown copyright and database right [2017] (for ONS)

Figure 4. CoFRI for Hilsea ward at OA level – Flood Zone 3 and 2, Day & Night. Numbers (Table 2) highlight certain neighbourhoods due to resulting risk levels. ©Crown Copyright/database right supplied by Ordnance Survey and Contains National Statistics data © Crown copyright and database right [2017] (for ONS)

Captions

Figure 1 – Hlisea

Tables

Table 1 Coastal Flood Vulnerability Index (CoFVI), Coastal Flood Hazard Index (CoFHI) and Coastal Flood Risk Index (CoFRI) results for each neighbourhood (OA) within Hilsea, during the day time, for floods of different magnitude (FZ3 and FZ2). Numbers highlighted in bold indicate neighbourhoods with notable vulnerability and risk levels during the day time

Hilsea Neighbourhoods	Output Area Codes	Day Coastal Flood Vulnerability Levels	Coastal Flood Hazard Levels - Flood Zone 3	Coastal Flood Hazard Levels – Flood Zone 2	Day Coastal Flood Risk Levels (Flood Zone 3)	Day Coastal Flood Risk Levels (Flood Zone 2)
1	E00086307	0.404	0.056	0.848	0.023	0.343
2	E00086279	0.551	0	0	0	0
3	E00086288	0.417	0	0	0	0
4	E00086289	0.414	0	0	0	0
5	E00086290	0.484	0	0	0	0
6	E00086283	0.41	0	0	0	0
7	E00086287	0.349	0	0	0	0
8	E00086316	0.311	0.329	0.853	0.102	0.265
9	E00086282	0.431	0	0	0	0
10	E00086285	0.383	0	0	0	0
11	E00086284	0.426	0	0	0	0
12	E00086286	0.369	0	0	0	0
13	E00086281	0.431	0	0	0	0
14	E00086318	0.341	0	0	0	0
15	E00086314	0.372	0	0.001	0	4E-04
16	E00086315	0.386	0	0	0	0
17	E00086304	0.321	0	0.043	0	0.014

18	E00086311	0.44	0	0.355	0	0.156
19	E00086320	0.316	0	0	0	0
20	E00086310	0.296	0	0	0	0
21	E00086313	0.395	0.01	0.168	0.004	0.066
22	E00086278	0.404	0.777	1	0.314	0.403
23	**E00086300**	**0.6**	**0.89**	**1**	**0.534**	**0.6**
24	E00086301	0.556	0.095	0.92	0.053	0.512
25	E00086305	0.397	0	0.636	0	0.252
26	E00086303	0.428	0.111	1	0.047	0.428
27	E00086309	0.347	0.779	1	0.27	0.347
28	E00086317	0.396	0.224	0.649	0.089	0.257
29	E00086319	0.373	0	0.064	0	0.024
30	E00086312	0.361	0.922	1	0.333	0.361
31	E00086308	0.459	0.006	0.621	0.003	0.285
32	E00086299	0.435	0.39	1	0.17	0.435
33	E00086306	0.481	0.54	1	0.26	0.481
34	E00086298	0.306	0.699	1	0.214	0.306
35	**E00086296**	**0.584**	**0.934**	**1**	**0.546**	**0.584**
36	E00086295	0.332	0.414	1	0.137	0.332
37	E00086294	0.529	0.966	1	0.511	0.529
38	E00086293	0.373	0.9	0.999	0.335	0.372
39	E00086297	0.436	0.981	1	0.427	0.436
40	E00086302	0.398	0.845	1	0.337	0.398
41	E00086291	0.461	0.601	0.971	0.277	0.448
42	**E00086292**	**0.248**	**0.691**	**0.999**	**0.171**	**0.248**
43	**E00086280**	**0.28**	**0.83**	**1**	**0.233**	**0.28**

Table 2 Coastal Flood Vulnerability Index (CoFVI), Coastal Flood Hazard Index (CoFHI) and Coastal Flood Risk Index (CoFRI) results for each neighbourhood (OA) within Hilsea, during the night time, for floods of different magnitude (FZ3 and FZ2). Numbers highlighted in bold indicate neighbourhoods with notable vulnerability and risk levels during the night time

Hilsea Neighbourhoods	**Output Area Codes**	**Night Coastal Flood Vulnerability Levels**	**Coastal Flood Hazard Levels - Flood Zone 3**	**Coastal Flood Hazard Levels – Flood Zone 2**	**Night Coastal Flood Risk Levels (Flood Zone 3)**	**Night Coastal Flood Risk Levels (Flood Zone 2)**
1	E00086307	0.394	0.056	0.848	0.022	0.334
2	E00086279	0.542	0	0	0	0
3	E00086288	0.414	0	0	0	0
4	E00086289	0.405	0	0	0	0
5	E00086290	0.478	0	0	0	0
6	E00086283	0.41	0	0	0	0
7	E00086287	0.354	0	0	0	0
8	E00086316	0.307	0.329	0.853	0.101	0.262
9	E00086282	0.43	0	0	0	0
10	E00086285	0.384	0	0	0	0
11	E00086284	0.424	0	0	0	0
12	E00086286	0.367	0	0	0	0
13	**E00086281**	**0.426**	**0**	**0**	**0**	**0**
14	E00086318	0.339	0	0	0	0
15	E00086314	0.376	0	0.001	0	4E-04
16	E00086315	0.382	0	0	0	0
17	E00086304	0.308	0	0.043	0	0.013

18	E00086311	0.432	0	0.355	0	0.154
19	E00086320	0.315	0	0	0	0
20	E00086310	0.302	0	0	0	0
21	E00086313	0.385	0.01	0.168	0.004	0.065
22	E00086278	0.421	0.777	1	0.327	0.42
23	**E00086300**	**0.614**	**0.89**	**1**	**0.547**	**0.614**
24	E00086301	0.519	0.095	0.92	0.05	0.478
25	E00086305	0.384	0	0.636	0	0.244
26	E00086303	0.422	0.111	1	0.047	0.422
27	E00086309	0.337	0.779	1	0.263	0.337
28	E00086317	0.395	0.224	0.649	0.088	0.257
29	E00086319	0.378	0	0.064	0	0.024
30	E00086312	0.363	0.922	1	0.335	0.363
31	E00086308	0.438	0.006	0.621	0.003	0.272
32	**E00086299**	**0.423**	**0.39**	**1**	**0.165**	**0.423**
33	E00086306	0.461	0.54	1	0.249	0.461
34	E00086298	0.309	0.699	1	0.216	0.309
35	**E00086296**	**0.566**	**0.934**	**1**	**0.529**	**0.566**
36	E00086295	0.326	0.414	1	0.135	0.326
37	**E00086294**	**0.517**	**0.966**	**1**	**0.499**	**0.517**
38	E00086293	0.396	0.9	0.999	0.357	0.396
39	**E00086297**	**0.438**	**0.981**	**1**	**0.43**	**0.438**
40	E00086302	0.391	0.845	1	0.331	0.391
41	E00086291	0.455	0.601	0.971	0.274	0.442
42	**E00086292**	**0.253**	**0.691**	**0.999**	**0.174**	**0.252**
43	**E00086280**	**0.282**	**0.83**	**1**	**0.234**	**0.282**