Vulnerability and Risk Assessment Against Climate Change Attributable Extreme Heat and Flooding Events: A Case Study of Southampton

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Abstract—**From a case study of Southampton, this paper aims to outline a framework for a qualitative approach to climate resilience risk assessments against flooding and heat. This paper originated from a collaboration with Southampton City Council which aimed to answer five questions: What impacts may climate change have? Where are the current vulnerabilities and risks? What can be learnt from current trends to future proof cities? What can be done to mitigate effects on vulnerable areas? Where does our current knowledge need strengthening? Vulnerability and risk were evaluated separately and together using data and reports of flooding. The report uncovered various surface water flooding hotspots and common causes, generalised as tide locking, debris issues, land elevation, and common high road traffic areas. These findings were integrated into the methodology in this paper, and recommendations were made for adapting to heat and flooding, such as a support call hotline, emergency cooling centres, and infrastructure upgrades. Socialised vulnerability support was also recommended to increase information availability, decrease economic and social deprivation, increase physical mobility, and increase neighbourhood cohesion. Key data gaps and limitations were discussed highlighting a need for greater information on the homeless population, building heat resilience, infrastructure quality, adulthood obesity, and economic mobility.**

Keywords—**Climate Change, Climate Resilience, Public Policy**

I. Introduction

A. *Motivations and key questions*

The DEFRA 2022 Climate Change Risk Assessment acknowledges that climate change is happening now [1]. Not only is it one of the biggest challenges of our generation but future generations too, and has already begun to cause damage to our planet that is irreversible for millennia [2, 3, 4]. Southampton itself has seen the effects of this, with residents at risk of losing homes [5] and climate extremes already [6, 7, 8]. The Southampton City Council cabinet meeting of 16th April 2019 declared a climate emergency [9], recognising that the extent and impacts of climate change will depend our success over the coming decades. For these reasons I pose the questions:

i. What impacts may climate change have?
ii. Where are the current vulnerabilities and risks?
iii. What can be learnt from current trends to future proof cities?
iv. What can be done to increase climate resilience in vulnerable areas?
v. Where does current knowledge need strengthening?

B. *What impacts may climate change have?*

Since 1997 to 2024, Southampton has continued to get warmer every year by approximately 0.042°C, and by 2100 at this linear rate Southampton will be over 3°C warmer [10]. Heat related mortality was estimated at 1,311 in 2024, significant throughout the south of England [11]. This can disproportionally affect those in highly urbanised areas and less insulated housing. For example, social housing in a highly urbanised area of Southampton has been reported so hot that a resident used makeshift air conditioning, utilising fans and a container of ice, adding: "We can't breathe we feel suffocated" [12]. This increase in risk to urbanised areas is primarily due to urban heat island effect, an environmental problem wherein urban air temperature is raised over surrounding rural areas. This is due to non-green urban landscapes that absorb and radiate solar heat in greater quantity than green and waste heat from building heat leakage and electricity heat loss, and higher greenhouse gas concentrations [13].

While in summers we are set to experience hotter and drier temperatures, winter is set to be warmer too, with more rain and less snow, though localised extreme colds still occur [14]. Extreme rainfall in the UK has increased from past levels, and is projected to increase further, due to increased moisture capacity in the worlds warming air. In Southampton, this has been apparent, with rainfalls of around 1000mm becoming commonplace during the 2010s and beyond. Analysis of Southampton Weather private

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station data shows a 24.3mm/yr increase of rainfall on average from December 2007 to November 2024 [15]. There are many implications of this change in frequency: increased risk of building and structural damage, increased disruptions to people and services, dangerous driving conditions, overwhelmed urban drainage systems, and dangerous pedestrian conditions [16]. Flooding will become more severe and common due to increased rainfall [17]. Water during floods can absorb into fragile ground causing landslides [18]. Other infrastructures such as dams, levees, and water treatment plants can also fail more often, causing a £56 billion commitment to be made to improve infrastructure throughout the country [19]. Floods can directly cause drowning and injuries including hypothermia and animal bites, disruption of essential medical supplies, and indirectly can cause infected wounds and injury complications, poisoning, poor mental health, communicable diseases, and food insecurity [20]. These indirect causes can then go on to leave a legacy of continued poor mental and physical health if unaddressed [21]. It is hard to know whether storms will increase in wind speed and frequency as regional models can conflict in results [22, 23].

A primary result of extreme heat and flooding is drought and water insecurity. Much of the south UK has had “hosepipe bans” to preserve water during the driest summer in 50 years [24, 25]. This has impacted river flows, which resulted in reduced marine life, reduced wading bird breeding, toxic algal outbreaks, poorer plant health, and other ecological stresses. Fires can also place our population and ecology at risk. In August 2022, a fire in Peartree Green nature reserve destroyed flora and fauna, and the Southampton Common ornamental lake dried up shrinking its aquatic life significantly during 35°C temperatures [26, 27]. Water insecurity can also result from discharge sewage into rivers and streams, often during times of heightened rainfall beyond what the system can cope. This decreases water quality for both humans and reliant ecosystems [28]. This has happened in Southampton with Storm Ciarán in 2023, wherein an incident at Testwood Water Supply Works caused adverse water quality, meaning water supply in surrounding areas was shut off [29].

Increased drought, flooding, over and underheating, and storm surges are not something that can be stopped for years to come as are exacerbated by a changing climate. If net-zero is achieved, our climate state is projected to stabilise and eventually begin to repair to a rate of change in-line with pre-industrial rate of climate change, but this is after hundreds of thousands of years [30, 31, 32, 33]. We must adapt as our climate changes alongside encouragement for us and future generations to act, so how can we adapt?

II. Methodology: Finding Vulnerabilities and Risks

C. *Risk analysis and the qualitative approach*

Risk to extreme weather is defined as likelihood to be affected by flooding and heat, i.e., an areas susceptibility to flooding due to lack of defences or poor drainage, or heat due to high density of high-rise buildings. Heat risk was analysed utilising percent of urbanisation, as urban heat island effect will cause heightened temperatures areas of higher urbanisation and lower green space.

Flooding can come from many sources, therefore is difficult to analyse quantitively like heat risk. For example, Southampton is at-risk of estuarine flooding from the Southampton Water estuary, fluvial flooding from the River Itchen, River Test, and multiple brooks, surface water flooding, and groundwater flooding. For this reason, I use flooding reports for surface water, and prior risk assessments for fluvial and estuarine flooding.

Southampton City Council has flood reports stored internally for as far back as 15 years. They display these digitally on a map tool, wherein employees can see location, date, and comments of each report. Comments are written both by residents who filed the report, responding highways staff, and investigating desk staff. This small part of their internal map tool was instrumental in detecting areas of surface water flooding.

The process for analysis is as follows. First display each flood report on a heat-map rather than separate data points. This helps to observe the map city-wide for areas of dense flood reports. In a cluster of reports, next observe the dates and comments of separate flood reports, looking for 7 main indicators.

i. Consistent, continued, and recent flooding. If all of these are not satisfied it is not at-risk (but may be in the future).
ii. Date patterns, e.g., flooding regular in Autumn may indicate leaf debris issues.
iii. Severity. Residents make severity and property damage known. High severity is high priority.
iv. Sewer nodes and layout. Gullies can be poorly placed, and pipes may have too many junctions, too many sharp turns, and poor gradient.
v. Land elevation. Close to sea level drainage can experience tide-locking or high pressure. Low land compared to surroundings can experience overwhelmed drainage.
vi. Area. Are the reports near a zone that may contribute to debris? Is the area well covered by greening?
vii. Upstream condition. Issues upstream, in both surface and sewer elevation, cause issues downstream.

All of these, and report comments, can help determine validity, type, and causation of the flooding.

Southampton City Council had conducted a strategic flood risk assessment [5], as have many other councils. Areas with a yearly chance of 1/30, 1/100, and 1/1000 surface water flooding are contained in the report, obtained from the Risk of Flooding From Surface Water map, or RoFSW map. This map was produced by the Environment Agency and is modelled for all areas of England [34]. Further, areas of type 2 (0.1-1% chance/yr of fluvial flooding and 0.1-0.5% chance/yr of coastal flooding) and type 3 (1+% chance/yr of fluvial flooding and 0.5+% chance/yr of coastal flooding) are shown based on Southampton Water modelling produced by the Environment Agency [5]. The surface water flooding chance shown here is used in conjunction with the flood reports. The flooding reports aid in determining issues happening throughout an area now, while the flood risk assessments can show which areas may become worse. This allows to see if a flooding hotspot is an anthropogenic issue (high flooding reports, no risk assessment flooding indication), natural issue (no flooding reports, risk assessment flooding indication), or a mix of both (high flooding reports and risk assessment flooding indication). This and information from flood reports allows suggestion of solutions tailored to an area and determination as to where future proofing is most necessary, as select areas may deal with heightened rainfall worse.

For fluvial and estuarine flooding, also applicable to coastal flooding, utilise knowledge of past events and flood risk assessments also. Knowledge of areas of type 2 and 3 flooding, as well as green space and flood defences can expose severity and likelihood of coastal flood risk. Like heat risk, this type of flooding is far less multi-faceted than that of surface water and groundwater flooding.

D. *Vulnerability analysis*

Vulnerability to extreme weather is defined as the population's preparedness for heat and flooding, i.e., if they experience an extreme climate event, how well can they prepare, evacuate, and or recover.

Risk must be evaluated with vulnerability. If they are evaluated separately or one is left out, it can be misleading. Considering only climate resilience: if an area is vulnerable but not at-risk flood defences are moot, if an area is at-risk but not vulnerable funding for insulation may be better used for a more vulnerable community.

A max-scaled scoring system was created from 4 primary sets of statistics: deprivation, physical mobility, information accessibility, and neighbourhood cohesion.

For a deprivation indicator, rate of children in need was used. This was used as familial economic dependencies are typically supported by those independent in the family and children are a dependant group within families, therefore the wellbeing of children within families can tell of family unit wellbeing. The limitation of this is that figures are underestimated in areas of lower youth population, therefore this statistic was utilised alongside multiple deprivation index and percentage of population ages 0 - 17. The former and rate of children in need had a 0.76 Pearson's correlation coefficient using values from each LSOA.

Physical mobility included reports of bad and very bad health, residents limited a lot by disability, school pupils who are a healthy weight, and ages 65+. Reports of bad and very bad health can be used for flooding but instead should be considered with respiratory and cardiovascular diseases for extreme heat, as these health conditions may make it difficult to cope in extreme heat. Limitations a lot by disability is applicable to both, as in the event of residency flooding or overheated housing getting external aid is of high importance. Percentage of school pupils who are a healthy weight indicates a lesser mobility if lower but is limited as obesity from adolescence into adulthood is not certain [35]. Similarly, considering flood vulnerability percentage of population ages 65+ does not guarantee lower mobility within this older population, who may be active. Percentage of population ages 65+ had a high Pearson's correlation with both reports of bad and very bad health (0.59) and residents limited a lot by disability (0.67) within the city. This data was supplemented with emergency hospital admissions due to falls in people aged 65+. Considering heat vulnerability, percentage of population ages 65+ was not considered with additional data as those ages 65+ have a lesser ability to adapt to temperature change than younger ages [36, 37]. When scoring flood vulnerability, two more indices were also considered: percentage of lone parent families with dependent children and pupils with special educational needs. Both may make it harder for a caregiver to evacuate themselves and dependant individuals in an emergency, although these vulnerable groups have no difference in ability to adapt to extreme heat.

Poor information accessibility indicates a lower ability to deal with extreme heat and flooding with appropriate knowledge. Percentage of households that have one or more persons with English as a main language, percentage of residents aged 16 and over with no qualifications, rate of people with current adult social care services, and social isolation (all-ages and 65+) was used. In Southampton 1 in 7 do not have English as a primary language and there are over 160 spoken languages. Climate resilience information is not translated and this severely limits communication. Residents aged 16 and over with no qualifications is utilised as an indicator of education level, which is proportional to income [38]. Further, this poor school performance may indicate a locational issue of information inaccessibility. Subsequently, this index was used with context of school suspension and absence rates. Rate of those in adult social care was used circumstantially. Adult social care workers can be instrumental in distributing information to vulnerable groups under their care. In Southampton, adult social care workers are not trained to distribute information regarding what to do in an extreme weather event. As it stands, people in social care are within a more vulnerable group in terms of climate resilience, but if workers distributed vital information and aided during

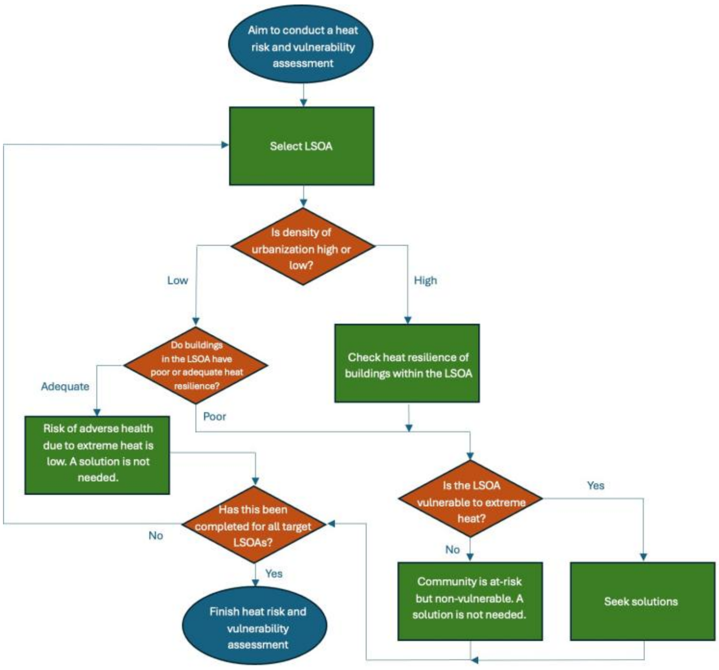

FIG. 1. HEAT RISK AND VULNERABILITY ASSESSMENT METHODOLOGY GENERALISED FLOWCHART. VULNERABILITY IS DETERMINED USING A SCORING SYSTEM OR OTHER PREFERRED METHOD.

flooding and extreme heat, those in social care may be less vulnerable. Both all-ages and 65+ ages social isolation indices were used. Social isolation can limit the spread of vital climate resilience information. The aim is to evaluate the isolation of vulnerable groups who might need aid to act. In terms of age, these groups are pensioners and youth. As youth have caregivers to provide aid it is negligible, but pensioner social isolation must be evaluated as they may not be in care and have a source of aid. Further, all-ages social isolation is used alongside other indices: mobility, deprivation, and risk. This shows whether non-age-dependant vulnerable groups are isolated.

All-ages social isolation also aids in identifying neighbourhood cohesion and isolation. Similarly, total crime is used. In times of extreme weather, residents may need to evacuate or ask for aid. In areas of high isolation or high crime, residents may not feel comfortable asking for aid or leaving their home unattended for a long period of time when police are otherwise indisposed during a flood.

All indices are used alongside forecast population change and multiple deprivation index change over time to see how this vulnerability will mobilise over years to come. Locational factors, such as proximity to aid services, council and community centres, and sports facilities are also considered.

Neighbourhood analysis is split into Low-layer Super Output Areas (LSOAs). These areas aim to contain 400 to 1,200 households, or 1,000 to 3,000 people. There are 152 LSOAs in Southampton.

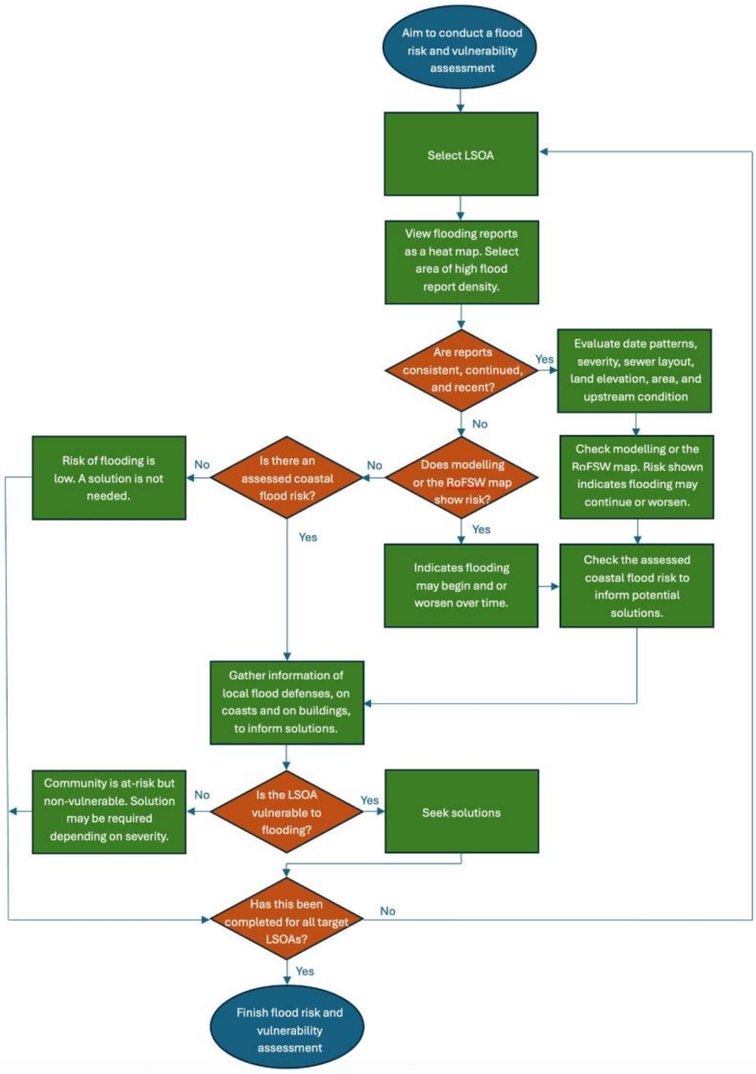

FIG. 2. FLOOD RISK AND VULNERABILITY ASSESSMENT METHODOLOGY GENERALISED FLOWCHART. VULNERABILITY IS DETERMINED USING A SCORING SYSTEM OR OTHER PREFERRED METHOD.

III. RESULTS AND DISCUSSION

E. Risk: what can be learnt from current trends to future proof cities?

1) Coastal flooding, tide locking, and drain capacity

The primary recommendation of the report originated from fluvial and estuarine flooding. This risk originates from building on mud flats, formed by the depositing of fine sediments on low flow coastal areas. Mud flats are regularly flooded in nature, as is their purpose: to store water. If this water storage is eliminated, the pressure against the now non-permeable structure there is extremely high. Evaluating land elevation and sea level rise, much of the west coast of the River Itchen was under type 3 flood risk, along with to a lesser extent west Redbridge and the east coast of the River Itchen. From the Itchen Bridge northwards up till Portwood's border including Northam in its entirety, there is severe type 3 flood risk. A model by the IPCC places this area underwater by 2021 [39]. This report overwhelmingly encourages flood defences in these areas, i.e., the continuation of the River Itchen Flood Alleviation Scheme, a scheme to construct appropriate flood defences in this very area. Afterwards, flood defences should be considered for other at-risk areas.

While the east coast of the River Itchen is guarded by raised land and green space, west Redbridge is not. It was found that in some low coastal areas, including west Redbridge, high pressure occurs in drains from backwashing of water during high tide, known as tide locking. This can be aided by using pumps, re-routing sewer lines, or installation of one-way flap valves.

Outdated foul sewer systems can cause tide locking, overwhelmed pipes, and more blockages than a dedicated surface water sewer line. This is due to several reasons: they deal with far more sources of water input, they often run along roads rather than following land elevation, degradation can cause leaks and blockages, and they handle far greater areas meaning they handle a greater water influx during storms. All of these can cause a higher pressure in the sewer line which leads to the above issues. A solution to this is installation of modern surface water sewers and re-routing of gullies to these lines. Within Southampton this primarily happens in Portswood. There are also many areas of degraded or defective sewer infrastructure, such as in Woolston. These areas of regular flooding must be investigated and flagged for improvements if an issue is seen.

Culverting open watercourses can cause flooding during high rainfall, as culverts limit volumetric water flow for open watercourses that may handle more water. One solution is opening culverts, causing a larger gap for water to flow increasing its capacity. This is unfeasible as it would be expensive and disrupt vital economic road traffic. A solution can be found upstream, to rather increase water storage capacity and or slow down flow, as if the water is fast and greater quantity then it has a higher ability to flood. Terracing waterways into green space creates artificial lakes during times of high water volume, acting as water storage which instead trickles water. Rerouting the waterway to create a winding downstream rather than direct flow, would reduce flow speed. This solution is a type of sustainable drainage system, or SuDS, a system which mirrors drainage seen in nature to passively drain water. SuDSs are highly circumstantial in their effectiveness and applicability but if used correctly can alleviate load on a wider drainage network. With exception to SuDSs such as bioswales, SuDSs also rarely involve channels, pipes, or drains, rather utilising permeable ground, therefore are immune to debris blockages.

2) Regular flooding due to debris

Throughout Southampton, regular flooding occurs due to blocked gullies caused by sediment and debris. This can occur for several reasons, primarily anthropogenic.

A natural reason for flooding may be changes in land elevation. Concentrations of flood reports were found to occur densely in areas where sloped non-permeable surfaces flatten, i.e., when land is lower in relation to the land around it. This may be as sediment and debris settle here. When transported by pedestrian or vehicular displacement, rainfall streams, or wind, sediment and debris have gravitational force moving them downhill. When this downhill flattens or becomes a shallower slope friction may overtake the gravitational force moving the sediment or debris, therefore stagnation occurs. This location of stagnation also often is where gullies are installed, as gullies are designed to be at low points where water flows towards. This is particularly bad in low points of multiple sides, or an urbanised dell. This can be aided by surface water sewers following these dells or increasing drainage capacity where debris collects.

The primary anthropogenic surface water flooding cause is busy roads. High rates of traffic deposit sediment and debris along the roadway through continuous use, which propagates to low points in the road where gullies are. Sediment can settle in pipes and decrease the capacity of the drainage system. Busy roads can also include bridges, schools, and green space. In Southampton, multiple flood reports were found on or around every bridge, around every school, and around every green space adjacent to a road. Bridges act as a chokepoint for traffic to get across bodies of water, as well as causing land elevation changes furthering debris issues. Schools become periodically busy due to the school run. Green space is responsible for dirt on nearby roads, as well as a slow but constant stream of natural debris such as leaves which increases dramatically during Autumn. This can apply to gullies near to trees and shrubbery. It was also found that a higher-than-average number of reports at construction sites, road junctions, traffic lights, gravel and dirt car parks, community and service buildings, and nightlife areas, although these had an inconclusive consistency. Construction sites leave behind an unavoidable and high level of dust and sediment during and after the project. Road junctions and traffic lights may cause heightened debris and sediment due to slower moving, stationary, or turning vehicles which may dislodge more debris. Gravel and dirt car parks without gravel grids may cause cars to track sediment onto tarmac roads. Community and service buildings such as leisure centres and general practitioners may cause increased traffic which leads to higher debris. Nightlife areas may face higher levels of littering and or foot traffic that can contribute to both natural and anthropogenic debris.

Areas with high levels of litter such as nightlife areas or schools may be combatted with public bins. Natural debris and sediment are harder to control. Preventing gully blockages are impractical as increasing drainage capacity can lead to roadworks on vital arteries of a city, kneecapping economic growth. Southampton City Council has an investigation process for floods which requires a threshold, determined at the discretion of the investigating officer, for investigation. The issue of a threshold for flooding investigation is that reports have shown hidden dangers, such as icy conditions that may develop due to flooding, inaccessibility for those with limited mobility, or pedestrians attempting to avoid the flooded area by walking into the road. Southampton City Council also passes flood reports through various departments and people; context can be lost. This has let recurrent issues with surface water flooding stand which has damaged houses, property, and seen reports threaten legal action. An investigation into why should be conducted, but investigations do not eliminate immediate danger. A dedicated highways team that operates gulley suckers and equipment to clear gullies should be adopted in years to come, especially considering the rising threat of surface water flooding. Residents should be able to call this department for immediate relief. Funding can come from both councils and water companies, as is an economic concern to both. During clearance, an on-the-ground report could aid the investigation process and give contextual information. In both cases of natural and anthropogenic debris, a flood response team could identify flood causes and make note of cause and recurring areas, increasing their efficiency to operate and possibly identifying solutions that cannot be reached by desk-based investigation. Areas where regular flooding occurs that is not caused by blockages, are separate and harder to fix issues and can be logged by the team. If a resident calls on this, they could be told the steps the council is taking to fix the issue and why. If the gully does not clear on rainfalls end or lower tide then, or the gully itself is visibly silted up or blocked, then it should still be investigated.

3) Heat resilience

For commercial new-builds, Southampton City Council requires a percentage of the property to remain private greening. This does not apply to private property. Each year, approximately 14,000 people in the UK apply for dropped kerbs [40]. The primary purpose of this is installation of non-permeable tarmac or asphalt for a car driveway, which eliminates private greening, exacerbating urban heat island effect and flooding. Southampton has many large green spaces, but localised heat island effect can occur outside of these areas where urban areas have 'de-greened'. Reduction of risk can be achieved with private greening encouragement, such as tax relief for those achieving a certain percentage of property greening.

Assessments of heat vulnerability become moot when dealing with areas of local tourism such as shopping centres, as all groups of various personal vulnerabilities converge on one zone. During heatwaves, the city must protect these people outdoors. Accessible, air-conditioned emergency cooling centres with seating, bottled water, and medically trained workers should be present to eliminate risk entirely. These can also be implemented in community centres of at-risk communities to provide a place to escape an overheated dwelling or to seek information. A heatwave helpline can be implemented that allows struggling residents to call for advice of how to deal with extreme heat. Mobile callers can be given advice on where to go and how to adapt, whereas those with mobility issues can be aided physically to give needed support. As heatwaves are predictable and not year-round like flooding, a network of heat related illness volunteers or temporary workers can be utilised for staffing rather than a dedicated team.

F. Vulnerability: what can be done to increase climate resilience in vulnerable areas?

4) Information distribution and neighbourhood cohesion

For both flooding and heat risk, the lack of spread and availability of information is a big issue. Some may not have access to information to prepare for floods or heat or effectively manage and recover when it happens. They may also not know where to go if they do not know how to manage it.

In Southampton, central wards with household English speaking of sub 85% have been reported by council workers to have communication difficulties. The logic is clear: information accessibility is lowered with poor language comprehension. For some LSOAs within these wards this is reduced to below 70%. Being able to translate this information is paramount to aiding these communities. This can be done using a translator app or preferably dedicated personel who analyse what cultures and languages make up a specific community.

A low percentage of residents aged 16 and over with no qualifications may impact information accessibility, being less enthused to research on climate crisis and its impact on them [41]. For some areas of the city this was more than a quarter of the population, and for one LSOA it superseded a third of residents.

Social isolation may impact information accessibility due a near loss of word-of-mouth communication. The borders of the city had the worst social isolation. For ages 65+ and all-ages, approximately 10% of LSOAs were top 10% for social isolation in England, with a higher density of socially isolated LSOAs occurring in the city centre.

Council funded and encouraged clubs, social events, and volunteer networks in multiple different formats can decrease isolation in a neighbourhood. The primary four drives for a club has been a focus on older ages which should involve light activity with plenty of sedentary breaks, a focus on youth which should involve all ranges of activity levels, a focus on other languages and cultures which should include opportunity for those external to the language and culture to interact with people and practises of those languages and cultures, and a focus on accessibility which should include making neighbourhood more accessible for those of limited mobility and poor health. There are also LSOAs which need crime rate reduction to improve safety, as residents may not feel comfortable going to these social spaces.

A flooding and heatwave phone line for residents, can also be implemented to distribute advice on how to adapt, cope, and recover from floods or heat, or where to go if they are finding it hard to cope.

5) Deprivation and Physical Mobility

In Southampton, 8.5% of LSOAs are top 10% most deprived, increasing to 30.2% in the 3rd decile of most deprived. The most deprived, in South Woolston, ranked 388 (out of 32,844) most deprived of LSOAs in England. For these at-risk areas, support is needed to prepare for, live through, and recover from extreme weather:

i. Preparation support in installation of resilience retrofits, such as insulation or flood doors.
ii. Support during an event such as clean water, safe spaces, information and guidance, physical evacuation, and medical aid.
iii. Support to recover such as insurance, clean-up advice to avoid pathogens, and economic aid.

Deprivation and health were correlated. Reports of bad or very bad health and limitations a lot by disability had a 0.51 and 0.48 correlation respectively with children in need. If using multiple deprivation index rather than children in need this rises to 0.70 and 0.67 respectively, but it is worth noting multiple deprivation index includes disability figures. Improvements in street level accessibility is key, as well as understanding the circumstantial health needs an LSOA has. In Southampton, this is already being tackled, with public health employees planning a research collaboration to determine detrimental effects on health city-wide by working with communities to understand their health and wellbeing priorities. Further, Sport England have identified areas with the most challenges to being active and are working on breaking down these barriers.

G. Where does our current knowledge need strengthening?

With increasing population leading to housing demand and little space for sprawling development within city unitary authority bounds, most new builds within city borders tend to be apartments. Flat blocks, especially those built in the 2000s and 2010s, have a larger number of windows and glass comparatively to low density housing which contribute to high heat due to injection of solar radiation into the indoor spaces. Flats also may have single cavity natural ventilation, which sports a far worse air turnover rate than intake-outlet natural ventilation, causing hotter temperatures within. Older, post-war housing stock is also not built for hotter temperatures. They can be the product of quick construction which lead to poor orientation, smaller rooms, and low shading, as well as having little insulation due to lower fuel prices in that period. These houses, as well as those older, may also be hard to retrofit due to deterioration or a proximity to vital infrastructure such as a rail line. They may even be heritage assets, areas of archaeological interest, or areas of ecological sensitivity, which cannot be added upon [42]. Historic England has guidance for historic building retrofits that should be considered. It is key to identify these buildings and if they have been retrofitted, as well as if and how they can be retrofitted such that residents can be effectively aided. Crucial data gaps within buildings and infrastructure are as follows.

i. A scoring index of houses and surrounding areas that are hard to navigate for those of limited mobility could be useful in determining areas that need investments for those of limited mobilities' safety.
ii. Buildings data is important as a vast amount is known about how well specific buildings deal with heat and flooding, as well as their ability to be retrofitted.
iii. Data about residency insulation, heating system, and flood defence can expose how proofed a building is for heat and flood. EPC rating data exists for the city but is unreliable as buildings not rented or bought after October 2008 do not have to obtain EPC ratings.
iv. Knowledge on if a house is rented or owned can tell if a low deprivation household is likely to make retrofits to flood and heat proof the house.

Other data gaps include indices of adult obesity, economic mobility, and homelessness population. While school pupil obesity was obtained, adult obesity rates may tell more about mobility in a flooded environment and heat adaptability. A dedicated economic mobility index would be of interest as it gives an insight into the ability for a residency to improve their multiple deprivation index, move home, or make retrofits over a long period of time. Data on homelessness population location, density, and numbers is absent and cannot robustly be estimated using other indices. This is important as they are amongst the most vulnerable during flood or heat events.

H. Methodological reproducibility and existing frameworks

This methodology was constructed around a report on Southampton, a coastal port city. Although there is a large focus on fluvial flooding, this methodology is transferrable to other cities within the UK as methodology to evaluate surface water and coastal risk are both independent. However, reproducibility worldwide is under question for several reasons. Culture differences impact validity of information accessibility and neighbourhood cohesion evaluation in vulnerability. Demographic differences impact neighbourhood cohesion evaluation. A different evaluator of multiple deprivation will be needed due to differences in cost of living and what retrofits are easily accessible to the public. Related to this is differences in buildings and infrastructure: building standards and effective methods of dealing with heat and flooding are not similar worldwide due to differences in local materials, methods of construction, and climate. Weather events can affect a non-temperate climate zone entirely differently than a temperate climate, questioning the validity of both risk assessment methodology and solution feasibility given in this paper. Finally, different data may be available country to country, making indices of vulnerability mentioned in this report not realistic to evaluate and requiring a different approach.

While this paper offers standardised UK specific metrics of vulnerability under four key categories, the approach draws from other literature aiming to compute climate vulnerability, particularly the socio-spatial flood and heat vulnerability index computed by Sarah Lindley and Mehebub Sahana [43]. The methodology highlighted in this paper differs in risk analysis. Previous risk analysis literature has been focused on the construction of a computational model [44, 45, 46, 47, 48, 49]. Qualitative methods within this paper achieve a different objective within both the results and methodology. Methodology used increases accessibility to council workers aiming to use a standardised method of assessing vulnerability and risk, as they may be untrained on state-of-the-art academic methods. This informs councils with city or town specific methods and solutions, making use of familiar analysis procedure such as on-the-ground community assessments and interviews, and local knowledge of past, present, and future city planning. While computational models give locations of heat and flood risk, they do not provide direct understanding to heat and flooding issues. The qualitative approach however can provide a greater understanding to heat and flood risk in an area through investigation therefore solutions are naturally presented through understanding. For this reason, it is best to use the computational model and qualitative approach together, identifying risk areas computationally to then analyse potential solutions with an area dependent approach.

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