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Routes Journal Volume 3 Issue 3

A Street Level Flood Risk Assessment of Morpeth, UK

By Constance Gerono (Liverpool John Moores University) and Dr Sarah Percival (Liverpool John Moores University)

Abstract

This study presents a detailed street level flood risk assessment of Morpeth, UK, a town with a history of devastating flood events, most recently in 2008 and 2012. Flood risk in Morpeth was calculated at street level by multiplying hazard and vulnerability indexes that involved the quantification of components relating to the environment and population (flood vulnerability). The main findings highlighted a greater number of streets will be inundated during a 1-in-1000-year event and the most influential vulnerability characteristics in Morpeth are the presence of critical infrastructure, impermeable surfaces, population density and age and vehicle access. The streets most a risk in Morpeth were Gas House Lane, Wellwood Gardens and Staithes Lane. In relation to the future flood risk in Morpeth, the predicted increase of fluvial flooding events due to climate change produces a requirement to improve the adaptive capacity of the town to ensure a greater resilience against flood events in the future.

1. Introduction

Globally, flooding is considered one of the most frequent and devastating natural disasters experienced by the world's population and these events are projected to increase in frequency and magnitude due to climate change (Wilby *et al.*, 2008; Balica, Douben and Wright, 2009; Balica and Wright, 2010). This emphasises the importance and necessity to improve our knowledge of these events, and the need to develop reliable methods to identify high flood risk areas (Kourgialas and Karatzas, 2017; Toosi *et al.*, 2019).

Risk can be defined as the product of a hazard and its consequences. Therefore, conducting a flood risk assessment is a multi-parametric approach, assessing flood hazard (a physical event or phenomenon that can cause loss of life, injury, social, economic, and environmental loss) and vulnerability (a complex interaction of the susceptibility of a population, economy, infrastructure, and environment to a hazard) (Birkmann, 2006: Kourgialas and Karatzas, 2017). It is also important to recognise that due to variants in the degree of vulnerability, hazard can be experienced differently on a local scale (Balica *et al.*, 2012; Percival and Teeuw, 2019). This highlights the importance of analysing vulnerability at a level of high spatial resolution to establish effective solutions.

This report investigates fluvial flooding in an urban environment, with the aim of providing a detailed street level flood risk assessment of Morpeth, United Kingdom (UK) (Figure 1). This is to gain a thorough understanding of the town's capacity to cope during and after a flooding event. This will be achieved through the production of a flood hazard and vulnerability index (FHI and FVI). These indexes are unique due to the choice of variables to represent vulnerability can produce diverse results (Fernandez *et al*., 2016). Morpeth was selected as the study site due to its recent history of flooding events in September 2008 and 2012, as well as many of its population living within the flood plain of the River Wansbeck (Javadinejad, 2011).

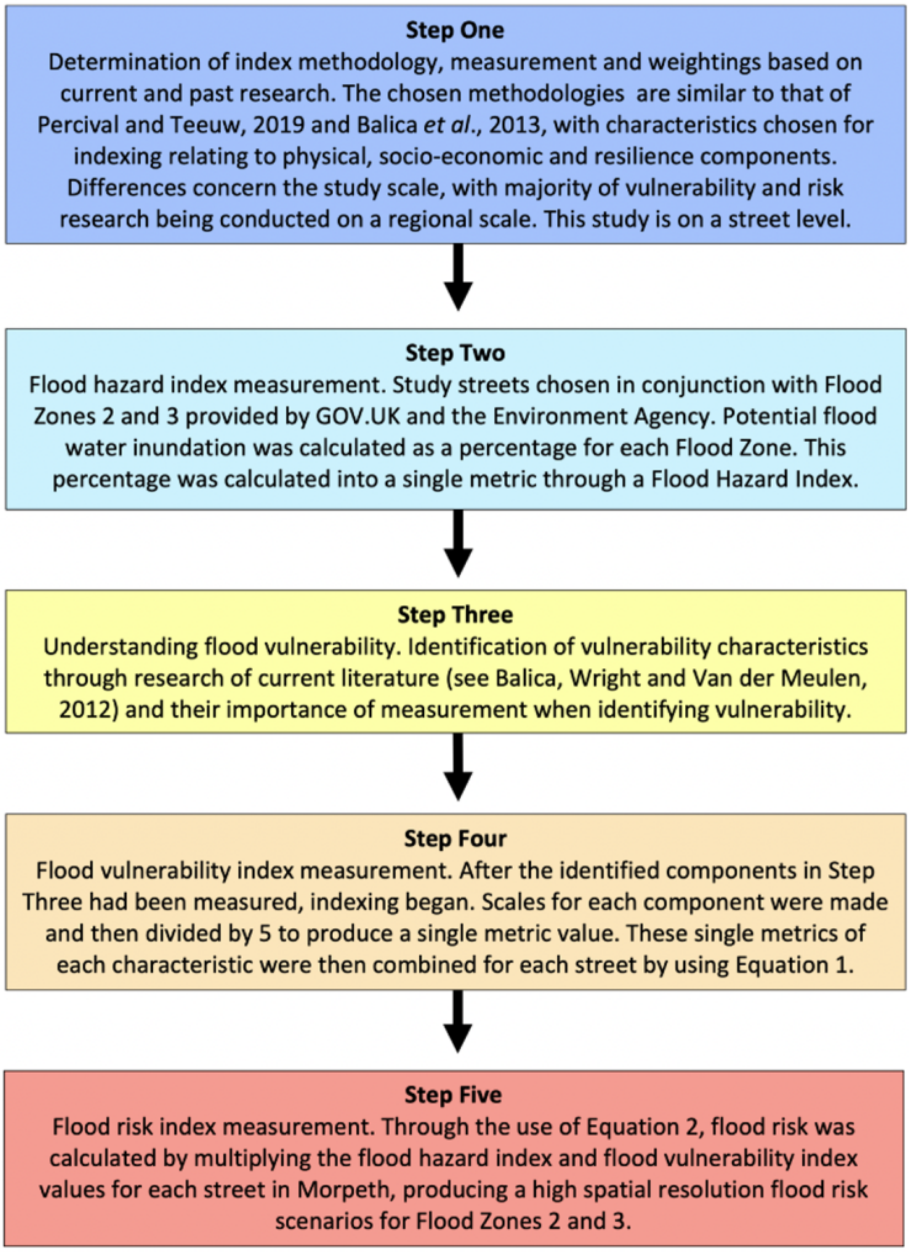
Figure 1: A map displaying the location of Morpeth, UK, including the surrounding environment of the River Wansbeck and the critical infrastructure within the town

2. Methodology

Data collection for this study involved 5 main steps. These can be seen summarised in the flow chart below (Figure 2), and further detail of each step is in the following text in Section 2.

2.1 Flood Hazard Index

Measuring flood hazard involves the establishment of the threat of an event and its probability of occurrence (Kron, 2005). To measure flood hazard in Morpeth, study streets were chosen in conjunction with Flood Zones 2 and 3 (FZ2/FZ3), datasets provided by GOV.UK that highlight areas in the UK where flooding could occur during events of varying magnitudes (Figure 3) (DEFRA, 2020). Tables can be found below of the corresponding street numbers and names that have been measured (Table 1), as well as flood zones and their probability of occurrence (Table 2).



Step One
Determination of index methodology, measurement and weightings based on current and past research. The chosen methodologies are similar to that of Percival and Teeuw, 2019 and Balica *et al*., 2013, with characteristics chosen for indexing relating to physical, socio-economic and resilience components. Differences concern the study scale, with majority of vulnerability and risk research being conducted on a regional scale. This study is on a street level.

Step Two
Flood hazard index measurement. Study streets chosen in conjunction with Flood Zones 2 and 3 provided by GOV.UK and the Environment Agency. Potential flood water inundation was calculated as a percentage for each Flood Zone. This percentage was calculated into a single metric through a Flood Hazard Index.

Step Three
Understanding flood vulnerability. Identification of vulnerability characteristics through research of current literature (see Balica, Wright and Van der Meulen, 2012) and their importance of measurement when identifying vulnerability.

Step Four
Flood vulnerability index measurement. After the identified components in Step Three had been measured, indexing began. Scales for each component were made and then divided by 5 to produce a single metric value. These single metrics of each characteristic were then combined for each street by using Equation 1.

Step Five
Flood risk index measurement. Through the use of Equation 2, flood risk was calculated by multiplying the flood hazard index and flood vulnerability index values for each street in Morpeth, producing a high spatial resolution flood risk scenarios for Flood Zones 2 and 3.

Figure 2: A flow chart of the five main methodology steps and a brief description of each step

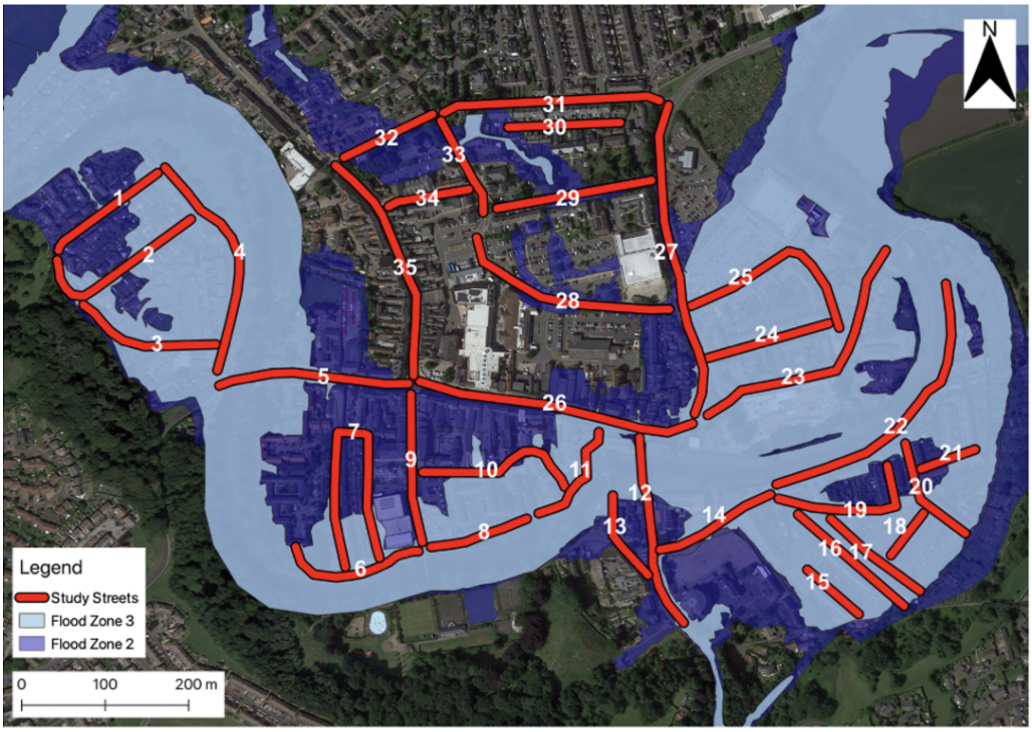


Figure 3: A map displaying Flood Zones 2 and 3 in Morpeth determined by the Environment Agency, as well as the 35 chosen study streets where data collection has taken place. Source: DEFRA (2020)

Street Name	Allocated Number on Maps
St Mark's Street	1
Hollon Street	2
Challoner's Gardens	3
Abbey View	4
Oldgate	5
Mathesons Gardens	6
Pretoria Avenue	7
Carlisle View	8
Newmarket	9
Whalebone Lane	10
Chantry Place	11
Bridge End	12
Hillgate	13
Goosehill	14
West Greens	15
Alexandra Road	16
Castle Street	17
Edward Street	18
Jackson Terrace	19
East View	20
Norman Terrace	21
Bennett's Walk	22
Gas House Lane	23
Wellwood Gardens	24
Staithes Lane	25
Bridge Street	26
Dark Lane	27
Stanley Terrace	28
Dacre Street	29
Maritime Place	30
Howard Road	31
St James Terrace	32
Well Way	33
Manchester Street	34
Newgate Street	35

Table 1: A table of the street names that were measured in Morpeth and their corresponding number that was used in the production of maps

Flood Zone Scenario	Year-Event	Probability of Occurrence
Flood Zone 2 (FZ2)	1-in-1000-year event	0.1-1% probability
Flood Zone 3 (FZ3)	1-in-100-year event	>1% probability

Table 2: A table displaying the conversion of Flood Zones to the equivalent year-event and probability occurrence

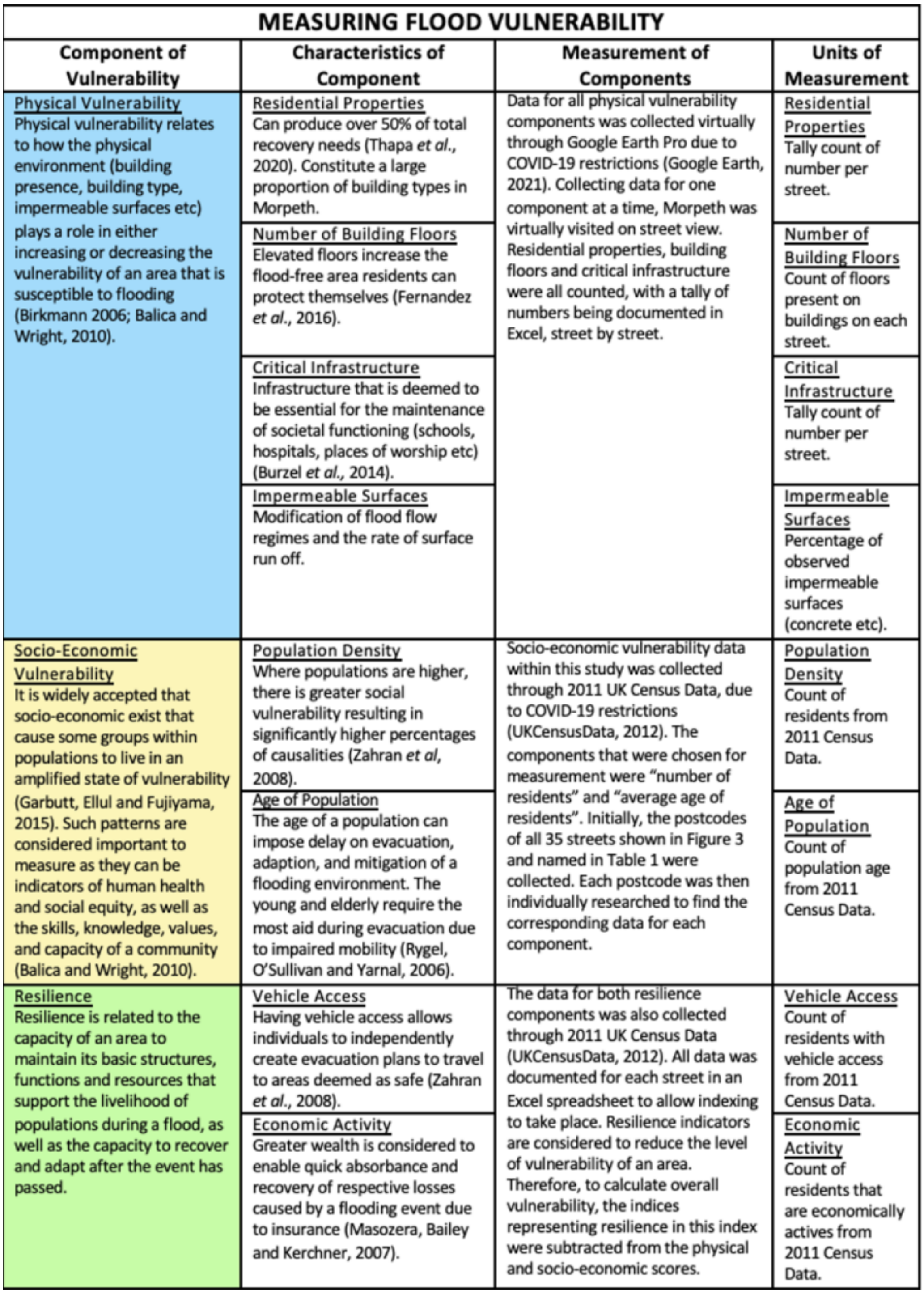
Initially, flood datasets were separately downloaded onto QGIS and the potential surface area of flood water inundation for each street was recorded as a percentage. For example, if a street was completely inundated it would be attributed a percentage of 100%, whereas if only half of the street was inundated by flood water, it would be attributed 50%. After all streets had been measured for both a FZ2 and FZ3 event, a FHI was produced to calculate numerical data into a single metric (Table 3).

Index	Flood Inundation Area Coverage	Flood Hazard Level
1	0-20%	Very Low
2	21-40%	Low
3	41-60%	Moderate
4	61-80%	High
5	81-100%	Very High

Table 3: A table displaying the FHI, and respective colour scheme used to indicated flood hazard level

2.2 Understanding Flood Vulnerability

A flood vulnerability assessment creates an understandable link between theoretical concepts of flood vulnerability and the day-to-day decision making of local populations (Balica *et al.*, 2012). Therefore, measuring vulnerability involves the analysis of multiple inherent characteristics, which provide a larger representation of an area's capacity to cope and recover (Balica *et al.*, 2012). The main components of vulnerability measured (physical, socio- economic and resilience) in this study and the characteristics used to populate them are presented in Table 4 (Percival and Teeuw, 2019). It is important to recognise how chosen, and un-chosen vulnerability characteristics may influence end results. Such characteristics have been chosen for this study due to their predominant use in current literature (see Balica and Wright, 2010; Percival and Teeuw, 2019) as well as their accessibility during desk-based measurement. To carry out analysis with a combination of in the field and through desk-based measurements such as that done by Tascon-Gonzalez *et al* (2020) provides opportunity for a more accurate snap shot of populations (Tascon-Gonzalez *et al.*, 2020). This is through a present-day representation of the current population in Morpeth rather than using Census data from 2011. However, if data collection was to be done in the field, observation methods such as foot fall counting can increase the likelihood of assumptions to be made regarding age and there is more opportunity for human error (Percival and Teeuw, 2019).



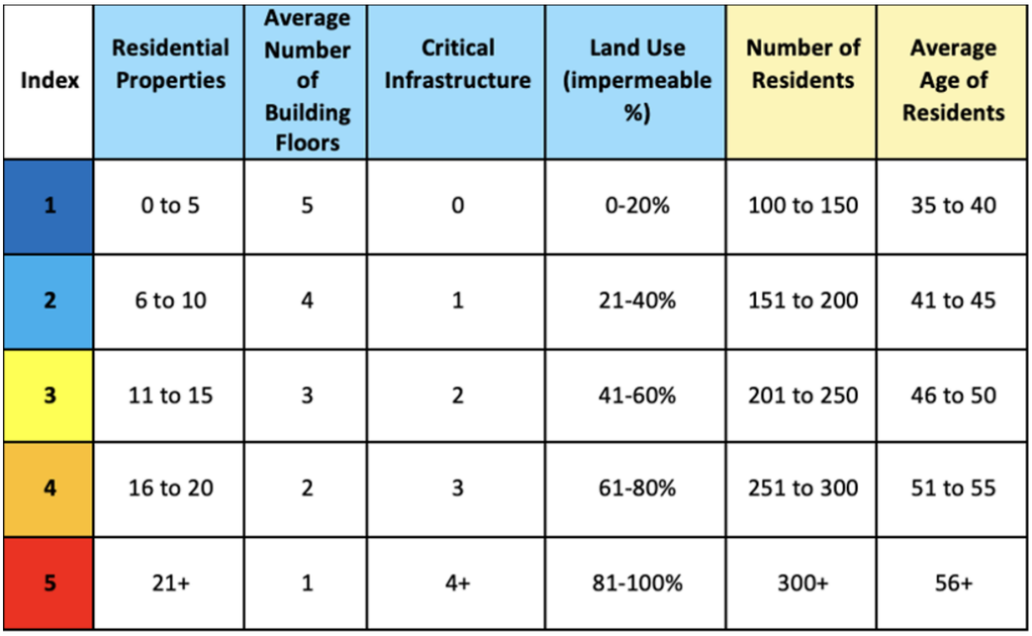
MEASURING FLOOD VULNERABILITY

Component of Vulnerability	Characteristics of Component	Measurement of Components	Units of Measurement
Physical Vulnerability Physical vulnerability relates to how the physical environment (building presence, building type, impermeable surfaces etc) plays a role in either increasing or decreasing the vulnerability of an area that is susceptible to flooding (Birkmann 2006; Balica and Wright, 2010).	Residential Properties Can produce over 50% of total recovery needs (Thapa *et al.*, 2020). Constitute a large proportion of building types in Morpeth.	Data for all physical vulnerability components was collected virtually through Google Earth Pro due to COVID-19 restrictions (Google Earth, 2021). Collecting data for one component at a time, Morpeth was virtually visited on street view. Residential properties, building floors and critical infrastructure were all counted, with a tally of numbers being documented in Excel, street by street.	Residential Properties Tally count of number per street.
	Number of Building Floors Elevated floors increase the flood-free area residents can protect themselves (Fernandez *et al.*, 2016).		Number of Building Floors Count of floors present on buildings on each street.
	Critical Infrastructure Infrastructure that is deemed to be essential for the maintenance of societal functioning (schools, hospitals, places of worship etc) (Burzel *et al.*, 2014).		Critical Infrastructure Tally count of number per street.
	Impermeable Surfaces Modification of flood flow regimes and the rate of surface run off.		Impermeable Surfaces Percentage of observed impermeable surfaces (concrete etc).
Socio-Economic Vulnerability It is widely accepted that socio-economic exist that cause some groups within populations to live in an amplified state of vulnerability (Garbutt, Ellul and Fujiyama, 2015). Such patterns are considered important to measure as they can be indicators of human health and social equity, as well as the skills, knowledge, values, and capacity of a community (Balica and Wright, 2010).	Population Density Where populations are higher, there is greater social vulnerability resulting in significantly higher percentages of causalities (Zahran *et al*, 2008).	Socio-economic vulnerability data within this study was collected through 2011 UK Census Data, due to COVID-19 restrictions (UKCensusData, 2012). The components that were chosen for measurement were "number of residents" and "average age of residents". Initially, the postcodes of all 35 streets shown in Figure 3 and named in Table 1 were collected. Each postcode was then individually researched to find the corresponding data for each component.	Population Density Count of residents from 2011 Census Data.
	Age of Population The age of a population can impose delay on evacuation, adaption, and mitigation of a flooding environment. The young and elderly require the most aid during evacuation due to impaired mobility (Rygel, O'Sullivan and Yarnal, 2006).		Age of Population Count of population age from 2011 Census Data.
Resilience Resilience is related to the capacity of an area to maintain its basic structures, functions and resources that support the livelihood of populations during a flood, as well as the capacity to recover and adapt after the event has passed.	Vehicle Access Having vehicle access allows individuals to independently create evacuation plans to travel to areas deemed as safe (Zahran *et al.*, 2008).	The data for both resilience components was also collected through 2011 UK Census Data (UKCensusData, 2012). All data was documented for each street in an Excel spreadsheet to allow indexing to take place. Resilience indicators are considered to reduce the level of vulnerability of an area. Therefore, to calculate overall vulnerability, the indices representing resilience in this index were subtracted from the physical and socio-economic scores.	Vehicle Access Count of residents with vehicle access from 2011 Census Data.
	Economic Activity Greater wealth is considered to enable quick absorbance and recovery of respective losses caused by a flooding event due to insurance (Masozera, Bailey and Kerchner, 2007).		Economic Activity Count of residents that are economically actives from 2011 Census Data.

Table 4: A table providing further detailed information on the measured components of vulnerability and their various characteristics and units of measurement, as well as the colour scheme to represent the different components

2.3 Flood Vulnerability Index

After vulnerability components had been identified and measured, indexing began by creating scales for each characteristic. This was completed by dividing the highest possible total for each characteristic by 5, creating equal intervals between the lowest and highest outcomes (Table 5 and 6). Next, to calculate each streets vulnerability level, Equation 1 was used with each components index total. Equal weightings were chosen for this index as no independent judgement was made on the importance of characteristics. Other research with the decision for the use of equal weightings has been carried out by Balica *et al.,* 2013 and Percival and Teeuw, 2019.



Index	Residential Properties	Average Number of Building Floors	Critical Infrastructure	Land Use (impermeable %)	Number of Residents	Average Age of Residents
1	0 to 5	5	0	0-20%	100 to 150	35 to 40
2	6 to 10	4	1	21-40%	151 to 200	41 to 45
3	11 to 15	3	2	41-60%	201 to 250	46 to 50
4	16 to 20	2	3	61-80%	251 to 300	51 to 55
5	21+	1	4+	81-100%	300+	56+

Table 5: A table displaying the respective index scale for physical and socio-economic vulnerability components. The colour scheme for vulnerability components represents the type of vulnerability (physical and socio-economic) and the index colour scheme represents the indication of the level of vulnerability used in the generation of maps in QGIS

Index	Residents with Vehicle Access	No. Economically Active
1	50 to 100	50 to 75
2	101 to 150	76 to 100
3	151 to 200	101 to 125
4	201 to 250	126 to 150
5	251+	150+

Table 6: A table displaying the respective index scale for resilience vulnerability components. The colour scheme for vulnerability components represents the type of vulnerability (resilience) and the index colour scheme represents the indication of the level of vulnerability used in the generation of maps in QGIS

$$\text{VULNERABILITY} = ((\text{physical vulnerability} + \text{socio-economic vulnerability}) - \text{resilience})\ (1)$$

2.4 Flood Risk Index

Once street vulnerability index totals had been calculated, further indexing was carried out using Equation 2. This involved multiplying hazard and vulnerability to calculate the overall level of flood risk of each street. This allowed the production of a high spatial resolution street level flood risk scenario for a FZ2 and FZ3 magnitude event.

$$\text{RISK} = \text{Hazard} \times \text{Vulnerability}\ (2)$$

3. Results

3.1 Flood Hazard

The results indicate that a greater number of streets will be acutely inundated in Morpeth during a FZ2 event. Figure 4 shows that 74.3% of study streets would be 80-100% inundated by water if a FZ2 event occurred. Considerably less study streets will be inundated to this degree if a FZ3 event occurred (Figure 5). During both events, the same pattern is found of streets that are more and least hazardous, with streets south of the River Wansbeck facing higher levels of hazard than those in the north.

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Figure 4: A flood hazard map displaying the most and least affected streets during a 1-in-1000-year flooding scenario (Flood Zone 2) which has a 0.1-1% chance of occurring

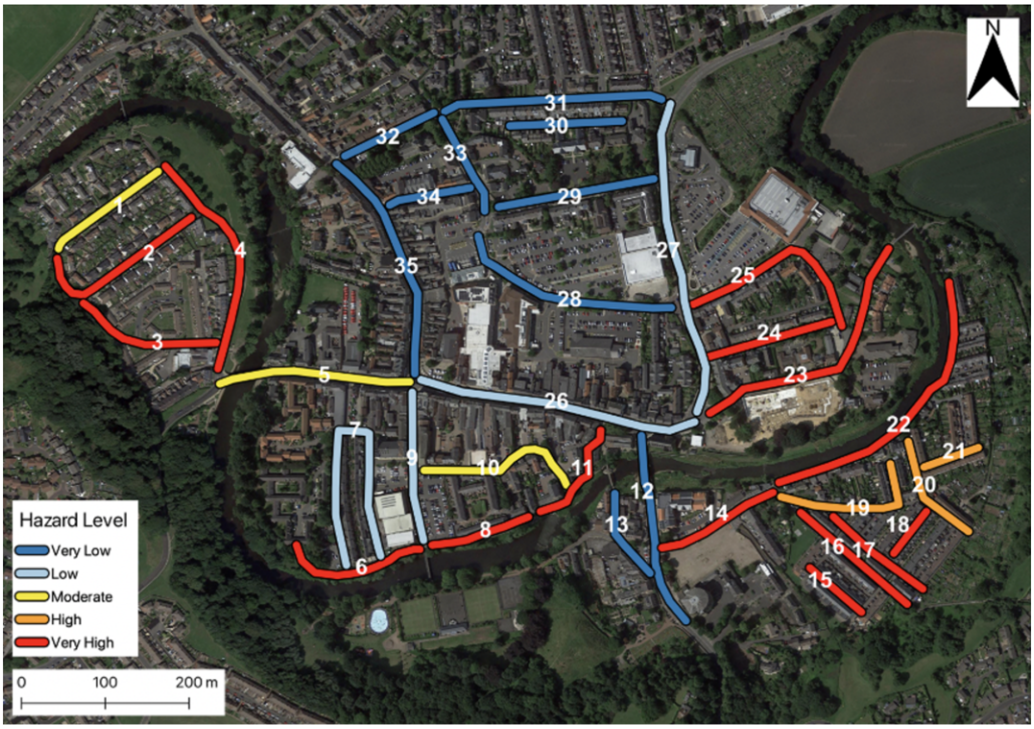

Figure 5: A flood hazard map displaying the most and least affected streets during a 1-in-100-year flooding scenario (Flood Zone 3) which has a >1% chance of occurring

3.2 Flood Vulnerability

Many streets in Morpeth (68.6%) are considered to have a moderate level of vulnerability (Figure 6). These streets can be found north of the River Wansbeck. There are only two streets with high vulnerability (25 and 29), due to CI presence and high socio-economic vulnerability. The streets with the lowest levels of vulnerability are located south of the River Wansbeck, due to high resilience.

Figure 6: A FVI map displaying the streets in Morpeth that are regarded to have between a very low and very high vulnerability level

3.3 Flood Risk

During a FZ2 event, 4 streets have high levels of flood risk (7, 23, 24 and 25) (Figure 7). This is due to a combination of very high levels of flood water inundation and moderate or high levels of vulnerability. Streets 30, 31, 34 and 35 are least at risk due to moderate vulnerability or very low hazard levels. These 4 streets also have high, or very high levels of resilience.

Figure 7: A flood risk map displaying the most and least affected streets of Morpeth during a 0.1-1% probability flood (Flood Zone 2)

During a FZ3 event, fewer streets in Morpeth are at risk of flooding (Figure 8). Streets 23, 24 and 25 remain to have high levels of flood risk, however, street 7 has changed from high to low risk. This is predominantly due to the change in levels of inundation during a FZ3 scenario i.e., flood water coverage would be less.

Figure 8: A flood risk map displaying the most and least affected streets of Morpeth during a >1% probability flood (Flood Zone 3)

4. Discussion

4.1 Hazard and Flood Magnitudes

It is clear from the results presented in Section 3.0, that during a 1-in-1000- year event (FZ2), more streets in Morpeth would be inundated and at a higher level of risk (Ridolfi *et al.*, 2021). Large scale events such as a FZ2 scenario are projected to increase as a result of climate change, meaning more populations will be at risk of flooding in the near future (Prudhomme *et al.*, 2010). Additionally, the repeated occurrence of a FZ3 magnitude flood still has the potential to cause serious impacts on Morpeth's physical environment and surrounding populations due to the weakening of infrastructure and defences (Chen and Mehrabani, 2019).

4.2 Key Components of Vulnerability

In addition to flood magnitudes affecting risk, the most influential vulnerability components in Morpeth are high population densities, CI, and residents without vehicle access. The presence of residential properties highlights the exposure of populations in dangerous, flood prone areas (Custer and Nishijima, 2015; Karagiorgos *et al.*, 2016). Congested neighbourhoods, such as the south and west of Morpeth, have been proven to be particularly susceptible to floods, increasing the risk of both short- and long-term consequences (Jasour *et al*., 2022). This emphasises the necessity to prepare for the rehoming of populations, a crucial consideration in the pre- planning stage of flood events (Felix *et al*., 2015). Furthermore, it is important to know the age of these congested populations due to both young children and the elderly potentially having difficulty responding to a disaster effectively on their own (Chang *et al.,* 2021). This has been supported with findings suggesting most flood related fatalities are due to others travelling to aid the elderly evacuate (Ahmed *et al*., 2020). This highlights that identifying highly populated areas and understanding who populates them is crucial to mitigating flood risk effectively.

The results highlight CI as an important factor to monitor in Morpeth, as they are present in all streets considered to be at a high flood risk during both FZ2 and FZ3 events. These CI included a care home, ambulance station, supermarket, and NHS health centre. The presence of CI is also increasing due to rising population levels, suggesting that there is possibility for future populations to become more vulnerable and at-risk during flood events (Fekete *et al*., 2020). This causes an increase in impermeable surfaces, creating additional surface run off, further enhancing vulnerability to flood events (Wang *et al*., 2019). During both a FZ2 and FZ3 event, all streets regarded as high and low risk in Morpeth contain 80-100% impermeable surfaces. The consequence of this is that if a flooding event was to occur, there would be very low possibility for flood water to infiltrate, increasing the probability of property damage and the threat of human health (Bertilsson *et al*., 2019).

Additionally, if congested neighbourhoods contain lower income households, there are lower levels of disaster preparedness (Benevolenza and DeRigne, 2019). This can involve expenditure on insurance, an assistor in the restoration of damaged properties, as well as having vehicle access that can aid independent evacuation during a flood to an area that is deemed as safe i.e., enhancing resilience (Lamond *et al.,* 2009). In Morpeth, the streets considered to be least resilient had populations without vehicle access and who were less economically active. Therefore, understanding flood resilience is vital, as those with low levels of resilience, have high levels of risk.

4.3 Considerations and Limitations

Great deliberation was taken upon choosing calculation techniques and characteristics to be measured. Indexing is the most favourable method of calculating flood risk and vulnerability as it allows the inclusion of multiple characteristics within one framework, whilst also ensuring a standardisation of data that can later be visualised through the production of maps (Percival and Teeuw, 2019). The choice of these characterises can be incredibly subjective, therefore, through literature reviews, the most predominant characteristics in current research were chosen for this research study (Balica, Wright and Van der Meulen, 2012; Percival and Teeuw, 2019). If this study was to be replicated, it would be recommended to consider measuring characteristics such as public transport (physical), average house prices (socio-economic) and emergency facilities (resilience). It could also be considered to try different weightings of characteristics to see how this influences results, although this would be recommended to be done through a team of researchers or stakeholders than by an individual.

5. Conclusion

This article has presented a unique methodology for the application of a high spatial resolution street level flood risk assessment during FZ2 and FZ3 events. The maps produced highlight streets in Morpeth that need most attention. It was determined that the characteristics that influence risk the most were complete flood water inundation, high numbers of residential properties, CI, and populations without vehicle access. It is also shown that a FZ2 event places more of the population at risk. These results help drive development of sound evacuation plans, a crucial development in areas such as Morpeth in order to heighten the safety of the community and future protection of the physical infrastructure. The findings from this study also highlight that to maintain a low level of vulnerability, it is essential FVI's are frequently evaluated and adapted to ensure findings produce accurate methods of adaptation and mitigation. Theoretical and practical implications of these findings concern that it has been carried out on a street level scale and therefore findings may not be a representative of flood risk and vulnerability on a larger scale. Additionally, further vulnerability characteristics than what have been chosen for this study could have been measured, such as household composition (dependent children) and disabilities. This may have influenced findings and the overall level of flood risk in Morpeth. Nevertheless, this study and its findings are still considered to be an insightful contribution to the field of vulnerability and flood risk.

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