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EXPLORING FLOOD MANAGEMENT IN AN URBAN AREA OF THE UK: CASE STUDY OF SHEFFIELD

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ABSTRACT

One of the main natural disaster facing Sheffield for a long period of time is flooding which has become a recurring environmental issue. This study explores urban flood management in Sheffield and also predicts flooding risk zones with the use of Geographic Information System. Secondary data that include DEM, land use map, soil map, and rainfall data of Sheffield were acquired from different sources, while flow accumulation, slope and elevation as well as distance from the drainage network were processed from the DEM using ArcGIS. All the data were processed into 7 thematic layers and were assigned weights based on their contribution to flooding. Thereafter, a weighted overlay was adopted in GIS to predicts the flood risk zones in Sheffield. Additionally, flood management approaches in UK and Sheffield in particular were critique. The results revealed that locations in the north-eastern and south-eastern of Sheffield are vulnerable to flooding as water flows from high elevation and steep slope to low elevation with gentle slope, and thereby control surface runoff and water concentration. Meanwhile, distance from the river drainage network, land use, topography, and flow accumulation appears to be the most significant factors responsible for flooding in Sheffield. It was therefore recommended that the international standard of permitted distance to water body which is 250m should be enforced in Sheffield; and land use management practices should be enhanced across the city for suitable flood management.

CHAPTER ONE

1.0 Introduction

1.1 Background

Flooding is widely recognised as one of the most disruptive natural hazards in the United Kingdom, causing significant social, economic, and environmental impacts. The frequency and severity of flood events are projected to increase due to climate change, placing a growing proportion of the population at risk and increasing associated economic losses (Committee on Climate Change, 2016; Thorne, 2014). Flooding occurs when water inundates areas that are normally dry, often as a result of excessive rainfall, river overflow, coastal surges, or groundwater emergence (UNISDR, 2015).

Floods occur in several forms, including fluvial flooding caused by prolonged rainfall leading to river overflow, coastal flooding resulting from storm surges and tidal influences, groundwater flooding associated with rising water tables, and pluvial flooding caused by intense rainfall overwhelming drainage systems (Ball et al., 2008; Houston et al., 2011). These flood types pose significant threats to communities, infrastructure, businesses, and ecosystems across the UK.

Climate change has been identified as a major factor increasing flood risk throughout the country. More frequent extreme weather events, combined with rapid urbanisation and land-use changes, have reduced natural infiltration capacity as permeable surfaces are increasingly replaced by concrete and tarmac (Evans et al., 2004a; Evans et al., 2004b; Rotherham, 2008). Consequently, many urban areas have become increasingly vulnerable to flooding. Historical events illustrate the scale of the problem. The autumn 2000 floods in England caused approximately £300 million in property damage (Environment Agency, 2004), while the 2007 and 2012 flood events generated estimated business losses of £740 million and £600 million respectively (Coates et al., 2016).

Traditional flood management strategies have relied on structural measures such as embankments and flood defences. However, their limitations in addressing increasing flood risks have encouraged a shift towards integrated catchment-based approaches that combine engineered defences with sustainable land-use planning and natural flood management techniques (Butler, 2008; Johnson & Priest, 2008; DEFRA, 2005). Furthermore, advances in Geographic Information Systems (GIS) and Remote Sensing (RS) have significantly enhanced flood prediction, hazard mapping, risk assessment, and damage evaluation (Opolot, 2013). Consequently, this study examines flood management approaches in the UK, with particular emphasis on Sheffield, and employs GIS techniques to identify and predict flood-prone areas within the city.

1.2 Statement of Research Problem

Flooding has remained one of the most persistent environmental challenges facing Sheffield for more than a century. The city's first major recorded flood disaster occurred on 11 March 1864, resulting in significant loss of life and widespread destruction of homes, bridges, mills, and other infrastructure (Harrison, 1974). Since then, several major flood events have affected the city, causing extensive damage to properties, businesses, transport networks, and public utilities. Sheffield's vulnerability to flooding is largely attributed to its location at the confluence of the Rivers Don, Loxley, Sheaf, and Porter, combined with increasing pressures from climate variability and urban development (Sheffield City Council, 2013).

Although flooding is a recurring phenomenon in Sheffield, certain events have had particularly severe consequences. Notable flood incidents occurred in 1973, 1991, 1998, 2000, 2007, 2009, 2012, 2018, and 2019, with the 2007 and 2019 floods regarded as the most destructive in recent history (Environment Agency, 2007; Madge, 2019). During the summer of 2007, exceptionally heavy rainfall across Yorkshire and surrounding regions caused river levels to rise rapidly, overwhelming drainage systems and triggering widespread flooding throughout Sheffield (Environment Agency, 2007). More than 1,200 homes were inundated, over 1,000 businesses were affected, and critical infrastructure such as roads, bridges, water supply systems, and electricity networks suffered extensive disruption. The total economic losses were estimated at approximately £3 billion (Environment Agency, 2007).

Similarly, the severe flooding experienced in 2019 followed one of the wettest summers recorded in the UK since 1910 (Madge, 2019). Intense rainfall events led to widespread flooding across Yorkshire and neighbouring regions, damaging properties, disrupting transportation, and affecting thousands of households (GOV.UK, 2019a; The Guardian, 2019). Insurance claims arising from damaged homes, businesses, and vehicles exceeded £110 million (Association of British Insurers, 2019).

The recurring nature of these flood events highlights the need for more effective flood management strategies. Existing challenges are exacerbated by continued development on floodplains, constrained river channels, and increasing rainfall intensity associated with climate change (Environment Agency, 2007). Consequently, there is a need to explore comprehensive flood management approaches and utilise Geographic Information Systems (GIS) to identify and predict flood-prone areas in Sheffield. Such information is essential for improving planning, enhancing preparedness, and reducing future flood-related losses.

Figure 1.1: The squeeze on the River Don
Source: Environment Agency, 2007

1.3 Objectives:

1. Review current literature around urban flood management in the UK
2. Explore recent urban flood management (rationale and policy) in Sheffield, as the case study location.
3. Predict the potential flood hazard risk areas in Sheffield using GIS.

1.4 Justification for the study

The projected climate change for Sheffield shows that Sheffield will experience warmer, wetter winters as well as summers becoming drier and combined with extremes rainfall events. This suggested that flooding will be more recurring at a huge scale and evident in Sheffield (Sheffield City Council, 2013). As a result of the increasing rainfall amount observed in the 2019 summer and winter, more water will be in the catchments, soil completely saturated, thus, rivers in this environment responding speedily to rainfall in the future. Therefore, the seasonal outlook for nonstop wet weather together with the soil being saturated shows that flooding will be continuous in UK and especially in Sheffield for many months ahead (UK Centre for Ecology and Hydrology, 2019).

Although, flood risk in Sheffield is being managed by raising defences and channel maintenance, while River Don and its tributaries are restricted to narrow canals and culverts across Sheffield (Environment Agency, 2010). Nonetheless, the development on the floodplains restricted the rivers from enlarging during any flood event which has consequently expose a huge quantity of properties to risk anytime there is huge flood event (Environment Agency, 2010). This is because River Don and its tributaries respond quickly to rainfall with a peak period of two hours or less. Hence, the flashy features of Don catchment provide the added importance to the necessity for a holistic and effective flood risk management in the city (Sheffield City Council, 2013). Hence, it is paramount to identify an approach that will serve as a long term approach to minimise flood risk in Sheffield.

1.5 The Study Area

The geographical location of Sheffield is shown in Figure 2. Sheffield is located at the base of the Pennines in the upper reaches of the River Don catchment. Sheffield is at the confluence of Don, Loxley, Sheaf and Porter (Sheffield City Council, 2013). The steep sided Pennine hills dictated the topography of Sheffield in the western part with a narrowed river valley. The Sheffield river valleys responds speedily to rainfall, as runoff takes place and travels swiftly through the catchment in the event of intense rainfall. In addition, the Sheffield city topography is flattened and the river valleys broaden towards the eastern section of the city centre (Sheffield City Council, 2013). Figure 3 shows the river network Sheffield.

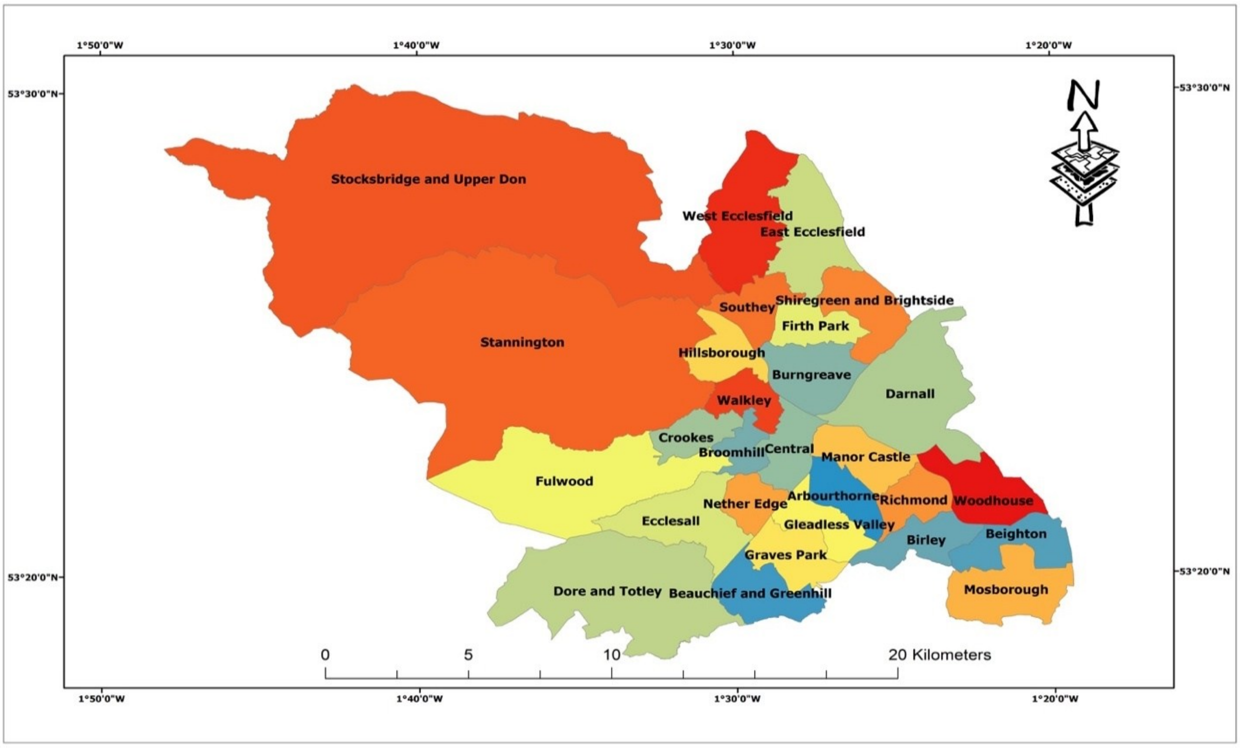

Fig 1.2: Sheffield, United Kingdom.
Source: Edina Digi Map

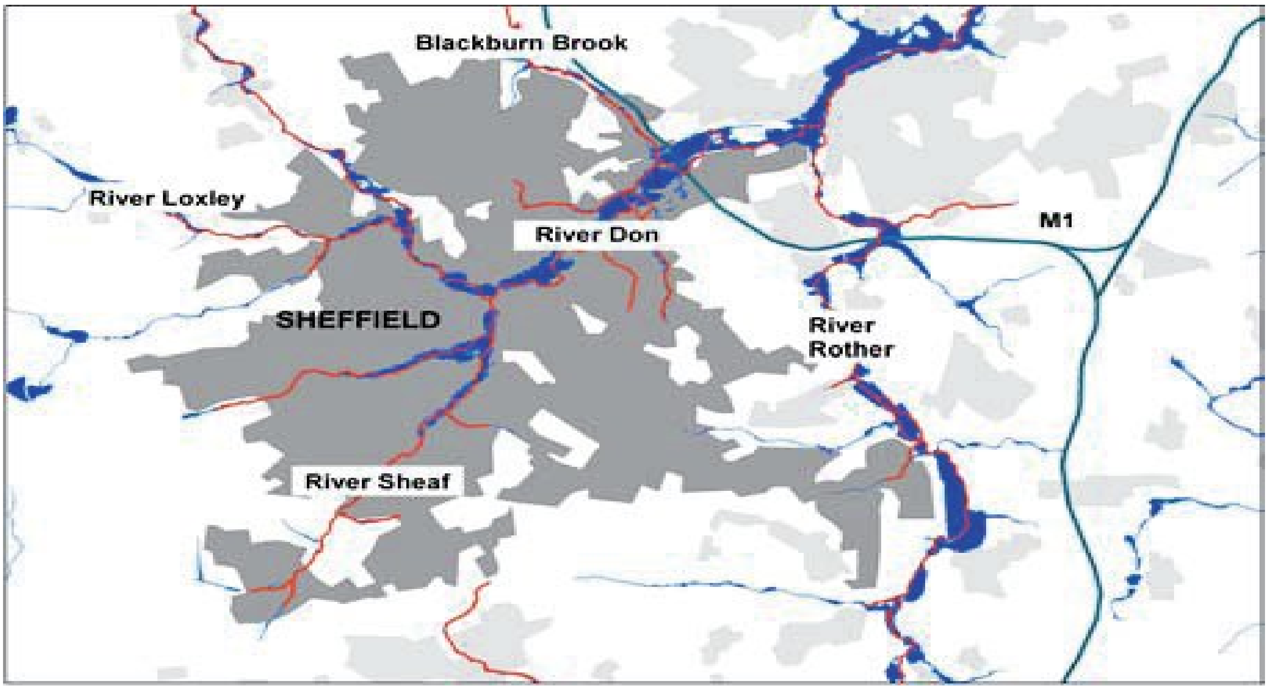

Fig. 1.3: Sheffield's river network
Source: Environment Agency, 2007

CHAPTER TWO

2.0 Literature Review

2.1 Urban Flooding

Urban flooding is one of the most common and destructive natural hazards worldwide, affecting more people than any other natural disaster (UNISDR, 2015). The risk is particularly severe in urban areas due to increasing urbanisation, population growth, and the concentration of economic activities and infrastructure (Chen, Zhou, Zhang, Du & Zhou, 2015). Urban flooding can occur in several forms, including pluvial, fluvial, groundwater, and coastal flooding. Pluvial flooding results from rainfall exceeding the capacity of urban drainage systems, while fluvial flooding occurs when rivers overtop their banks or bypass flood defences. Groundwater flooding results from elevated groundwater levels, whereas coastal flooding is caused by storm surges and tidal effects (Saul et al., 2011).

Urban floods are commonly triggered by intense rainfall, river overbank flow, or coastal surges. Inadequate drainage systems, urban development on floodplains, and increasing surface impermeability often exacerbate flood severity (Tingsanchali, 2012). Climate change is expected to increase the frequency and intensity of extreme rainfall events, making urban flooding more severe and difficult to predict (IPCC, 2007).

The impacts of urban flooding extend beyond physical inundation. Because cities function as major economic and social centres, flood events often result in extensive disruption to infrastructure, transportation networks, businesses, and public services (Jha et al., 2011). Floods disproportionately affect vulnerable and low-income populations who often lack the resources necessary for effective recovery (ActionAid, 2006). Rapid urban population growth further increases exposure to flood hazards, particularly in developing regions where urban expansion frequently occurs without adequate planning (IFRC, 2010).

Urban flooding has become a major concern for governments worldwide. Events such as the severe floods experienced in England in 2007 demonstrated the significant economic and social consequences of urban flood disasters (Cabinet Office, 2008). Consequently, improving urban flood risk management through sustainable planning, effective drainage infrastructure, and advanced monitoring technologies has become a priority at all levels of governance (Fang, 2016).

2.2 UK Experience of Urban Flooding

Urban flooding represents one of the most significant environmental and socio-economic challenges facing the United Kingdom. Flood events pose substantial threats to public safety, infrastructure, and economic development, with estimated annual flood damages exceeding £1 billion (Hall, Sayers & Dawson, 2005). The impacts of flooding have become increasingly severe due to climate change, which is expected to alter rainfall patterns and increase the frequency and intensity of extreme weather events, thereby elevating flood risks in many urban areas across the UK (Ashley, Balmforth, Saul & Blanskby, 2005; Wheater & Evans, 2009).

Recent flood events have demonstrated the vulnerability of urban areas to both fluvial and pluvial flooding. The winter storms of 2013/14 and 2015/16 caused widespread flooding across the UK, resulting in significant economic losses and disruption to communities, businesses, and critical infrastructure (Muchan, Hannaford & Parry, 2015; Priestley, 2016). The costs associated with the 2015/16 winter floods alone were estimated to exceed £5 billion (KPMG, 2016).

One of the most notable urban flood events occurred during the summer of 2007, which was recorded as the wettest summer in the UK since systematic records began. Intense rainfall over short periods caused extensive flooding across Yorkshire, the North East, the East Midlands, and parts of South-West England (Cabinet Office, 2008). Approximately 55,000 properties were flooded, 13 people lost their lives, and around 7,000 individuals required rescue assistance. The floods also disrupted essential services, leaving nearly half a million people without access to mains water and electricity, while transportation networks experienced widespread failure (Cabinet Office, 2008).

Another significant example was the Newcastle pluvial flood of June 2012, which resulted from an intense storm delivering 49 mm of rainfall within two hours. The event caused severe disruption to transportation systems, road networks, and public services throughout the city (Environment Agency, 2012; Pregnolato, Ford, Wilkinson & Dawson, 2017). Similarly, severe storms during the winter of 2013 generated extensive urban and river flooding across Northern Ireland, Scotland, and southern England (Thorne, 2014). In addition, exceptional rainfall in Cumbria during 2015/16 caused widespread flooding, affecting approximately 16,000 properties (Marsh, Kirby, Muchan, Barker, Henderson & Hannaford, 2016).

These events demonstrate the increasing vulnerability of UK urban areas to flooding and highlight the importance of effective flood risk management strategies, resilient infrastructure, and improved preparedness measures to mitigate future impacts.

2.3 Critical Flooding Incidents in the UK

Flooding is recognised as one of the most significant risks facing the United Kingdom and is consistently identified on the National Risk Register as a major threat to communities, infrastructure, and economic development (Cabinet Office, 2013). It is widely regarded as the most frequent and damaging natural hazard in the country due to its extensive social, economic, and environmental consequences (Harries, 2013). The impacts of flooding often extend beyond the immediate inundation period, causing long-term displacement of residents, disruption of businesses, and damage to critical infrastructure. For example, following the severe floods of 2007, many affected households were forced to remain in temporary accommodation for several months while repairs were undertaken (Environment Agency, 2010).

The severity of flood impacts is influenced by the source of flooding, which may include fluvial, pluvial, coastal, groundwater, or sewer flooding. These sources can occur independently or simultaneously, increasing the scale and complexity of flood events and their consequences (Environment Agency, 2009). The widespread nature of flood risks has prompted successive UK governments to introduce a range of policies and strategies aimed at improving flood risk management and enhancing resilience.

Among the most significant initiatives is the National Flood and Coastal Erosion Risk Management (FCERM) Strategy for England, which provides a long-term framework for managing flood and coastal erosion risks (Defra, 2011). The Flood and Water Management Act 2010 established clearer responsibilities for managing local flood risks and strengthened the role of local authorities in flood governance (UK Government, 2010). Similarly, the Flood Risk Regulations 2009 introduced requirements for flood risk assessments, mapping, and management planning. Other notable initiatives include the National Planning Policy Framework (2012), Future Water (2008), Making Space for Water (2005), the Foresight Future Flooding Report (2004; updated 2008), and the Pitt Review (2008), which was commissioned following the devastating 2007 floods to improve national flood resilience and emergency preparedness (Cabinet Office, 2008; Defra, 2004).

A notable development in UK flood governance has been the increasing involvement of local authorities in flood risk management. This shift reflects broader trends in water governance where responsibilities are shared between national and local institutions (Moss & Newig, 2010; Benson, Jordan & Smith, 2013). The Flood and Water Management Act 2010 introduced the concept of Lead Local Flood Authorities (LLFAs), which are responsible for developing, maintaining, and implementing local flood risk management strategies within their jurisdictions (UK Government, 2010). These strategies are required to include flood risk assessments, management objectives, cost-benefit evaluations, and stakeholder engagement processes.

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In Sheffield, this approach is reflected in the Sheffield Flood Risk Management Strategy (SFRMS), which provides a coordinated framework for managing flood risks across the city. The strategy adopts a catchment-wide approach, addressing flood risks associated with the River Don and its tributaries, as well as surface water, sewer, and smaller watercourse flooding (Sheffield City Council, 2017.). By integrating national policies with local implementation measures, the SFRMS aims to improve flood resilience and reduce the impacts of future flood events across Sheffield.

2.4 Approaches to Flood Management

Flood management refers to the application of technical, administrative, and operational measures aimed at reducing flood risks and minimising their impacts on people, infrastructure, and the environment (Mitchell et al., 2010). It is generally approached from two perspectives: the development of physical flood defence structures and the implementation of risk-based strategies that focus on flood assessment, preparedness, and mitigation (Ali, Bajracharya & Koirala, 2016).

Flood management methods are broadly classified into structural and non-structural approaches. Structural measures involve the construction of engineered systems such as dams, dykes, reservoirs, floodwalls, drainage channels, floodgates, and detention basins to control water flow and reduce flood impacts (Li et al., 2016). These measures are particularly effective in urban and coastal areas where protection of lives and property is a priority. However, increasing flood risks associated with climate change have highlighted the limitations of relying solely on structural solutions.

Non-structural approaches focus on reducing vulnerability and improving preparedness through flood forecasting, hazard mapping, land-use planning, zoning regulations, flood insurance, emergency response planning, and public awareness programmes (Nkwunonwo, Whitworth & Baily, 2016; Zhou, Liu, Zhong & Cai, 2017). Flood modelling is one of the most widely used non-structural tools for predicting flood behaviour and assessing risk.

Flood models are commonly categorised as one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D). One-dimensional models such as MIKE 11, HEC-RAS, and ISIS are computationally efficient but simplify hydraulic processes (Samuels, 1990; Bates & De Roo, 2000). Two-dimensional models, including TUFLOW, MIKE 21, and SOBEK, provide more detailed representations of flood dynamics and urban flow patterns (Bates et al., 2005). Three-dimensional models offer the most comprehensive hydraulic simulations but require substantial computational resources (Neelz & Pender, 2009).

Advances in GIS, remote sensing, satellite imagery, and Digital Elevation Models (DEMs) have significantly improved flood monitoring, hazard mapping, and flood-prone area identification (Jeyaseelan, 2004; Kussul, Shelestov, Skakun & Kravchenko, 2008). These technologies provide essential information for effective flood risk management and decision-making (Kourgialas & Karatzas, 2011).

2.5 Case Study of Flood Management in Sheffield, River Don and South Yorkshire

The Don catchment covers more than 1,800 sq. Km with more than 1.3 million people living within the catchment. The upper parts of the Don catchment cover the steep-sided, distinct valleys of the Pennine peripheral which include Sheffield, Chesterfield and Barnsley. The middle part of the catchment comprises of Rotherham and a wide artificially ordered washlands structure. The lower reach of the catchment comprises Doncaster, the floodplain area of the Humberhead Levels, Old Google and the communities of Swinefleet and Reedness (Environmental Agency, 2010, The Don Network, nd).

As a consequence of the long history of flooding in the catchment, a quite number of engineering structures has been put in place to minimise the flood risk in the area. There are about 530 defences erected across the catchment, this include raised defences, screens, culverts and washlands. The defences provide different standards of protection and these defences are located in the major urban areas that include Sheffield, Chesterfield, Doncaster and Rotherham. Various activities are carried out to minimise the possibility of flooding across the catchment (Environmental Agency, 2010) which include:

a) Maintenance of the defences which involve steady scrutiny to guarantee they are in good conditions;
b) Maintenance of over 221 km of river channels which include the abstraction of obstructions that are possible to increase chances of flood risk;
c) working with the local authorities in order to guide the location and design of development, making sure that unsuitable development is not permitted in the floodplain.
d) Flood risk mapping by employing modelling to have an insight into likely flooding areas;
e) Provision of flood prediction and warning service through seventy different flood warnings. This service also alarms other expert partners and emergency responders to activate flood response;
f) promoting alertness of flooding to organisations and members of the public so that they are ready in case there is need to take action at times of flooding; and

g) providing resilience and resistance measures for the properties that are already located within the floodplain.

CHAPTER THREE

3.0 RESEARCH METHODS

The outcome of any research endeavour and its significance for future research work is dependent on the quality of the data utilised. The data type could be primary or secondary. Often time, a large quantities of primary data are gathered and archived by researchers or relevant institutions across the world. This has given rise to more widespread potential of using existing data for research besides the original purpose of which it was collected (Andrews, Higgins, Andrews, Lalor, 2012; Johnston, 2014). Based on the nature of this research and the type of data involved which cannot be easily acquired directly by an individual, we adopted the secondary data. Hence, secondary data is a data that was originally collected by someone or an organisation for a different primary purpose. Therefore, the use of an existing data offers a practical option for investigators that may have limited time and resources (Johnston, 2014).

The use of an existing data can hasten the speed of research based on the fact that some of the time consuming stages of a standard research project such as measurement development, and data collection, etc. are eliminated (Doolan & Froelicher, 2009). The use of secondary data permits a timely completion of the research as well as generating findings much faster, hence, making the development and contribution of novel knowledge to be in a timely manner (Johnston, 2014). Although, the researcher using the secondary data has no control over the quality if such data, that is why it always better to use existing data collected my Government and some other official institutions because the quality of the data are usually guaranteed in most cases (Sindin, 2017). Therefore, all the secondary data used in this research are primarily collected by Government and reliable official institutions.

3.1 Nature and Types of Data Used

The data used for this study are mainly secondary in nature. The type of data used for the study include:

i. Information on the flood management in Uk and current flood management approach in Sheffield;
ii. Sheffield Land use map;
iii. Sheffield soil map;
iv. Sheffield Rainfall data;
v. 30 m Digital elevation model (DEM);
vi. flow accumulation;
vii. slope and elevation data; and
viii. distance from the drainage network.

The data set ii to viii above were chose based on their influence on flooding in any given environment as reported in literature (Argaz, eta al., 2019) which are observed to have contributory effect on Sheffield flooding.

3.2 Sources of Data Used

i. The Information on the flood management in Uk and current flood management approach in Sheffield will be extracted from literature;
ii. Land use map of Sheffield was extracted from UK Centre for Ecology and Hydrology database (Rowland, Morton, Carrasco, McShane, O'Neil, & Wood, 2017);
iii. The Sheffield soil map was extracted from the Harmonised World Soil Data base(http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/) ;
iv. The Sheffield rainfall data was obtained from the Worldclim database (https://www.worldclim.org/data/worldclim21.html); and
v. The digital elevation model was downloaded from Advanced Land Observing Satellite (ALOS) database (https://www.eorc.jaxa.jp/ALOS/en/aw3d30/).
vi. The flow accumulation, slope and elevation data, drainage network were processed from the 30m Digital Elevation Model (DEM).

3.3 Data Processing

The drainage line and flow accumulation in Sheffield were processed from the DEM by employing the archydro tool in ArcGIS. Similarly, the spatial analysis tool in ArcGIS was adopted in processing the slope and elevation of Sheffield in ArcGIS. In addition, we used the Sheffield shapefile to extract the area of interest from the land use map, rainfall map and soil map. A buffer analysis was performed to create distances from the river network as follows: <100m (very high), 100-200m(High), 200-300 (Moderate), 300-400 (Low), 500 and above (Very Low).

3.4 Method of Data Analysis

The urban flood management approaches in the UK were critically explored, as well as the current flood management approaches in Sheffield. All the data layers were resampled to a resolution of 30m and the relationships that existed between the generated maps and their attributes were computed using the Analytical hierarchy process (AHP) that is frequently adopted in defining the relative importance of the stated criteria in a multi-criteria decision-making issues (Yalcin & Akyurek, 2004). The pairwise comparison of the flood risk factors in Sheffield was evaluated and the results was placed in a comparison matrix (Saaty, 1980). The matrix was populated by adopting values from 1 to 5, and the fractions will signify the importance of one factor compared to another All the data set were assigned relative weight based on their level of contribution to flood event. We adopted the weighted overlay to perform the multi-criteria analysis employing the weights of each variable in predicting the flood risk area in ArcGIS. Thereafter, the flood risk areas were classified into high and low.

3.5 Ethical Consideration

All the data sources that will be used in this research will be duly acknowledged. However, the data required for this study are secondary data, no human subject will be involved and no right of any individual will be violated. Nevertheless, flooding is a very dangerous hazard that affects peoples home and businesses, hence, all created data and maps will be treated with appropriate care.

CHAPTER FOUR

4.0 Findings and Discussion

4.1 Urban Flood Management in the United Kingdom

Urban flooding in the United Kingdom is primarily caused by intense rainfall that exceeds the infiltration capacity of the ground and overwhelms drainage systems, resulting in surface runoff and inundation of urban areas (Jenkins, Surminski, Hall & Crick, 2016). The occurrence and severity of urban flooding depend on several interacting factors, including rainfall intensity and duration, land-use characteristics, urban surface configurations, and the design of drainage and sewer networks (Jenkins et al., 2016). Effective flood management is therefore essential for reducing flood risks and protecting lives, property, and infrastructure.

The devastating floods of 2007, which caused economic losses estimated at £3.2 billion, highlighted weaknesses in existing flood management systems and prompted significant reforms in flood risk management across the UK (Environment Agency, 2010; MARE, 2013). Since then, flood management has increasingly focused on risk assessment, resilience, and integrated approaches that combine structural and non-structural measures (Miller & Hutchins, 2017). Structural approaches include flood defences, drainage networks, embankments, and engineered channels designed to control floodwaters and reduce inundation (Jha et al., 2011; Tingsanchali, 2012). However, such measures are often costly and may encourage further development in flood-prone areas, thereby increasing long-term vulnerability (Levy, Gopalakrishnan & Lin, 2005).

Non-structural approaches focus on planning, governance, flood forecasting, land-use management, and community preparedness. In England, flood risk management responsibilities are shared among the Environment Agency, Lead Local Flood Authorities (LLFAs), water companies, and other stakeholders, reflecting a multi-level governance framework (Rubinato et al., 2019). This collaborative approach supports integrated flood risk management, which promotes coordination among institutions and communities to enhance resilience (Batica, 2015; Dieperink et al., 2018).

A key component of contemporary urban flood management is the adoption of Sustainable Drainage Systems (SuDS), which mimic natural hydrological processes by promoting infiltration, storage, and controlled runoff (DEFRA, 2011a; DEFRA, 2011b). In addition, advanced hydraulic models such as InfoWorks, MIKE, TUFLOW, and Flood Modeller Pro are increasingly used for flood prediction and preparedness (Rubinato et al., 2019). Green infrastructure, including parks, wetlands, and vegetated swales, further contributes to natural flood management by reducing runoff volumes and enhancing urban resilience (Schubert et al., 2017; O'Donnell et al., 2020). These integrated approaches have become central to sustainable urban flood management in the UK.

4.2 Recent Urban Flood Management Policies and Initiatives in Sheffield

The devastating floods of 2007 marked a turning point in flood risk management within Sheffield. Prior to this event, flood awareness among residents, businesses, and policymakers was relatively low despite the fact that large sections of the Don Valley had long been identified as vulnerable to flooding (MARE, 2013). The severe impacts of the 2007 floods exposed weaknesses in existing flood protection measures and highlighted the need for a more coordinated and proactive approach to flood management. Consequently, Sheffield City Council (SCC), in collaboration with the Environment Agency and other stakeholders, introduced a range of policies and initiatives aimed at improving the city’s resilience to future flooding.

A key outcome of the post-2007 flood strategy was the adoption of an integrated, multi-agency approach based largely on the recommendations of the Pitt Review and supported by initiatives such as Managing Adaptive Responses (MARE) and Climate Adaptation Mainstreaming through Innovation (CAMINO) (Environment Agency, 2010; Goodchild, Sharpe & Hanson, 2018). The Lower Don Valley (LDV), one of Sheffield's most important economic zones, was identified as a priority area for intervention because of its vulnerability to flooding and its significance to the city's economy (SCC, 2013a). Since conventional flood relief measures were difficult to implement within the heavily developed floodplain, the strategy focused on strengthening existing flood defences and improving flood preparedness.

An innovative aspect of the LDV scheme was the establishment of a Business Improvement District (BID), through which local businesses agreed to contribute financially towards flood protection measures (Goodchild et al., 2018). This partnership enabled the construction and enhancement of flood defences along approximately 8 km of the River Don, protecting more than 500 businesses and thousands of jobs (SCC, 2018). Additional measures included river channel maintenance, debris removal, invasive species management, and the development of coordinated emergency response procedures.

More recently, Sheffield City Council and the Environment Agency launched six major flood protection schemes to be delivered up to 2028. These include the Upper Don Valley Flood Protection Scheme, Sheaf Catchment Flood Protection Scheme, culvert renewal programmes, sustainable drainage projects, and natural flood management initiatives such as wetland creation, tree planting, floodplain restoration, and woody debris dams (SCC, 2020). Collectively, these initiatives aim to enhance flood resilience, support climate change adaptation, improve biodiversity, and ensure the long-term sustainability of Sheffield's urban environment.

4.3 Sheffield Flood Hazard Assessment and Potential Future Risk Sites

The assessment of potential flood risk areas in Sheffield was conducted using seven key factors known to influence flood occurrence: land use, slope, elevation, rainfall, soil type, distance from drainage networks, and flow accumulation (Kourgialas & Karatzas, 2011; Argaz et al., 2019). To ensure consistency, all datasets were resampled to a 30 m spatial resolution and processed into raster layers. A weighted overlay analysis in ArcGIS was subsequently employed to integrate the seven thematic layers and identify areas with varying flood risk levels.

Analysis of the elevation and slope maps revealed considerable topographic variation across Sheffield. High elevations and steep slopes are predominantly located in the north-eastern and south-eastern sections of the city, whereas lower elevations and gentler slopes occur in parts of the central, western, and north-western areas. Topography is a critical determinant of flood behaviour because it influences the direction, speed, and concentration of surface runoff (Kia, Pirasteh & Pradhan, 2012). Water naturally flows from areas of higher elevation and steeper gradients towards lower-lying zones where runoff accumulates.

Consequently, low-lying areas with gentle slopes are more susceptible to flood hazards due to increased water concentration and reduced drainage efficiency. Based on these characteristics, several wards, including the Central Area, Burngreave, Darnall, Hillsborough, Firth Park, and Nether Edge, exhibit relatively higher vulnerability to future flood risks and therefore require enhanced flood management and planning interventions.

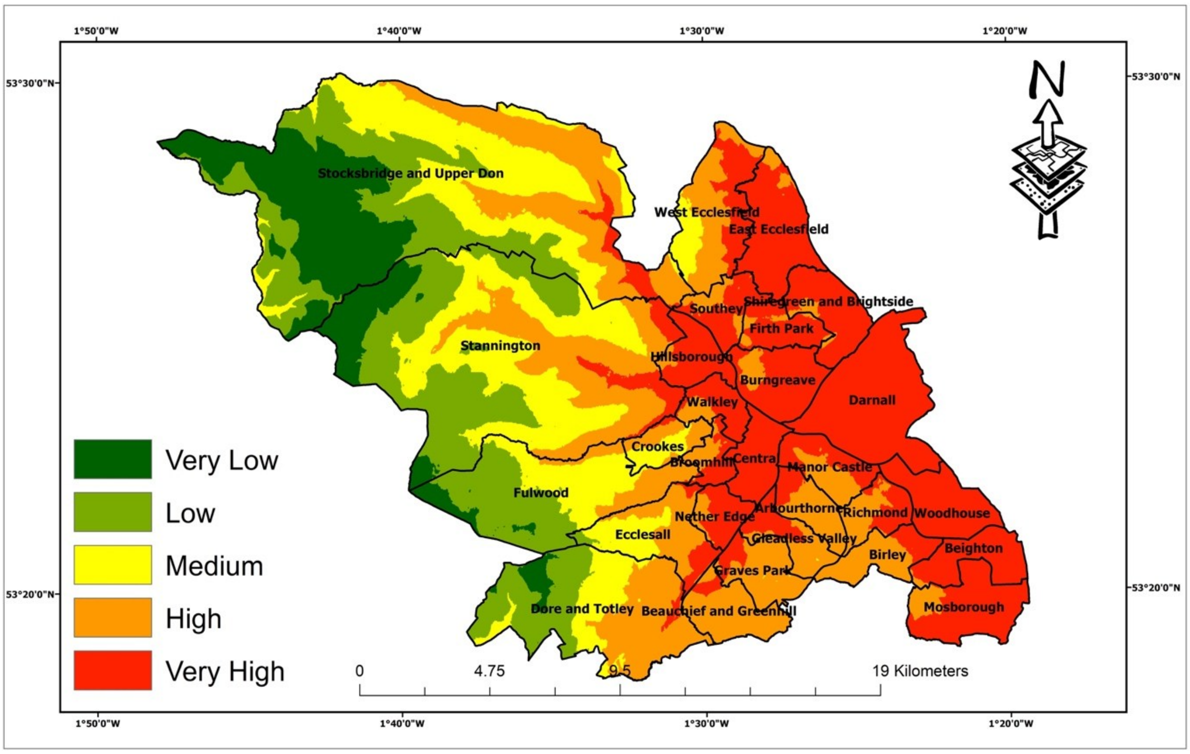

Figure 4.1: Elevation Map of Sheffield (Weighted)

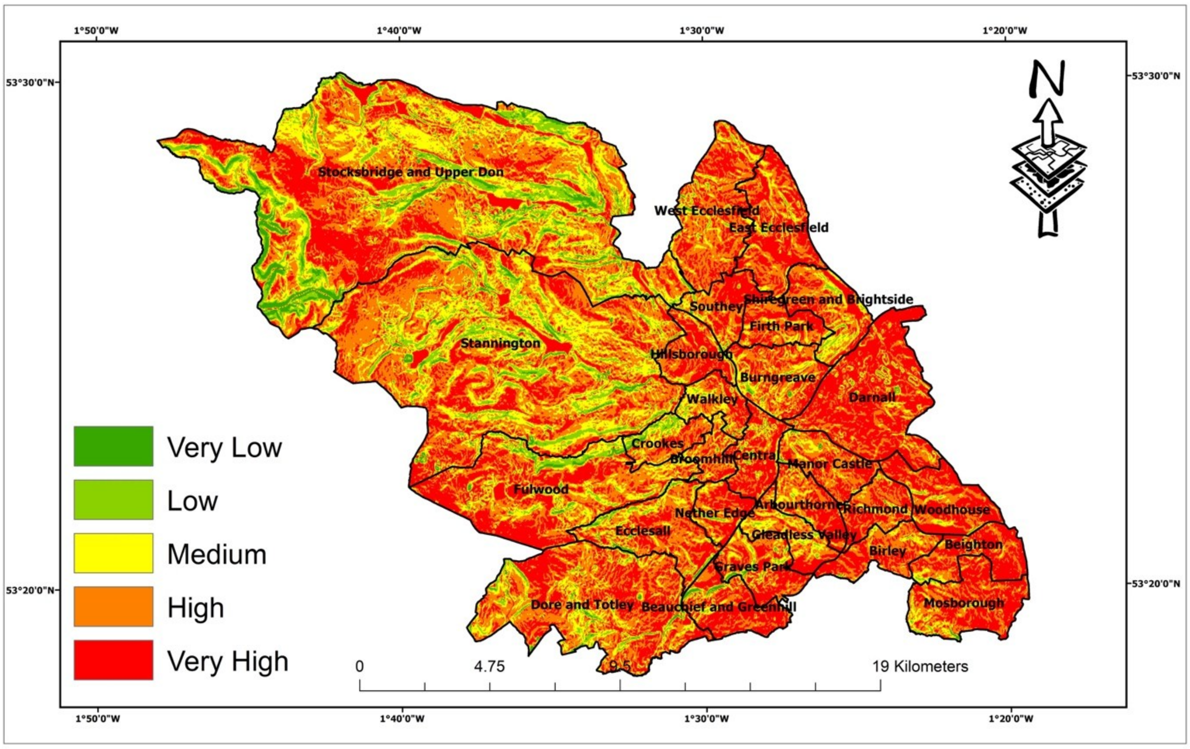

Figure 4.2: Slope Map of Sheffield (Weighted)

The amount of rainfall received in an area determines the amount of surface water that will result to overland flow and surface runoff (Ashaolu, Olorunfemi, Ifabiyi, Abdollah & Batelaan, 2020). The annual rainfall data was processed from the WorldClim version 2 and the weighted spatial distribution of annual rainfall amount over Sheffield is presented in Figure 4.3. The highest amount of annual rainfall amount in Sheffield is recorded in the north-western part in part of Stocksbridge and Upper Don. There is no extensive physical development in this area and it is only Stocksbridge (lies in the east of Peak District) at the steep sided valley of the Little Don River and Oughtibridge located in the valley of River Don are the main population centre in the ward.

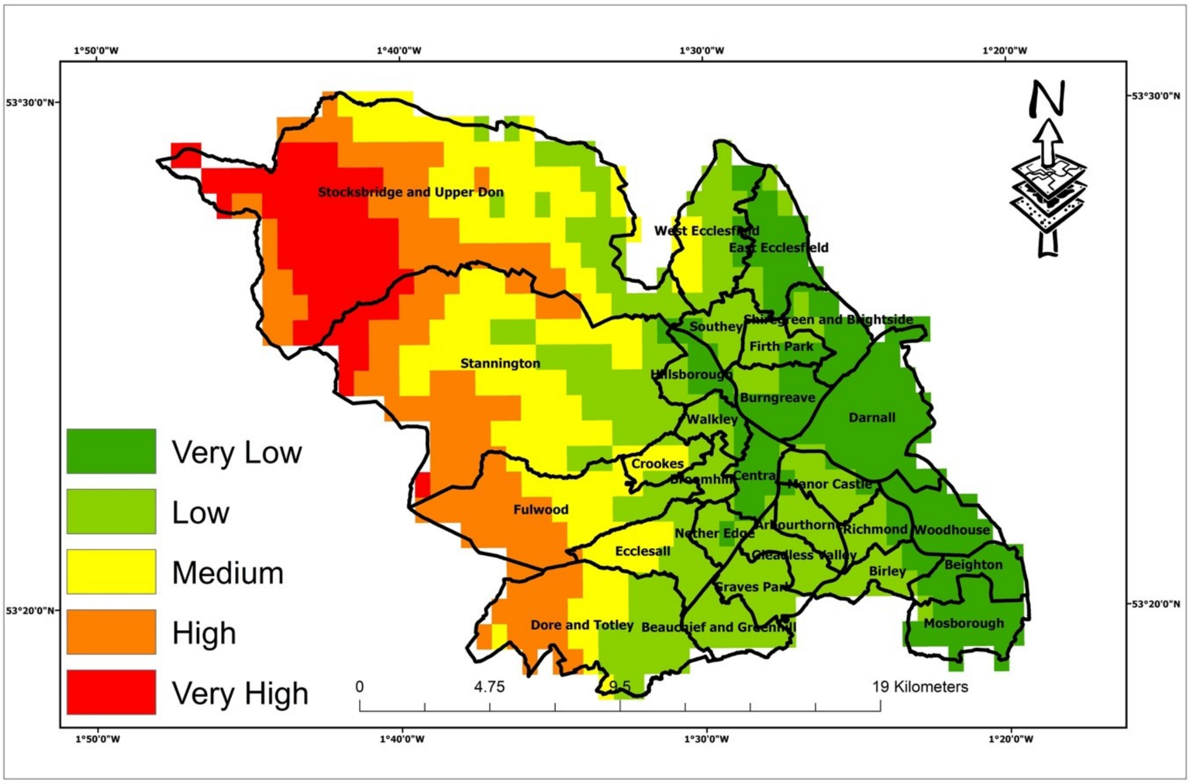

Figure 4.3: Annual Rainfall Distribution in Sheffield (Weighted)

Although the locations of this area makes them vulnerable to flooding, but the other contributing factors such as land use, flow accumulation are not really significant in this area. On the other hand, low annual rainfall amount is recorded in the eastern part to the south-eastern part of Sheffield as depicted in Figure 4.3. It is important to note that it was the annual spatial rainfall distribution employed in this analysis, thus, extreme rainfall event like that of 2007 was not captured. Therefore, extreme cases of rainfall amount might disrupt the pattern presented.

The flow accumulation processed from the DEM is presented in Figure 4.4. The analysis reveals that very high and high flow accumulation is concentrated in the drainage network from Hillborough to Walkley through Central area to Burngreaves down to Darnall, which are located at the Lower Don Valley. Flow accumulation is an indirect measurement of the drainage area that constantly increases from the drainage towards the river outlet (Kourgialas & Karatzas, 2011). Hence, the flow concentration as shown in Figure 4.4 is an indication that flood risk vulnerability will be high in those parts of Sheffield (Kazakis, Kougias & Patsialis, 2015). This is because during an individual rainfall event, the surface water will be concentrated in this area before flowing out towards the cities at the downstream.

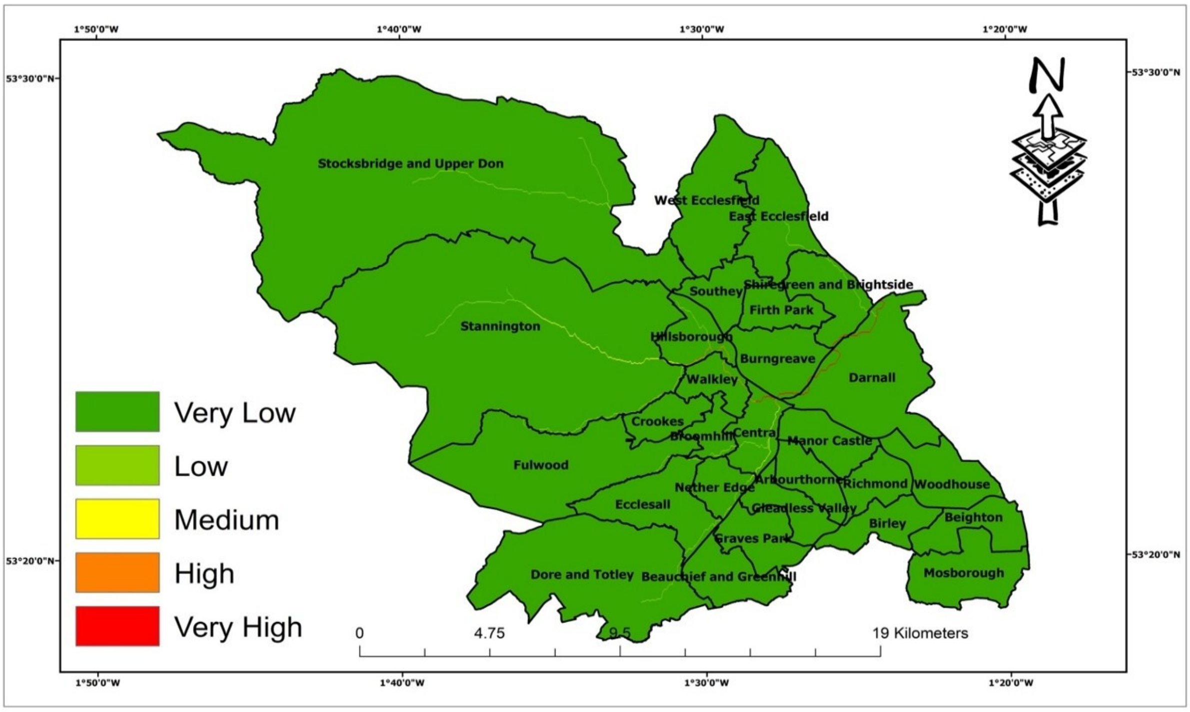

Figure 4.4: Flow Accumulation Map of Sheffield (Weighted)

The distance of a location to the river drainage network determines the vulnerability of the area to flood risk. As shown in Figure 4.5, the distance of entire Sheffield to the river drainage network were divided into five using buffering analysis in GIS. These are <100m (Very high risk), 100-200m (High risk), 200-300m (Moderate risk), 300-400m (Low risk), 500m and above (Very Low risk). The areas within a buffer of < 100m of the river drainage network are designated as high risk areas, whereas within the range of 500m and above from the drainage network are designated as very low areas to flood risk vulnerability. The high risk areas cut across most of the wards (21) in Sheffield. Hence, if the river overflow its banks as a consequence of heavy downpour for a longer duration, these areas within the < 100m, and 100-200m are at risk of flooding.

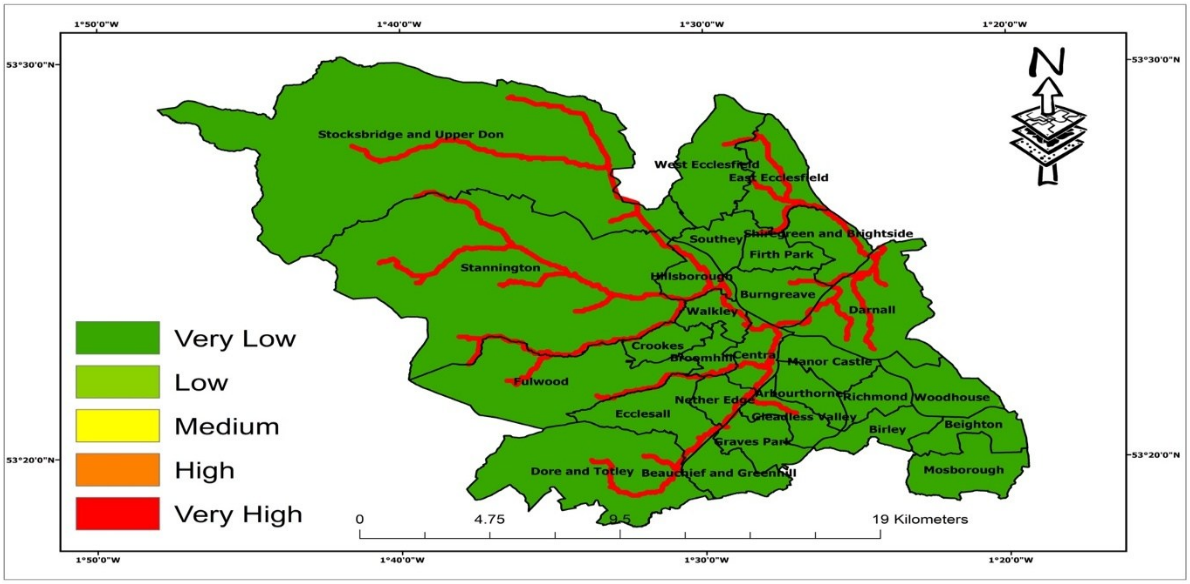

Figure 4.5: Distance from the River Network in Sheffield (Weighted)

The land use type in any location, particularly locations that are urbanised with paved surfaces usually affect the hydrology of the area, especially the infiltration rate and surface runoff (Butt, Shabbir, Ahmad & Aziz, 2015; Ashaolu, Olorunfemi & Ifabiyi, 2019), which consequently result to flooding. Looking at Figure 4.6, flood risk is expected to be very high in locations that are urbanised with large proportion of paved surfaces such as the central ward, Broomhill among many others and the semi urban wards such as Mosborough. This is as a result of the surfaces and artefacts of the urban centres that are likely to increase surface runoff, and inhibit large scale infiltration, hence high likelihood of flooding.

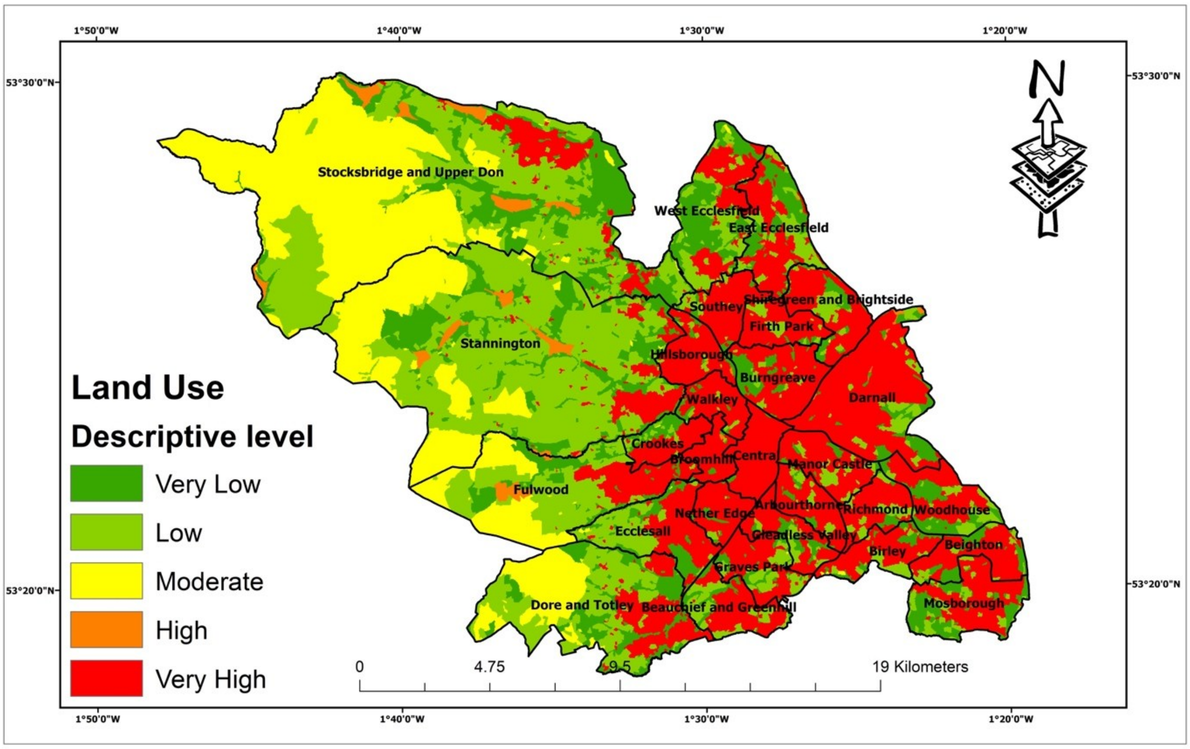

Figure 4.6: Land Use Map Types in Sheffield (Weighted)

The weighted soil map of Sheffield in presented in Figure 4.7. The dominant soil type in this area before weight are assigned are clay soil, silty clay and heavy clay (Harmonised World Soil Database, 2012). The rate of infiltration in the soil types found in Sheffield is very low, therefore, locations with clay soil are assigned the highest weight and designated as very high in terms of the locations to flood risk, while areas on silty clay and heavy clay were categorised as moderate and low, respectively (Figure 4.7). Based on the soil type, the areas with high soil clay are expected get more flooded as the soil in such areas will be compacted and consequently minimise infiltration, and increases surface runoff as well as water logging. The areas with white background on the weighted soil map (Figure 4.7) are the areas such as Central, Burngreaves, Walkley, etc. that the majority of their surfaces are paved.

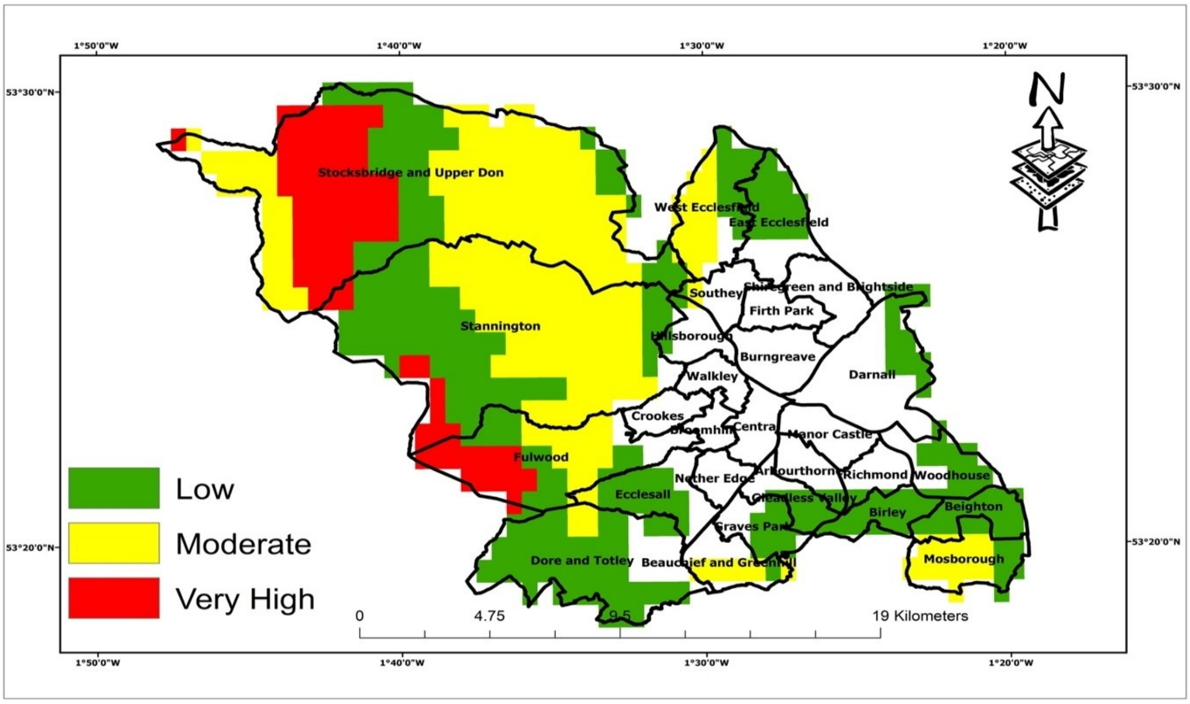

Figure 4.7: Soil Map of Sheffield (Weighted)

Finally, all the weighted 7 thematic maps displayed above were used for a weighted overlay analysis to predict the flood risk zones of Sheffield (Figure 4.8). As revealed by the analysis, varying degree of flood risk vulnerability are predicted for Sheffield and this range from very low flood risk to very high flood risk. As shown in Figure 4.8, the centre ward, towards the eastern and north-eastern part of Sheffield are predicted to have flood risk that ranges from high to very high. These are areas located at the lower part of River Don valley towards the downstream. Based on the pattern of flood risk predicted for Sheffield, it can be contended that the most crucial factors responsible for flooding in Sheffield are the distance from the river drainage network, land use, topography, and flow accumulation. Although, rainfall extremes that is expected as a consequent of climate change might altered the pattern of flooding based on rainfall amount and intensity. Nonetheless, an increasing rainfall amount or rainfall extremes will combine with the identified crucial factors to exacerbate flooding in the predicted areas. These areas are Central ward, Darnall, Hillsborough, Woodhouse, part of Nether Edge, while varying degrees of flooding is expected in other part of Sheffield even in locations in upper River Don valley.

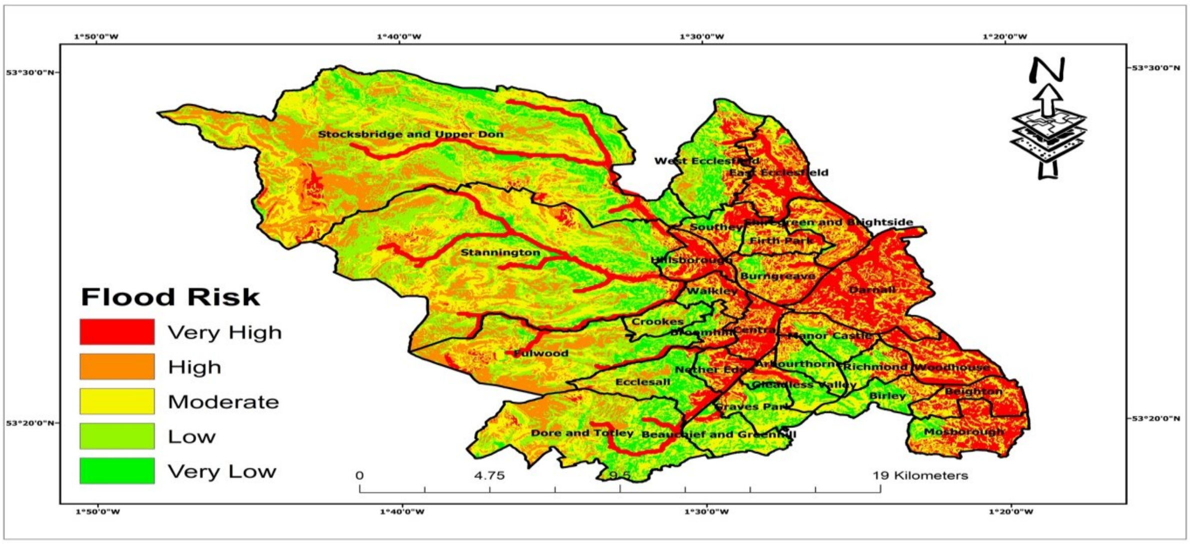

Figure 4.8: Predicted Flood Risk Map of Sheffield

In conclusion, this chapter discussed flood management approaches employed in the UK, before narrowing down to flood management in Sheffield, as well as predicting flood risk areas in Sheffield using the multicriteria weighted analysis of 7 crucial factors responsible for flooding. It was discovered that prior to 2007 flood incidence, flood risk and management has not really been in the consciousness of both the expert and the populace of UK. The flooding occurrence was an eye opener that resulted to various policy advice at EU level and at National level (Pitt review). Across the Uk, the most common flood management approach is the use of flood defences, which has consumed millions of pounds, whereas, the Sheffield city council adopted the strategic flood management plan, by attending to the priorities area first in terms of building flood defences and the general approaches geared towards regenerating those high flood risk areas and making them more attractive to potential investors.

CHAPTER FIVE

5.0 Conclusion and Recommendation

This chapter presents the conclusions drawn from the study, recommendations based on the findings, and suggestions for future research. The study reviewed urban flood management practices in the United Kingdom, examined recent flood management policies and initiatives in Sheffield, and predicted potential flood-prone areas using Geographic Information Systems (GIS).

5.1 Conclusion

The findings indicate that urban flood management in the UK relies on a combination of structural and non-structural approaches, although traditional flood defences and drainage infrastructure remain the dominant methods of flood protection. While these measures have reduced flood impacts, they require substantial financial investment and may encourage development within flood-prone areas, potentially increasing future risks if defences fail. Recent approaches increasingly emphasise integrated flood risk management, Sustainable Drainage Systems (SuDS), green infrastructure, and resilience-based strategies aimed at enhancing long-term adaptability to flooding.

The study further revealed that flood management in Sheffield is guided by a strategic and collaborative framework involving Sheffield City Council, the Environment Agency, businesses, and local communities. Priority has been given to vulnerable economic zones such as the Lower Don Valley, where significant investments have been made in flood protection infrastructure and river management. The city has also adopted natural flood management measures and long-term flood resilience initiatives to address the growing challenges associated with climate change.

GIS-based flood hazard assessment identified distance from drainage networks, land use, topography, flow accumulation, and rainfall as the most influential factors affecting flood occurrence in Sheffield. The analysis showed that low-lying areas with gentle slopes, particularly within parts of the Central Area, Burngreave, Darnall, Hillsborough, Firth Park, and Nether Edge, are more susceptible to flooding. The study also suggests that future increases in rainfall intensity and extreme weather events could further exacerbate flood risks within these areas.

5.2 Recommendations

Based on the findings, a resilience-based flood management approach that combines structural and non-structural measures should be further promoted in Sheffield and across the UK. Greater emphasis should also be placed on sustainable land-use planning, enforcement of development controls near watercourses, and expansion of SuDS and green infrastructure. Furthermore, flood preparedness programmes and community awareness initiatives should be strengthened, particularly in identified high-risk areas.

5.3 Areas for Further Research

Future studies should investigate the effects of individual extreme rainfall events on flood risk prediction, develop higher-resolution flood hazard models at ward or neighbourhood level, and estimate the population and infrastructure most vulnerable to flooding. Such research would provide more detailed information for planning, emergency response, and long-term flood risk management.

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