MAPPING FLOOD VULNERABILITIES OF THE EAST RIDING OF YORKSHIRE

Thesis submitted for the degree of

Doctor of Philosophy

at the University of Leicester

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September 2013

Abstract

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Title: Mapping Flood Vulnerabilities of the East Riding of Yorkshire

Flooding has caused intensive damage to communities both economically and socially in recent decades. Comprehensive Emergency Management (CEM) aims at reducing the diverse impacts of disasters, while vulnerability has been recognised as its most beneficial phase. This study contributes to the assessment of vulnerability at a sub-regional scale through the development of appropriate sets of indicators and methods.

A modified version of the BBC (Bogardi, Birkmann, and Cardona) model was selected as the conceptual framework of the vulnerability assessment. This model depicts characteristics and components of vulnerability and defines four pillars of sustainable development as the sub-components of vulnerability. Notwithstanding some shortages in the model, it has been a great vehicle for vulnerability assessment and has been successful in operationalising the research objectives. Three sectors of land use were extracted in order to cover the context-relevant characteristics of vulnerability. Indicators were developed in order to measure and map flood vulnerability: 15 indicators for the arable sector, 15 for the wildlife sector, and 34 for the urban sector. The development of indicators involved steps including a review of previous works, the building of vulnerability components and sub-components, the identification of indicators, and data collection.

Geographical Information Systems (GIS) provided the basis for all analytical and methodological processes of the work. A 1 km grid cell raster map was set as the format of the final mapping. In order to map the final vulnerability for the East Riding of Yorkshire, indicators needed to be transferred, normalised, weighted and integrated. Since this approach is greatly reliant on the decisions made at different analytical and methodological steps, an evaluation of the outcomes seems necessary. A sensitivity analysis was applied to this study to examine the sensitivity of the model to changes in methods and data.

Acknowledgement

First and foremost, praises and thanks to the God, the Almighty, for His showers of blessings throughout my work to complete the research successfully. The writing of this dissertation has been one of the most significant academic challenges I have ever faced. Without support and guidance of the following people, this study would not have been completed.

I am inevitably and deeply indebted to my supervisors, Professor Pete Fisher and Professor Heiko Balzter, for their invaluable expertise and continuous support. I doubt I will ever be able to convey my appreciation fully to them. They bear a rare quality of supervision. Their precious comments, guidance, wisdom and patience improve this thesis immeasurably and without them this endeavour would not be possible.

My acknowledgement extended to Professor Colin Green and Dr Claire Jarvis (the committee of the thesis) for their advice during the viva. I would like also to thank Mr Peter Darling for reading my thesis and his valuable comments.

I would like to thank my friends, who motivated me with their scientific enthusiasm and provided me with mental support. Special thanks to my friends and colleagues at the University of Leicester and the Department of Geography; I will always remember the time we spent together. I am also very grateful to one of my best friends Firdos Almadani for her unconditional support and help in final preparation and submission of this thesis.

I acknowledge all data providers who were willing to share their data and documents with me, without their collaboration this research would not have been possible; The Environment Agency, Ordnance Survey, British Geological Survey, The Centre for Ecology & Hydrology, Casweb, The Office for National Statistics, Natural England, Forestry Commission, and Department for Environment, Food and Rural Affairs (Defra).

I thank my family, my parents, sister, brother, and in-laws who have always supported, encouraged, and believed in me and in all my endeavours. A special thanks to my dad and my mom in-law for their unsparing support and love.

Last but not least, I am grateful to my husband Mohsen and my son Amirabbaas for their incredible patience, support and understanding, and for helping me during the course of the study. Words cannot express how thankful I am to them. I truly thank Mohsen for sticking by my side, even when I was irritable and depressed.

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List of figures

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List of abbreviation

ACDR= Accommodation/eating services

AGE= Age

AGWR= Agricultural workers

ALC= Land productivity

ATT= Attractions

BBC= Bogardi, Birkmann, Cardona

BGS= British Geological Survey

BLD= Buildings and assets

CAR= Vehicle

CEH= Centre for Ecology and Hydrology

CEM= Comprehensive Emergency Management

CER= Communal establishment residents

CFMPs= Catchment Flood Management Plans

CL= Contaminated land

CMRC= Commercial services

CONS= Construction and Repair services

CRED= Centre for Research on the Epidemiology of Disasters

Defra= Department for Environment, Food and Rural Affairs

DEM= Digital Elevation Model

DFR= Farm livestock

DSS= Decision Support Systems

EcVI= Economic vulnerability index

EnVI= Environmental vulnerability index

EW= Equal weighting

FARM= Farm location

FEMA= Federal Emergency Management Agency

FLA= Felling license areas

FRST= Natural habitat

FRWR= Forestry workers

FVI= Flood Vulnerability Index

FWD= Flood-line Warning Direct

FZ= Flood zones

GHLT= General health

GIF= Geological indicators of flooding

GIS= Geographical Information Systems

GPS= Global Positioning System

GVA= Gross Value Added

HHSZ= Household size

HLTH= Health services

IDES= International Disaster Emergency Services

INCM= Income

INFR= Infrastructure

LCM= Land Cover Map

LFS= Landfill sites

LLTI= Limiting long term illness

LNPR= Lone parents

LPAs= Local planning authorities

LWL= House level

MEA= Millennium Ecosystem Assessment

MGR= Migrant

MNU= Manufacturing and production

MOHS= Household type

MOVE= Methods for the Improvement of Vulnerability Assessment in Europe

NFM= Natural Flood Management

NUTS= Nomenclature of Territorial Units for Statistics

OS= Ordnance Survey

PA= Biodiversity action areas

PAR= Pressure and Release

PhVI= Physical vulnerability index

PI= Pollution Incidents

POP= Population

PPS= Planning Policy Statement

PRB= Permeability

QUAL= Qualification

RESC= Central and local government

ROAD= Roads

RPA= Rural Payment Agency

RPBs= Regional planning bodies

RS= Remote sensing

RTL= Retails

SCHL= Schools

SEX= Sex

SoVI= Social vulnerability index

SPR= Sport and entertainment services

SPZ= Groundwater areas

STWY= Students away from home

SuDS= Sustainable Drainage Systems

SWF= Surface water

TNUR= Tenure

TRN= Train stations

UN/ISDR= United Nations International Strategy for Disaster Reduction

UN-EHS= United Nations University-Institute for Environment and Human Security

UNEP= Unemployment

WCDM= World Conference on Disaster Management

List of publication

- Royal Geographical Society Conference. Vulnerability Assessment to Flooding. London. 31 August- 2 September, 2011.
- Physical Geography Seminar Series. Vulnerability to Flooding: Framework and Indicators. University of Leicester, Leicester. 19 January, 2012.
- Festival of Postgraduate Research. Flood Vulnerability Assessment. University of Leicester, Leicester. 17 May, 2012.
- GIS Research UK Conference. Flood Vulnerability Assessment: Contributions from Bogardi/ Birkmann/ Cardona (BBC) Framework. Lancaster, U.K. 11-13 April, 2012.
- Royal Geographical Society (RGS-IBM) conference. GIS Contributions to Evaluating Socio-economic Indicators of Flood Vulnerability for England. Edinburgh, Scotland. 3 July 2012.
- East Midland Universities Annual Conference. Indicator Development for Flood Vulnerability Assessment. Nottingham, England. 5 July 2012.
- Centre for Landscape and Climate Research (CLCR) poster competition. Winner of the third prize: Flood Vulnerability. Department of Geography, University of Leicester, Leicester, 15 September, 2012.

1. Introduction

1.1. Problem description

Flooding is reported as the most common natural hazard, and has affected a greater number of people than any other natural disaster (Brivio, Colombo et al. 2002, Centre for Research on the Epidemiology of Disasters (CRED) 2011, Vlachos 2010, Green, Parker et al. 2000). Even in 2013 the number, extent, and global impacts of flood events have been extraordinary, and have accounted for almost 47% of global economic losses from natural disasters (Wake 2013). Over the last thirty years, a total of 3,119 floods have been reported worldwide; these floods have resulted in the deaths of more than 200,000 people and have affected more than 2.8 billion others (Jakibicka, Phalkey et al. 2010).

Floods are bodies of water from runoff, river, or tidal origin which rise to overflow onto normally dry land. Natural flood plains have been heavily transformed by human activities, especially since the industrial revolution in the 19th century (Turner, Clark et al. 1990), so that natural environment cannot absorb flood water easily any more. The transformation in the natural system on the one hand and reliance on the productive and regulatory role of flood plains on the other hand make human settlements more susceptible to the impacts of flooding, and it is therefore more likely that a natural hazard will turn into a social disaster.

In response to the great damage from flooding and societies' demand for improved flood disaster management throughout the world, a rethinking of functions and management practices is taking place. Comprehensive Emergency Management (CEM) is the profession and skill of applying science and technology to manage and deal with disasters that can inflict enormous amounts of damage on nations (Drabek, Hoetmer 1991, Committee on Planning for Catastrophe: National Research Council 2007).

In the field of disaster management, the term ‘vulnerability assessment’ is well known for its contributions towards reducing the impacts which disasters bring to communities. An ongoing scientific discussion on the coupled functions of human and biophysical systems of vulnerability (Berkes 2007, Adger 1999) has inspired the development of a variety of conceptual and analytical frameworks.

The objective of this work is to investigate the vulnerability of a community to the impacts of flooding by implementing the techniques and functions of Geographical Information Systems (GIS) on the basis of a holistic conceptual framework of vulnerability. However, applied research that focuses on the operationalization of such frameworks is rare and needs more investigation in terms of scale and the context dependency of the terms. Numerous studies exist which capture the social dimension of vulnerability (Adger 1999, Liverman 1990, Bohle 2001, Cutter, Finch 2008, Green 2004, Downing, Aerts et al. 2006) or its physical dimensions (Sanyal, Lu 2005, Sanyal, Lu 2004, Ip, Dohm et al. 2006, Sophiayati Yuhaniz, Vladimirova 2009, Gabor, Griffith 1979, Godschalk 1991, Pelling, Uitto 2001). On the other hand, several projects are solely concerned about specific issues such as climate change (Adger 1999, Penning-Rowsell, Peerbolte et al. 1992, Fussel 2007, Keogh, Apan et al. 2011). National indicators of vulnerability also exist, such as the Environmental Vulnerability Index (EVI) (Kaly, Pratt et al. 2004), which integrates a number of environmental and social factors. However, an applied approach targeted at a multi-dimensional study of vulnerability to flooding in England has not previously been carried out. This study therefore attempts to fulfil the objectives below:

- identification of an appropriate vulnerability framework
- development and evaluation of vulnerability indicators based on the chosen framework and research context
- identification of adequate analytical methods
- conducting a sub-regional analysis
- mapping multi-dimensional vulnerability.

1.2.Research challenges

A sub-regional approach is carried out in this research, which allows for detection of medium-scale patterns and underlying factors of vulnerability for a British county. However, a sub-regional approach is also very challenging as the author has to face many constraints (discussed in more detail in the thesis).

The quality of analysis is mainly dependent on the availability, accessibility, and, of course, quality of datasets. In the UK most data are available, but some are restricted to regional level. In addition, some data are held by organisations and therefore are limited by privacy, high access costs, or data inconsistency. Collection of some qualitative datasets is restricted to expert interviews which can provide a highly valuable source of information. However, some concerns hindered the involvement of experts in this work: (a) experts need to have both local and regional knowledge; (b) the experts need to be happy to give some time to this research; and (c) the time available for this work was limited.

Moreover, this approach attempts to simplify the complex term of vulnerability, which in turn requires some thought. Furthermore, indicators are important tools in terms of vulnerability assessment and mapping, and therefore the complex and interrelated process of indicator identification requires adherent quality criteria. Inevitably, indicator selection and the development of a composite indicator are based on a sequence of subjective decisions and judgements. Hence, it is of great importance to validate the outcomes of analysis. A thoughtful sensitivity test has to be developed to ensure the scientific soundness and quality of the results.

The conceptualization of a multi-dimensional and context/scale-dependent vulnerability is also challenging. A framework needs to be identified or modified that on the one hand can involve all the necessity components of vulnerability and on the other hand be understandable and practical.

Finally, the GIS-relevant issues are the main concerns of this work. The development of a method which is sufficient to overcome the problem of scale in the work is seen as the main challenge. In addition, the data inconsistency in terms of scale, date, geographical extent, and background are some of the other GIS-relevant problems dealt with in this work.

1.3. Research questions

In order to accomplish the overall research objectives, the following research questions are addressed in this thesis:

- Broad research question:

  How can vulnerability to flooding be captured and visualized by implementing Geographical Information Systems (GIS) techniques and functions in a British context?

- Specific research questions:

  1. How can the concepts of vulnerability and flood management be linked to each other?
  2. Which conceptual framework facilitates best the assessment of vulnerability?
  3. What are the indicators of vulnerability?
  4. How can GIS thinking and functions be implemented to overcome the technical issues in datasets?
  5. What is the best methodology to create a vulnerability index?
  6. How the quality of results can be evaluated?
  7. Is the developed approach transferable to other countries?

1.4. Thesis structure

The main body of the thesis is divided into six parts and is framed by an introduction of the topic at the beginning, and discussion, conclusion, and outlook at the end of the work. The arrangement of this thesis is as follows:

1. The Introduction deals with research problems, objectives, challenges, and questions.
2. The Literature review shows the research background and describes the main inspirations of the work: flooding, emergency management, vulnerability, conceptual frameworks, and terms related to vulnerability.
3. The Methodology is dedicated to the conceptualization of the present research. This chapter presents the topics of the study area; the selected conceptual

framework and modifications applied to it; GIS issues of land stratification, scale, unit, and data quality; indicator selection and development; methods of composite indicator development; and visualization.

4. Chapter 4 deals with flood vulnerability assessment in the context of arable land on the basis of the methods described in Chapter 3.
5. Chapter 5 presents the assessment of vulnerability of wildlife to flooding, using the methods introduced in the methodology chapter.
6. Chapter 6 is dedicated to the assessment of flood vulnerability in the context of urban and built-up lands, implementing the methods presented in Chapter 3.
7. The sensitivity chapter deals with the evaluation of the research outcomes.
8. Chapter 8 discusses the concepts and results of the work.
9. Chapter 9 offers the main conclusions of the thesis and refers back to the research questions introduced in Chapter 1. In addition, possibilities for future research are proposed.
10. The list of references used in this work is presented.
11. Appendix 1 shows the flood history of the East Riding of Yorkshire.
12. Appendix 2 presents the indicators fact sheets and maps.

2. Research background

2.1.Introduction

We hear about vulnerability frequently. Vulnerability is a word people use even when they do not have any idea about its scientific definition. Even researchers explain the concept in a way which is compatible with their objectives. Being susceptible to harm is the first phrase that comes to mind when one is explaining vulnerability. However, vulnerability has a much broader definition when it comes to emergency management and disaster risk reduction. In terms of flood management, vulnerability plays a vital role as it helps decision makers and policy managers to lessen the impact of floods and help people to cope with.

Geography is an important part of vulnerability analysis. The reason is the spatial distribution of socio-economic characteristics of people within a society. Geographical Information Systems (GIS) is a powerful tool for tempo-spatial analysis. GIS can be effectively utilised along with ancillary datasets to reveal the pattern of vulnerability within society. This outcome can be one of the most crucial and effective tools for decision makers.

The first part of this chapter talks about floods. The definition, types, sources, advantages, and disadvantages of floods are basics in this discussion. In addition, climate change will be introduced as a leading factor in the increase in disaster and specially flood risk. Furthermore, flood management strategies and trends both globally and locally (in the UK) will be discussed.

The second part addresses the cycle of emergency management. Its four phases are explained and the roles of GIS and remote sensing are highlighted.

The third part of this chapter discusses the notion of vulnerability. A table of definitions of this concept is developed. In addition, the origins, causes, factors, dimensions, frameworks, and methodologies used in this arena are presented. Terms such as ‘hazard’, ‘disaster’, ‘risk’, ‘coping capacity’, and ‘sustainability’, which are often associated with the term ‘vulnerability’, are also defined.

2.2. Flooding

The climate of an area is its average weather over a period of time, which might be a few months or a few years (Houghton 2009). Climate and global environmental change are familiar topics which we all hear about on the news. One of the main outcomes of global climate change is a rise in the quantity and severity of extreme events. Flood is one of the weather-related natural hazards, and has been highlighted in this research owing to its high impact on human settlements.

In this chapter, some basic backgrounds related to flooding are presented. Firstly, some flood definitions will be given which show the ways different scholars have looked at the phenomenon. Secondly, types of flooding will be introduced which are based on the causes of floods. Thirdly, a discourse on the advantages and disadvantages that floods create is put forward. Fourthly, figures and reports about global and UK flood trends are presented. Fifthly, climate change is discussed as one of the major issues related to flooding. Sixthly, flood management strategies are presented.

2.2.1. What is flooding?

Floods are the most frequent and devastating type of natural disaster (Centre for Research on the Epidemiology of Disasters - CRED 2011, IFRCRCS (International Federation of Red Cross and Red Crescent Societies) 1998, Bogardi, Damm et al. 2010). The underlying reason is the extent and excess of river valleys in the geographic areas where humans have been most interested in residing. Flood impacts on the settlements are increasing, owing to both increased severity of flooding and human-driven factors. In fact, there are many causal agents of flooding, which vary over time and geography: urbanisation, deforestation, land use change, flood plain development, more mobile populations, the increasing value of flood-affected properties, coastal erosion, changes in social environments, poor drainage, lack of knowledge and experience related to flooding, changing and straightening of the river beds, soil sealing, and climate change (Vlachos 2010, Vlachos 2010, Jakibicka, Phalkey et al. 2010, Penning-Rowsell, Peerbolte et al. 1992, Bogardi, Damm et al. 2010, Schmidt-

Thomé 2006, The Department for Communities and Local Government 2006). Floods are a component of the dynamic process of the hydrological cycle, although they have a variety of causes. Jakibicka et al. (2010) have defined rainfall, melting snow, glacial outbursts, and dam breaks as the leading causes. Floods have been largely understood to be related to rainfall pattern, climatological factors, terrain and topography, antecedent conditions, and stream networks; however, climatic shift, mega-ruptures, metabolism, socio-political context, trans-boundary dependencies, and the fast pace of technological development have portrayed a process of complexification for flooding (Vlachos 2010, Green, Parker et al. 2000, Jakibicka, Phalkey et al. 2010, The Department for Communities and Local Government 2006).

Various definitions of flooding have been proposed:

- A significant rise of water level in a stream, lake, reservoir or coastal region (Centre for Research on the Epidemiology of Disasters (CRED) 2011)
- Water accumulation that is not submerged (Jakibicka, Phalkey et al. 2010)
- The result of runoff where runoff depends on the intensity and areal extent of the precipitation (Green, Parker et al. 2000).
- Floods are high-water stages where water overflows its natural or artificial banks onto normally dry land (Schmidt-Thomé 2006).
- A flood is a body of water which rises to overflow land which is not normally submerged (Ward 1978).

In this work, however, 'flood' is defined as a body of water from runoff, river, or tidal origin which rises to overflow onto normally dry land.

Floods have some measurable characteristics, comprising depth, discharge (magnitude, volume), frequency (return period), duration, velocity, extent, and seasonality (Green, Parker et al. 2000). Despite all these facts, floods are only hazards and not disasters; they are threats to human life, infrastructure and other valuable resources. For some regions they are part of life and may even be seen as beneficial. However, there are complex and varied negative impacts of flooding on human settlements, such as death, injuries to physical and psychological health, damage to infrastructure and buildings, and losses to farmlands and crops (Eulisse 2010, Werritty, Houston et al. 2007).

"Floodplains are areas where either there are ecologically important wetlands, or there were such areas in the past, and are also areas that have competitive advantages for human settlement" (Green, Parker et al. 2000). On the other hand, flood plains are generally low-lying land, close to rivers and therefore in flood risk zones. And here comes the problem: human settlements on flood-prone land when flood hazard might turn into disaster. Runoff and drainage control systems are among the flood mitigation strategies that can be applied in these areas. Integrated flood risk management is a preliminary solution where understanding hazard, risk and vulnerability are the key factors.

2.2.2. Flood types

Floods can happen anywhere and anytime. They have been a great problem for societies since settlements have been located in low-lying flood plains. Other factors such as soil sealing and the changing, straightening and relocating of river beds also contribute to the severity of the issue. The type of flood is linked to the source of flooding. The main sources of flooding or flood types are:

1) River flooding: when the amount of water directed into the river bed exceeds its capacity and therefore water overflows to the adjacent land. In large and flat areas the flood level rises slowly, giving appropriate time for action and warning. But in steep and small catchments it is more likely that flash floods will happen, when there is a rapid rise in the water level with little time given for warning and emergency action.
2) Sea (or tidal) flooding: This type of flooding is the result of storm surge or high tides and can be more serious than river flooding. A number of factors can participate in tidal flooding, such as weather, wind, waves, topography, height of tides and flood defences.
3) Surface (or land) flooding: Surface water runoff is caused by intense rainfall, often in short duration, which cannot soak into the ground or flow into the

drainage system, or sometimes as a result of overwhelmed rivers and watercourses. This kind of flooding is usually difficult to predict and its severity is highly relevant to topography and the permeability of the ground.

4) Groundwater flooding: Groundwater is water below the surface of the ground, and this type of flooding happens when the water level rises above the surface elevation. Low-lying, permeable areas such as chalk or sandstone are more susceptible to this type of flooding. Groundwater flooding takes weeks or months to subside as the groundwater flow is much slower than that of surface water.
5) Sewer flooding: In urban areas, surface water and sewage are directed into the sewer system. When sewers become blocked or overwhelmed by heavy rainfall, land and property are highly at risk of flooding. This type of flood is usually polluted and is likely to contaminate river flows as well.
6) Reservoir flooding: Reservoirs contain high volumes of water above the surface elevation. Although the safety of dams is high and standard there is still a possibility of failure resulting in flooding.

Other sources of flooding have been mentioned by some authors: watercourses, snow melt, glacial outbursts, freeze up riverine, and mud floods (Jakibicka, Phalkey et al. 2010, The Department for Communities and Local Government 2006, Hyder Consulting (UK) Limited 2011, The Environment Agency 2011).

2.2.3. Flood costs and benefits

Flooding is an evitable event, so it is not reasonable merely to defend against it; we need to understand its rationales and impacts in order to manage it wisely by long-term integrated systems of institutions and people.

Assessing the impacts of flooding is a complex process. There has been a great amount of literature on the adverse aspects of flooding; however, there are positive perspectives as well (Green, Parker et al. 2000):

- It adds to soil fertility and productivity.
- It restores soil moisture.

- It is beneficial to ecosystems and human livelihoods.
- It adds to the spirit and bonding of the community.
- It provides financial gains to industries in the medium and long term,
- It increases industrial efficiency.
- It encourages the rethinking of designs for towns and buildings to make them more resilient to flooding.

There are various ways to classify the diverse aspects of flooding. One way is to group them into 'tangible' and 'intangible': tangible impacts are those which are measurable in monetary terms, such as damage to houses; intangible impacts are hard to estimate in monetary terms, and include damage to historical sites or people's mental health. A further way of dividing flood losses is to group them into 'direct' and 'indirect': direct losses such as death, and indirect like the loss of sales suffered by a factory because of flooding. The following are the main losses imposed by flooding (Green, Parker et al. 2000, Jakibicka, Phalkey et al. 2010, Werritty, Houston et al. 2007, Werritty, Houston et al. 2007, Environment Agency 2009, East Riding of Yorkshire Council 2010):

- damage to vital energy, water, communication, and transport infrastructure
- damage to schools and hospitals
- death
- physical and psychological health injuries
- diverse effects on children, elderly people, and domestic animals
- damage to cropland (which greatly depends on the time of year)
- losses to human settlements.

2.2.4. Trends in flooding

Flooding is reported to be the most common natural hazard and has affected a greater number of people than all other natural disasters (Brivio, Colombo et al. 2002, Centre for Research on the Epidemiology of Disasters (CRED) 2011, Vlachos 2010, Green, Parker et al. 2000). Even in 2013, the number, extent, and global impacts of flood events have been extraordinary and have formed almost 47% of global economic losses from natural disasters (Wake 2013). Over the last thirty years, a total of 3,119 floods worldwide have been reported in EM-DAT; these floods have resulted in the deaths of more than 200,000 people and affected more than 2.8 billion others (Jakibicka, Phalkey et al. 2010).

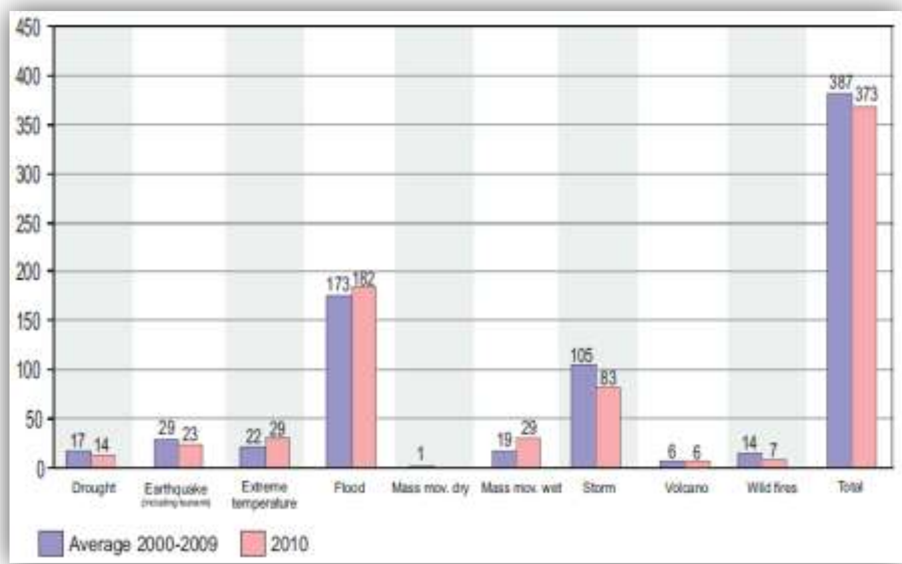

Figure 2-1: Natural disaster occurrence by disaster type (2000-2010)
Source: EM-DAT: The OFDA/CRED International Disaster Database

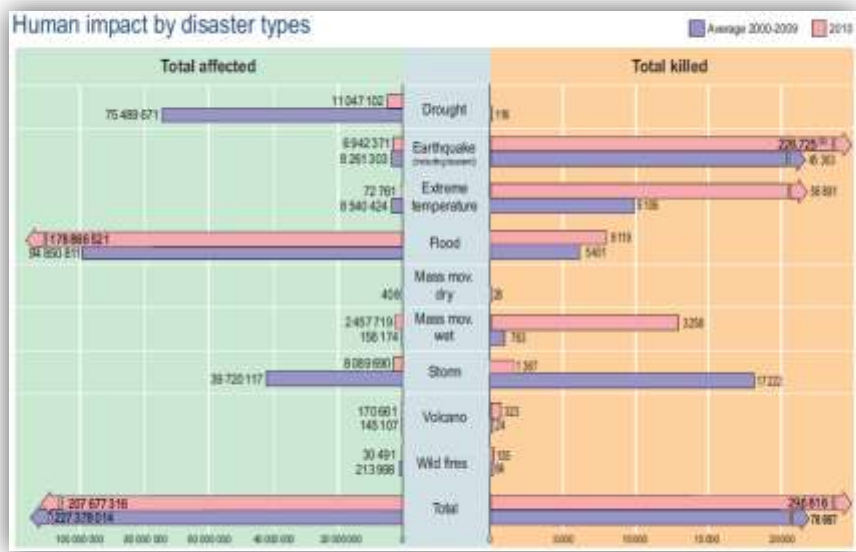

Figure 2-2: Human impact by disaster type (2000-2010)
Source: EM-DAT: The OFDA/CRED International Disaster Database

Nearly half of the natural disasters reported in 2010 were floods (Figure 2-1). In addition, flooding has the most impact on human life (people killed or affected) of all natural disasters, as shown in Figure 2-2. Furthermore, the occurrence (Figure 2-1) and human impact (Figure 2-2) of floods have been increasing.

2.2.5. Flooding in the UK

Flood is the major natural hazard in the UK, with a current annual estimated damage cost of £1.1 billion (The Parliamentary Office of Science and Technology 2011, Tunstall, Johnson et al. 2004). As Table 2-1 and Table 2-2 report, flooding has been the principal cause of human and economic damage in the UK in recent decades.

Table 2-1: Top 10 Natural Disasters in the United Kingdom
Source: EM-DAT: The OFDA/CRED International Disaster Database

Disaster	Date	Affected population
Flood	20/07/2007	340000
Storm	24/12/1998	250000
Flood	25/06/2007	30000
Storm	28/10/2000	19504
Storm	27/10/1996	12000
Earthquake	28/04/2007	4501
Flood	19/11/2009	3900
Storm	01/01/1998	3000
Storm	07/01/2005	3000
Flood	06/09/2008	3000

Table 2-2: Top 10 Natural Disasters in the United Kingdom
Source: EM-DAT: The OFDA/CRED International Disaster Database

Disaster	Date	Damage (000 US$)
Flood	11/10/2000	5900000
Flood	25/06/2007	4000000
Flood	20/07/2007	4000000
Storm	25/01/1990	3400000
Storm	15/10/1987	1565000
Storm	28/10/2000	1500000
Storm	18/01/2007	1200000
Storm	25/02/1990	900000
Storm	05/01/1991	900000
Storm	24/10/1998	665400

Climate change projection indicates that there is a high possibility of an increase in rainfall in winter and a decrease in summer, which means an increased risk of flooding. There are maps of flood zones (also known as flood plains) for England which could be affected by flooding from river or sea. These maps are based on topography, flow information, sea level and wave data, historical data, digital terrain models, and LiDAR technology (The Environment Agency 2011).

2.2.6. Climate change

Scientific evidence and research show that climate change is transforming the landscape through global warming, a rise in sea level, higher precipitation and a reduction in biodiversity (Green, Parker et al. 2000, Keogh, Apan et al. 2011, Houghton 2009, The Department for Communities and Local Government 2006, The Department for Communities and Local Government 2006, The Department for Communities and Local Government 2006, East Riding of Yorkshire Council 2011b, East Riding of Yorkshire Council 2011b). The last 50 years have been the warmest in the northern hemisphere in the last 1300 years (Houghton 2009). Climate change projections anticipate wetter winter periods and warmer summers, and more frequent short-duration high-intensity rainfall, which can cause a higher risk level for inland river flooding as it is directly linked to the amount of precipitation (Houghton 2009, Schmidt-Thomé 2006, The Department for Communities and Local Government 2006, East Riding of Yorkshire Council 2010, The Parliamentary Office of Science and Technology 2011, East Riding of Yorkshire Council 2011b, EEA 2008). The overall evidence shows that there is a higher risk of flooding as the frequency, intensity and duration of precipitation are increasing because of climate change (The Department for Communities and Local Government 2006).

To evaluate the vulnerability to climate change in the UK and to plan the right strategies, the government has launched the UK Climate Impact Programme (UKCIP). In the line of this centre other research and action have taken place such as Planning Policy Statement 25 (PPS25) which "ensures that flood risk is taken into account at all stages in the planning process to avoid inappropriate development in areas at risk of flooding, and to direct development away from areas at highest risk. Where new development is, exceptionally, necessary in such areas, policy aims to make it safe without increasing flood risk elsewhere and where possible, reducing flood risk overall" (The Department for Communities and Local Government 2006).

Climate change is inevitable and therefore we had better plan for it. The latest UK climate projection claims that by the 2018 "there could be around three times as many days in winter with heavy rainfall (defined as more than 25mm in a day). It is plausible that the amount of rain in extreme storms (with a 1 in 5 annual chance, or rarer) could increase locally by 40%" (East Riding of Yorkshire Council 2011b).

In addition to the direct impacts of climate change on flood risk, there are indirect impacts that should be considered in flood risk management, such as changes in cultivation, crop type, and land use which affect flood runoff. The main issues related to climate change are flooding, coastal erosion, groundwater and mine-water, biodiversity, business and economy, and health and welfare. The most appropriate flood management strategy is an integrated approach to land use, water resources, transport, biodiversity, and recreation which takes into account the effects of climate change and also attempts to slow climate change and alleviate it (Green, Parker et al.

2000, The Department for Communities and Local Government 2006). The Centre for Landscape and Climate Research (CLCR) is one of the research centres launched recently within the University of Leicester directed by Prof. Heiko Balzter (CLCR 2012). It aims at finding international and interdisciplinary solutions to problems related to climate change.

2.2.7. Flood management

Flooding is part of the natural process and it is not financially or logically beneficial to protect all properties against it; we need to prepare for it. In research by Keogh et al. (2011) for Queensland, Australia, it was revealed that connections between and within social and institutional bodies play a vital role in the community's coping. Preparing staff adequately for extreme events, keeping people and staff informed regularly, providing appropriate temporary accommodation for elderly people and domestic animals, and testing the warning systems are other factors that can boost adaptation (Keogh, Apan et al. 2011).

The logical approach to flood management starts by understanding the problem. Identifying available options is the next step which involves the process of decision making. Decision making is complex and our knowledge is limited; therefore, cost-benefit and multi-criteria analyses are tools that can help us. Finally, the best available option needs to be selected; this option will be appropriate to local conditions with regards to public outlook, maintainable, and adaptive (Green, Parker et al. 2000).

Four generations of flood management have been identified by Green et al. (2000):

1) Indigenous flood adaptation

   Settlements in flood-prone areas have developed some indigenous methods to protect against flooding, such as building houses on stilts above the anticipated flood level. These are effective for local, small-scale areas; however, experience shows they fail with modernization.

2) Flood control and defence

This generation of flood management dates back to the late nineteenth century and is known as the engineering approach; the rationale was to train rivers to stop them entering human communities. Strategies include flood control dams, embankments, flood defences, and channels. However, there are problems because this scheme may cause worse flooding downstream, create further flood plains, and damage the environment, and are likely to fail.

3) Non-structural approaches

   The third wave was based on keeping people away from flood risk areas. Flood-proofed buildings, insurance, and land use planning are some of the strategies proposed at this stage. Unfortunately, there was not sufficient knowledge and awareness of the difficulties in working successfully with this approach.

4) Holistic approach

   Finally, flood mitigation has been replaced by flood control in terms of "coping with floods". Flood hazard management and flood risk management are the strategies introduced. Holistic catchment and coastal management, involvement of local communities, land use planning, response capacity improvement, and enhancement of flood disaster resilience are approaches taken at this level.

Increasing vulnerability, complexity, and uncertainty call for intergovernmental co-operation, in which three premises should be involved: first, the expansion of our knowledge in order to understand and forecast climate change and biophysical conditions, develop new techniques, improve the use of remote sensing data, etc.; second, vigilance in monitoring and assessing any human or natural changes; third, learning how to live in a dynamic system of humanity, biosphere and climate (Vlachos 2010).

For constructive flood management it is of vital importance to learn how to do better; success and failure are both lessons. There are gaps between design/construction and operation/maintenance which need attention in an integrated management system. With both the previous points in mind, designing a dynamic risk management system through coordinated work is the best approach. On this basis, there are some schemes run by the Department for Environment, Food and Rural Affairs (Defra) and the Environment Agency:

- Natural Flood Management (NFM) aims to minimise the amount of water reaching downstream and/or delay the peak of the flood in order to give more time for preparation. Some approaches taken in NFM plans are as follows (The Parliamentary Office of Science and Technology 2011):
    1. using ponds, ditches, land, or channels for water storage
    2. increasing soil infiltration
    3. slowing the flow of water
    4. reducing water flow connectivity
- Sustainable Drainage Systems (SuDS) apply measures for sustainable drainage, including good housekeeping (e.g. reducing the potential for pollutants), source control (e.g. permeable surfaces), site control (e.g. small ponds), and regional control (use of landscape to collect run-off) (Hyder Consulting (UK) Limited 2011)
- Catchment Flood Management Plans (CFMPs) are a planning tool through which the agency aims to work in partnership with other key decision-makers within a river catchment to explore and define long-term sustainable policies for flood risk management. CFMPs are a learning process to support an integrated approach to land use planning and management (East Riding of Yorkshire Council 2010).
- Planning Policy Statement (PPS) 25 has been launched to manage future developments: "PPS25 requires local planning authorities to review the variation in flood risk across their jurisdiction, and to steer development away from areas at risk. Where this cannot be achieved and development is to be permitted in areas that may be subject to some degree of flood risk, PPS25 requires the Council to adopt a sequential approach that will minimise the risk of flooding that is posed to vulnerable land use. The Council must also demonstrate that there are sustainable mitigation solutions available that will ensure that the risk to property and life is minimised (throughout the lifetime

of the development) should flooding occur" (The Department for Communities and Local Government 2006).

- Building Practice Grants are a series of grants to make existing and new building flood-resistant (i.e. by dry-proofing) and flood-resilient (i.e. by wet-proofing) (East Riding of Yorkshire Council 2010).
- Flood-line Warning Direct (FWD) is a service provided by the Environment Agency and the Met Office to provide early flood warnings to the people in the areas at risk of flooding, by telephone, mobile, SMS, email, fax, or paper (Environment Agency 2009).

The following activities are promoted to control and manage flood risk in England (when there are adequate economic and environmental reasons) (The Environment Agency 2011):

1. keeping and maintaining barriers and pumping stations
2. clearing ivers
3. controlling aquatic river weeds
4. managing river embankments (e.g. trees, grass)
5. repairing and maintaining flood defences
6. maintaining river/ditch channels and banks
7. consultation on new developments
8. providing flood warnings.

There are a number of obstacles in the way of integrated, sustainable flood risk management (Green, Parker et al. 2000, The Department for Communities and Local Government 2006, The Parliamentary Office of Science and Technology 2011):

1. limited resource and investment
2. the absence of a definite list of flood zones, as there are a number of factors linked to the extent of floods, like weather, rainfall pattern, and topography
3. institutional limitations
4. professional roles
5. the problem of importing solutions from outside the local system
6. lack of knowledge and research

7. lack of effective public involvement
8. corruption

Department for Environment Food and Rural Affairs (Defra)	Defra has national policy responsibility for flood and coastal erosion risk management and provides funding through grants to the Environment Agency.
Environment Agency	The Environment Agency is the principal flood risk management authority in England and Wales. It is responsible for forecasting and mapping flood risk, providing warnings, advising on development in the floodplain, building and keeping defences in good order and taking part in emergency planning and response. The Environment Agency manages central government grants for capital projects carried out by local authorities and internal drainage boards.
Local authorities	Local authorities lead in reducing risks from development in the floodplain and management of drainage and small watercourses. They will play an increasingly important role in helping to manage the risks associated with surface water flooding. They also take the lead in emergency planning for flooding and handling the recovery of areas that have been effected by flooding.
Internal drainage boards (IDBs)	IDBs are independent bodies responsible for land drainage in areas of special drainage need. These are mostly low-lying areas that need active management of water levels.
Regional flood defence committees (RFDCs)	RFDCs have a duty to take an interest in all flood matters in their area. They are responsible for decisions about the annual programmes of improvement and maintenance work carried out by the Environment Agency.
Local resilience forums (LRFs)	These are the local planning forums for all emergencies, including flooding. They bring together the emergency services, Environment Agency, NHS and other bodies like water and energy companies. Together they plan for prevention, control and reducing the impact of floods on the public.
Insurance industry	The Association of British Insurers (ABI) and its members is vital in providing cover and handling claims for damages caused by a flood. Under an agreement with the Government, they have committed to continue insurance coverage for most properties, even some at significant risk, in return for action by government to identify and manage risks.
National Flood Forum	A registered charity providing advice to those at risk and campaigning for better protection from flooding.

Figure 2-3: Organisations responsible for flood management in England, Source: SFRA, 2010

In England there are organisations and government bodies that have predefined responsibilities for flood risk management, as listed in Figure 2-3. The highest level of flood management responsibility, which is at national level, relates to Defra (Department for Environment, Food and Rural Affairs). The Environment Agency takes the second level, where it is responsible for prediction and mapping of flood risk, warning systems, flood plain developments, flood defences, and emergency planning and responses. Local authorities stand on the third level and are in charge of reducing risk from development in the flood plain and the management of drainage and small watercourses. Other organisations responsible in flood management are internal drainage boards, regional flood defence committees, local resilience forums, insurers, and the national flood forum.

The first step in flood risk management is the delineation of flood plains, areas which are prone to flooding with a certain frequency, by applying information on past flood event locations, terrain data, and discharge patterns (Schmidt-Thomé 2006). However, caution should be taken as there is no definite boundary for flood zones; floods are mostly linked to a combination of weather, rainfall pattern, and topography (The Department for Communities and Local Government 2006).

Integrated flood management is the policy adapted by DEFRA and the Environment Agency for flood management. Regional planning bodies (RPBs) and local planning authorities (LPAs) are asked to prepare and apply strategies to insure sustainable development through reducing and managing risk (East Riding of Yorkshire Council 2010). Under the light of this policy, government investment is the key factor. Grants can be spent on maintaining flood defences, running new strategies such as Catchment Flood Management Plans (CFMPs) (for more information see (East Riding of Yorkshire Council 2010) and Sustainable Drainage Systems (SuDS) (for more information see (Hyder Consulting (UK) Limited 2011), and research for better understanding of flood risk management. In addition, on-time warning systems are important for enabling the emergency services and the public to prepare. The National Flood Forecasting Centre is a new service from the Environment Agency and the Met Office which provides a better monitoring and predicting system for flood events. Lastly, land use management is the golden rule for sustainable flood management (The Department for Communities and Local Government 2006, Environment Agency 2009, The Parliamentary Office of Science and Technology 2011). Natural Flood Management (NFM) and Planning Policy Statement (PPS) 25 are two strategies for better land use management in flood-prone areas in England.

2.2.8. Intermediate conclusion

Floods are the most devastating weather-related natural hazard worldwide. In this work, however, a flood is defined as a body of water from runoff, river, or tidal origin which rises to overflow onto normally dry land. Floods can be characterised by their depth, discharge, frequency, duration, velocity, and extent. Despite the general perception of flooding as a purely disadvantageous event, it has some benefits to the environment, community, and society (please refer to section 2-2-3).

According to global reports, climate change has caused a rise in the number and severity of extreme events and especially floods. It is the same in the context of the UK, where flooding has imposed the highest human and economic lost.

As a result of the issues of flooding that have been discussed, societies have been attempting to manage floods. The last findings show that we need to cope with floods. Flood hazard management and flood risk management are the strategies introduced. Holistic catchment and coastal management, involvement of local communities, land use planning, response capacity improvement, and enhancement of flood disaster resilience are approaches taken at this level.

Integrated flood risk management is a preliminary solution where understanding of hazard, risk and vulnerability is the key factor. The problems that flooding causes for settlements are increasing as vulnerability to flooding is growing because of the severity of flooding and because of human-driven factors. In the UK, Defra and the Environment Agency are the leading organisations for flood management. The strategies most recently introduced are Natural Flood Management (The Parliamentary Office of Science and Technology 2011) and PPS25 (The Department for Communities and Local Government 2006).

From the point of view of integrated flood management, vulnerability assessment is an important preliminary process as it will reveal the pattern of ecological, physical, social, and economic vulnerabilities within the community. The results of such research can greatly help local decision makers to make better plans for future floods. However, it is important that vulnerability is part of a broader context of risk management, which in turn is one of the activities designed for emergency management. In the next two chapters the principles of emergency management and the concept of vulnerability will be presented.

2.3.Emergency management

The global risk from natural hazards is increasing, as Figure 2-4 shows (Centre for Research on the Epidemiology of Disasters (CRED) 2011, Keogh, Apan et al. 2011). There was a dramatic increase in the number of disasters (the black line on the graph) and the number of affected people (the blue line) in the period from 1900 to 2010. However, thanks to technical improvements and mitigation, rescue, and preparedness strategies, the number of people killed has decreased.

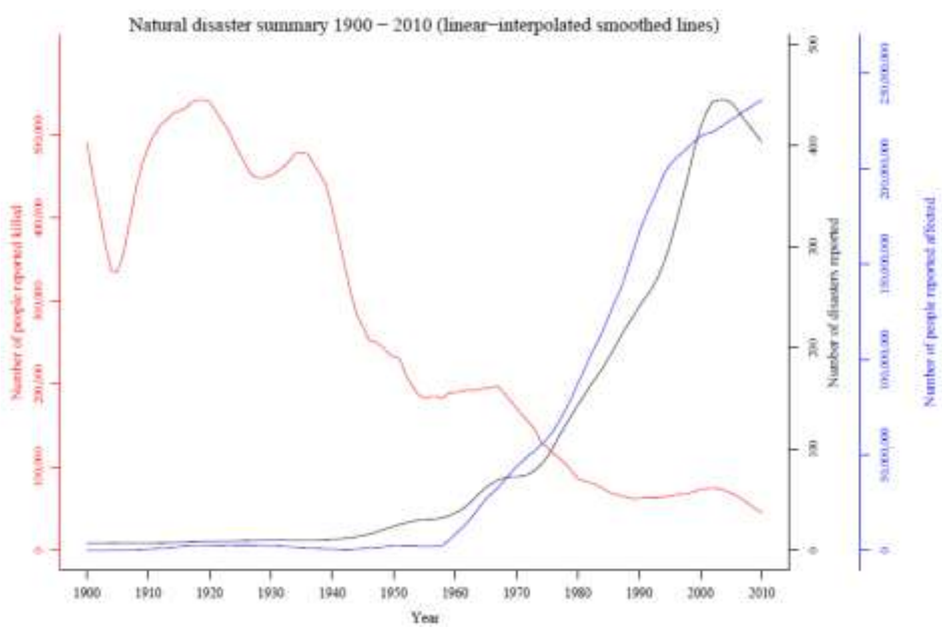

Figure 2-4: Natural disaster summary (1900-2010)
Source: (Centre for Research on the Epidemiology of Disasters - CRED 2009)

The fact is, the reports on emergency events and their impacts on human life show a positive rate, and organisations all over the world have therefore made a great effort to move toward a more stable, steady situation if an extreme event should occur; FEMA (Federal Emergency Management Agency), UNISDR (The United Nations International Strategy for Disaster Reduction), CRED (Centre for Research on the

Epidemiology of Disasters - CRED 2009), IDES (International Disaster Emergency Services), and WCDM (World Conference on Disaster Management) are examples of these organisations.

In this chapter, comprehensive emergency management (CEM) is discussed. Geographical Information Systems (GIS) and remote sensing (RS) are introduced as two tools effectively used in this arena, and their contributions to CEM and effective disaster risk reduction are discussed.

2.3.1. Disaster

The way we look at a concept explains the way it is defined, and the solutions we may think about (Weichselgartner 2001). "Disasters are a result of the complex interaction between a potentially damaging physical event (e.g. floods, droughts, fire, earthquakes and storms) and the vulnerability of a society, its infrastructure, economy and environment, which are determined by human behaviour" (Birkmann 2006c).

Disasters have been a threat to nations, both economically and socially, and their economic impact is both local and global (Cutter 2003). Societies have attempted to reduce the extent of the losses inflicted by disasters with pre- and post-disaster activities, because disasters are large, rapid incidents which can affect many people. Their result and occurrence is uncertain and difficult to predict. They are rare, dynamic events, and their benefits, losses, and risks are difficult to assess (Committee on Planning for Catastrophe: National Research Council 2007, Cutter 2003).

2.3.2. Comprehensive Emergency Management (CEM)

Comprehensive Emergency Management (CEM), also named emergency response cycle or emergency management cycle (Drabek, Hoetmer 1991, Committee on Planning for Catastrophe: National Research Council 2007, Cutter 2003), demonstrates four phases in terms of pre- and post-disaster event activities, as shown in Figure 2-5.

New approaches to CEM apply multi-dimensional methods to cover all four phases throughout the temporal and spatial dimension of the disaster events; CEM as the profession and skills of applying science and technology to manage and deal with disasters that can inflict enormous amounts of damage on nations (Drabek, Hoetmer 1991, Committee on Planning for Catastrophe: National Research Council 2007).

Figure 2-5: Comprehensive Emergency Management (CEM)

Preparedness is about getting ready before a disaster happens. It covers all the activities that facilitate the operational capabilities, like public and staff training, data acquisition, developing information and skills, and identifying the requirements. This phase helps to improve the efficiency and speed in the next phases, and even modelling the scenario of a disaster can provide a prior experience. Preparing the data sets and information all within one frame and also sharing them with all the organisations involved would make the preparedness phase much more productive.

The response and relief phase of CEM involves actions before, during and immediately after a disaster, when the main activities involve rescuing people in danger, restraining further destruction, and providing first aid. The rapid acquisition of data (including images) on the event and its geo-spatial dimension are critical in order to provide maps and reports for decision makers.

The recovery phase involves short-term and long-term activities that return living conditions to their previous, normal level. This phase covers activities from food provision and sheltering (short-term) to reconstructing buildings (long-term). Geo-spatial data such as the location of hospitals, suitable places for temporary shelter, and provision of basic services and essential needs are important components for helping the decision makers to guide the recovery process. In addition, archiving the geo-spatial data in this phase can be very helpful in the preparedness and mitigation phases as well.

Mitigation is a long-term process that attempts to reduce the degree of long-term risk to society from hazards, with activities such as lessening vulnerability, developing risk maps and analysing them, identifying hazards, and introducing solutions to reduce the impact of forthcoming disasters to human life. Simulation models of disasters, comparing multiple alternatives for mitigation plans and visualising the plans are some of the geo-spatial activities in this phase (Committee on Planning for Catastrophe: National Research Council 2007, Cova 1999).

The mitigation phase is the one most cited by scientists as the main platform for disaster risk reduction activities as it focuses on the underlying factors of disaster scenarios. Weichselgartner (2001) suggested that the mitigation of natural hazards should concentrate on the human-related aspect rather than the hazard because we have no control over the physical part of a hazard. In addition, he stated that a proactive approach (rather than reactive), along with constantly modified policies and programmes which aim at the internal structure rather than the external sources, can significantly improve the mitigation phase.

Within the domain of mitigation activities, vulnerability is one of the most operative actions where it utilizes the geo-spatial data and analysis to develop a conceptual framework of all kinds of disasters in order to assess the resilience and predicted losses of the society affected. Therefore, a great deal of literature has marked it, attempting to develop up-to-date and more accurate methods.

2.3.3. Geographical Information Systems (GIS) and CEM

"Geographic information systems are a special class of information systems that keep track not only of events, activities, and things, but also of where these events, activities, and things happened or exist" (Longley, Goodchild et al. 2011). Spatial aspect of analysis is critical in every emergency event, where GIS has the potential to integrate spatial Decision Support Systems (DSS) with geo-spatial information; GIS creates rich databases and adds the spatial analysis. In this research, GIS has been cited in its broadest meaning, which involves Geographical Information (GI) methods, techniques, and analysis, and technologies like the Global Positioning System (GPS) and remote sensing.

GIS is a powerful tool that should be used in every phase of comprehensive emergency management (CEM) as it can dramatically improve the efficiency of CEM activities. Geospatial data along with geospatial technologies can be effectively utilised if embedded in the right human system (Committee on Planning for Catastrophe: National Research Council 2007).

The general roles of GIS in emergency management are: firstly, collecting spatial data and integrating them within the systems; secondly, Interoperability, dynamic monitoring of human and physical processes; thirdly, applying the concepts of GI, uncertainty, scale, and spatial analysis to the system, to the benefit of decision support systems (DSS) (Cutter 2003).

In the preparedness and response phase (the first step of CEM), the potential of GIS can be clearly seen in its accurate answers to urgent spatial queries. The fundamental operation of GIS is the integration and diffusion of spatial information. Navigation, real-time monitoring and warning systems, evacuation and automated mapping, and hazard modelling are among uses of GIS in preparedness and response activities (Cova 1999). Sea Lake and Overland Surges from Hurricanes (SLOSH) (hazard simulation modelling for hurricanes and storms) (Griffith 1986), and Computer Aided Management of Emergency Operations (CAMEO) (Cartwright 1990) are examples of the application of GIS in hazard modelling.

Recovery activities take place when recurrence prevention, returning life to normal, improving the situation, rebuilding and public training are the main focuses. Coordinating recovery activities, navigating, and damage assessment are examples of GIS applications in this phase (Cova 1999). For instance, GPS, coupled with GIS and remote sensing data, has been employed to assist in assembling quick damage estimates (Ramsey, Hodgson et al. 2001). In long-term mitigation planning, the role of GIS is in hazard, vulnerability, and risk mapping. Hazard analysis uses the geo-spatial data on the physical aspect of a disaster (human vulnerability is implicit) while vulnerability emphasises the human environment. To sum up, risk maps integrate both natural hazards and human vulnerability in one concept. However, Cova (1999) put forward the fact that in some extreme events such as hurricanes there is little that can be done about the physical part of the hazard and it is necessary to focus on the mitigation of human vulnerability.

2.3.4. Remote sensing and CEM

Remote Sensing (RS) is a valuable source of spatial information through the capability to quantify the geographical phenomenon. Various types of data and image processing have been utilised in order to map, monitor and even foresee natural hazards (Joyce, Belliss et al. 2009, Gillespie, Chu et al. 2007). In addition, RS has been used to reconstruct the history of the land surface to predict hazards (Tralli, Blom et al. 2005).

The role of RS data in the phases of CEM, from preparedness and response to recovery and mitigation, is clear from the context above. RS imagery has the advantage of near-real-time imagery, which is of vital importance in the preparedness and response phase of disaster monitoring. Furthermore, RS and GIS techniques can be used to predict extreme events and support early warning systems (Sharif, Hashmi 2006).

There are several studies on the utilisation of passive sensors (MODIS, QuickBird, SPOT, Landsat, AVHRR, and IKONOS) in mapping inundated areas and in damage assessment (Sanyal, Lu 2005, Sanyal, Lu 2004, Ip, Dohm et al. 2006, Sophiayati Yuhaniz, Vladimirova 2009, Al-Khudhairy, Caravaggi et al. 2005, Sandholt, Nyborg et al. 2003), although there are considerable limitations to the application of passive sensors, such as atmospheric interference and the vegetation canopy, that cause gaps and distortions in data. However, Sandholt et al. (2003) showed that high temporal resolution sometimes (such as AVHRR) can overcome the problem of cloud cover as there is a greater chance of achieving a cloud-free image.

Ip et al. (2006) developed a rapid-response flood monitoring system, using Hyperion imagery. The on-board processing algorithm takes advantage of three spectral bands and a base image in order to map the flooded area in detail. Moreover, Sophiayati Yuhaniz and Vladimirova (2009) introduced an on-board automatic change detection algorithm. This method is employed aboard small satellites and acts upon an image tile (rather than an ordinary image pixel). Also, this process benefits from a fuzzy inference engine, which acquires spectral information and cloud cover as input. They concluded with a highly accurate and more robust map.

Conversely, active sensors are more powerful in flooding applications as they disregard weather conditions and canopy cover (Brivio, Colombo et al. 2002, Sanyal, Lu 2005, Joyce, Belliss et al. 2009, Gillespie, Chu et al. 2007). However, large pixel size, classification accuracy and revisit time are limitations on active sensors (Brivio, Colombo et al. 2002, Sanyal, Lu 2004).

Brivio et al. (2002) used ERS-1 SAR images integrated with GIS techniques to map the flooded areas just a few days after the occurrence of a disaster. This process surmounts the problem of low temporal resolution, especially in damage assessment analysis. Efforts have been made to improve change detection algorithms which are the basis of mapping and monitoring flood propagation. For instance, Amici et al. (2004) proved that the neuro-fuzzy technique for SAR classification is accurate, and even the potential flooded areas can be predicted. SAR images have been widely used along with spectral information and DEM to assess the damage and the depth of inundation, and to map the extent of flooding (Sanyal, Lu 2005, Sanyal, Lu 2004, Joyce, Belliss et al. 2009, Gillespie, Chu et al. 2007). Advances in satellites, sensors, ancillary information and data distribution can make a great contribution to progress in CEM planning.

2.3.5. Intermediate conclusion

The global risk from natural hazards is increasing, as the reports by the Centre for Research on the Epidemiology of Disasters (CRED) show (

ure 2-4). Disasters are best defined as the interaction between potentially damaging hazardous events and vulnerable situations in the society affected (Birkmann 2006c). Comprehensive Emergency Management (CEM) is a way to deal with disasters. It comprises four pre- and post-disaster activities: mitigation, preparedness, response, and recovery. Mitigation has been seen as the most important phase of the cycle for decreasing the effects of a disaster. Mitigation covers strategies such as risk and vulnerability assessments. Vulnerability assessment is the aim of this work and will be explained in depth in the next chapter.

Geographical Information Systems (GIS) are an operational tool in emergency management because geography is a critical aspect of emergency events. GIS has the potential to integrate spatial Decision Support Systems (DSS) with geo-spatial information to create rich databases.

In addition, remote sensing (RS) plays a vital role in collecting spatial data on various hazardous events. In the case of flooding, numbers of passive or active sensors have been utilised to support data acquisition for early warning systems, inundated area mapping, damage assessment, and determining the depth and extent of flooding.

To sum up, the rising global trend in disasters has been the inspiration for this work. Effectively enhance the outcome of emergency management leads the work to vulnerability analysis. GIS and some RS ancillary datasets are the tools which this work will employ to reveal the pattern of vulnerability of society to flooding as the hazard case. The definition, frameworks, factors, and related terms of vulnerability are the subject of the next section.

2.4. Vulnerability

In recent years, more attention has been paid to the concept of vulnerability. Although the concept of vulnerability was first perceived as uncertain, ill-defined and wide, it has shed a light on clarification in the context on risk, hazard and disaster management and separation of the concepts. Historically people would think of an act of God, luck, or fortune when considering the issue we call risk today (Weichselgartner 2001, Weichselgartner, Berten 2000). Vulnerability is an internal component of risk which helps us in disaster management. It explains the characteristics of a system feasible to the damage of an event (hazard) (Cardona 2003, Blaikie, Cannon et al. 2004, Villagrán de Léon, J. C. 2006).

Everybody is vulnerable to some degree (Blaikie, Cannon et al. 2004, Anderson 1995). However, the task is to determine who and what are vulnerable, to what and where. These facts help us to make decisions on the actions required in risk management. Fundamentally, we assess vulnerability levels in the system to assist in reducing the effects of disasters. Vulnerability is a relational term (i.e. vulnerability to, from, of, because) which should be rethought pro-actively in a compound, interactive, and complex system, both qualitatively and quantitatively (Weichselgartner 2001, Turner, Kasperson et al. 2003, Green, Penning-Rowsell 2007). CAPRA (Comprehensive Approach for Probabilistic Risk Assessment) is an example of such an attempt (Cardona, Ordaz Schroder et al. 2010).

In the discourse of vulnerability, language is important. Individuals use language purposefully to persuade others on an action. They make use of language to define a framework of vulnerability which gives a specific insight into the problem. The way a problem is defined determines where we look for solutions and the tools we design for action (Weichselgartner 2001, Green, Penning-Rowsell 2007). Therefore, it is important to understand the nature and purpose of language when we discuss vulnerability.

2.4.1. Definitions of vulnerability

"Vulnerability is the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards." (UN/ISDR, 2004)

Green (2004) states that we can discuss the concept of vulnerability without sharing the same definition. However, to assess vulnerability we need to have a clear understanding of the concept. Vulnerability is a multifaceted and relational term; some scientists have even stated that it cannot be defined without specification of the hazard, system, interactive environment, and temporal dimension (Brooks 2003, Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) 2008). Any definition of vulnerability promotes an understanding of the world and gives us an insight into the nature of the problem. Stakeholders have defined vulnerability from diverse points of view, compatible with the goals and objectives they follow (Green, Penning-Rowsell 2007, Birkmann 2006b).

It is not possible and more importantly not beneficial to unify definitions of the term 'vulnerability', for the reason that there are concepts, natures, and purposes embedded within each definition. However, it is important to state what one means in a research study which includes vulnerability. The reason is the variety of choices which need to be taken: methods and factors which will be used and tools which will be thought of for vulnerability reduction. For the purpose of this research the definition given above has been chosen; however, Table 2-3 shows some extra definitions of vulnerability.

Table 2-3: List of vulnerability definitions proposed by scholars

Definitions of Vulnerability
(Gabor, Griffith 1979) Vulnerability refers to the threat to which a community is exposed taking into account not only the properties of the chemical agents involved but also the ecological situation of the communities and the general state of emergency preparedness at any given point in time. Vulnerability is the risk context.
(Liverman 1990) Distinguishes between vulnerability as a bio-physical condition and vulnerability as defined by political, social and economic conditions of society. She argues for vulnerability in geographic span: (where vulnerable people and places are located) and vulnerability in social space (who in that place is vulnerable).
(Pelling 2003) Denotes exposure to risk and an ability to avoid or absorb potential harm.
(Godschalk 1991)

Susceptibility to injury or damage from hazards.
(Berkes 2007) Vulnerability is registered by exposure to hazards, but it also resides in the resilience.
(Bohle 2001) Interaction between exposure to hazards and the coping capacity of the affected people (individual, group, and society) or in a short term social response to external events.
(Davidson 1997) Vulnerability is a component of risk assessment. It is defined through the parameters of physical infrastructure, population, economy, social-political systems.
(Turner, Kasperson et al. 2003) Vulnerability is the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress-stressor.
(Cutter 1993) Vulnerability is the likelihood that an individual or group will be exposed to and adversely affected by a hazard. It is the interaction of the hazards of place (risk and mitigation) with the social profile of communities.
(Anderson 1995) To be vulnerable is to exist with a likelihood that some kind of crisis may occur that will damage one's health, life, or the property and resources on which health and life depend.
(Weichselgartner, Berten 2000) By vulnerability we mean the condition of a given area with respect to hazard, exposure, preparedness, prevention, and response characteristics to cope with specific natural hazards. It is a measure of capability of this set of elements to withstand events of a certain physical character.
(Centre for Research on the Epidemiology of Disasters - CRED 2009) Degree of loss (from 0% to 100%) resulting from a potential damaging phenomenon.
(Downing, Aerts et al. 2006) Vulnerability is the differential exposure to stresses experienced or anticipated by different people.
(Green 2004) From a systems perspective, vulnerability can be defined as the relationship between a purposive system and its environment, where that environment varies over time.
(Renaud 2006) Vulnerability is the intrinsic and dynamic feature of an element at risk that determines the expected damage or harm resulting from a given hazardous event and is often even affected by the harmful event itself.
(Katsuhama, Grigg 2010) Physical and social weaknesses which increase the exposure to flood damage.
(Birkmann 2006c)

Vulnerability is defined through exposed and susceptible elements, on the one hand, and the coping capacity of the affected entities on the other. The BBC conceptual framework addresses various vulnerabilities in the social, economic, and environmental sphere.
(United Nations Development Programme (UNDP) 2004) A human condition or process resulting from physical, social, economic and environmental factors, which determine the likelihood and scale of damage from the impact of a given hazard.
(Intergovernmental Panel on Climate Change (IPCC) 2001) The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.
(Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) 2008) A degree of susceptibility or fragility of elements, systems or communities including their capacity to cope under a hazardous condition.
(UN/ISDR 2004) The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards.
(Adger 1999) Vulnerability is defined in this paper as the exposure of individuals or collective groups to livelihood stress as a result of the impacts of such environmental change.
(Blaikie, Cannon et al. 2004) Characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard
Gallopin Vulnerability as the risk that a “system”, such as a household, region or country, would be negatively affected by “specific perturbations that impinge on the system” or to the probability of a “system” undergoing a negative change due to a perturbation.
(Carreno, Cardona et al. 2005) Vulnerability seen as an internal risk factor should be related not only to the level of exposure or the physical susceptibility of the buildings and infrastructure material elements potentially affected, but also to the social fragility and the lack of resilience of the exposed community.
(Balica, Wright 2010) Vulnerability is considered in the study of Flood Vulnerability Index (FVI) as the extent of harm which can be expected under certain conditions of exposure, susceptibility and resilience.
(Kron 2005) Vulnerability is the lack of resistance to damaging/destructive event

2.4.2. The history of vulnerability

The discussion of vulnerability requires a clear understanding of the origin of the concept. In total, three origins of vulnerability assessment have been distinguished: social, physical, and socio-physical (the vulnerability of places). Vulnerability research can be traced through social science, where it has its roots in the analysis of risk reduction and disaster resilience (Birkmann 2006c, Cardona 2003, Blaikie, Cannon et al. 2004). In this way, hazard has been seen as a passive factor from an external source, while vulnerability is a dynamic internal characteristic of the system. In social science, vulnerability has been seen as a tempered response to hazardous events where concepts such as resilience and coping capacity in a human system are considered. Social vulnerability studies the social aspects of vulnerability, such as cultural, historical, and global change, and economic features (Adger 1999, Liverman 1990, Bohle 2001, Cutter, Finch 2008, Green 2004, Downing, Aerts et al. 2006).

Physical vulnerability has its roots in geography and natural hazard analysis (Fussel 2007). The human system has been taken as a passive factor, modifier to disaster damage with least attention, while hazard plays the active role. In this approach, vulnerability is perceived as a pre-existing condition determined by exposure and hazard. Indicators such as hazard zone, distribution, impact, human occupancy, duration, distribution of losses, magnitude, frequency, and quickness have been utilized (Sanyal, Lu 2005, Sanyal, Lu 2004, Ip, Dohm et al. 2006, Sophiayati Yuhaniz, Vladimirova 2009, Gabor, Griffith 1979, Godschalk 1991, Pelling, Uitto 2001).

There is a third approach to vulnerability that considers it as an interaction between human and biophysical systems, where vulnerability is defined as a combination of biophysical hazard and social response within a geographic area. This method takes social and physical indicators, but explicitly emphasises the geography of the place, which is why the method is famous as the study of vulnerability of places. This methodology has been applied to spatial environments including local, regional, national, and international spatial contexts (Jakibicka, Phalkey et al. 2010, Berkes 2007, Downing, Aerts et al. 2006, Penning-Rowsell, Peerbolte et al. 1992, Weichselgartner 2001, Turner, Kasperson et al. 2003, Methods for the Improvement of Vulnerability

Assessment in Europe (MOVE) 2008, Roberts, Nadim et al. 2009, Cutter 1996, Cutter, Mitchell et al. 2000, Smith 2000, Wei, Fan et al. 2004).

2.4.3. Characteristics of vulnerability

Vulnerability reduction is the first step towards a disaster-resilient society. A great deal of literature has emphasised the interactive nature of vulnerability (Downing, Aerts et al. 2006, Birkmann 2006c, Anderson 1995, Naude´, Santos-Paulino et al. 2009). Birkmann has clarified in his book that "vulnerability is a complex interaction between a potentially damaging physical event and the vulnerability of the society" (Birkmann 2006c).

Multi-dimensionality, differentially, scale dependency, and dynamics are the three chief characteristics of vulnerability mentioned by great many studies (Adger 1999, Downing, Aerts et al. 2006, Birkmann 2006c, Vogel, O'Brien 2004).

In addition, some scientists have insisted that vulnerability cannot be assessed without clearly specifying the hazard type, system, variables of concern, and temporal frame (Fussel 2007, Brooks 2003, Metzger, Leemans et al. 2005). Downing and colleagues (2006) distinguished several features of vulnerability: differential exposure to stress, a dynamic process with interlinked timescales, multiple attributes of human actors, multiple scales, and inherent. Furthermore, Anderson (1995) put forward a list of vulnerability characteristics which is still worthy of consideration:

1- Complex: vulnerability is a complex and multi-faceted concept. Several factors from different settings contribute in shaping vulnerability, which is therefore specific to location, target group, and context.
2- Dynamic: vulnerability is a result of interaction between social and environmental systems. Because factors contributing to vulnerability are always changing, vulnerability changes over time as well. Designing a model which tracks the direction and magnitude of vulnerability change is beneficial.

3- Cumulative: people who have experienced a disaster are often left more vulnerable to future hazardous events. This is because they will not have the same level of resilience, owing to the loss of some resources.
4- Self-compounding: factors shaping vulnerability are inter-related. Therefore when a group is vulnerable because of poverty, it is likely to be vulnerable because of health or lack of education.
5- Irreversible: some causes of vulnerability are rooted in natural resources. Degradation of these resources results in increasing vulnerability which is often irreversible.
6- Borderless: environmental hazards cannot be contained or limited to borders.

2.4.4. Causes of vulnerability

As people gain more experience and knowledge in disaster risk management, they have to acknowledge the complex and interconnected nature of vulnerability. Vulnerability is intrinsically tied into various social and environmental processes. Cardona et al. (2003) believe that vulnerability has its roots in economic, demographic, environmental, and political practices that distribute resources among groups. In addition, some global trends such as population growth, urban change, global warming, war, climate change, and international financial pressure should be considered.

Other grounds for vulnerability can be traced through physical fragility and exposure to the sources of hazardous events (i.e. unsafe location, non-resistant physical infrastructure), socio-economic weaknesses and susceptibility, and lack of resilience (i.e. limited access, incapacity to respond).

Despite all the new technologies, economic progress, and social development, the vulnerability of societies to hazards is increasing. The widening gap between poor and rich, the thought that rationality can be gained by pricing, the feeling that everything can be done, higher expectations, urbanisation, suburban expansion, population growth, invention of dangerous techniques, and production of litter and waste are the main trends related to increased vulnerability (Anderson 1995).

2.4.5. Vulnerability dimensions and factors

Birkmann (2005) has delineated a model which shows the widening concept of vulnerability (Figure 2-6). Almost every researcher agrees vulnerability as the internal side of risk. Some scientists have defined vulnerability as a characteristic of the elements at risk (Cardona 2003, Blaikie, Cannon et al. 2004, Davidson 1997, Cardona 2011). For instance, Blaikie et al. (2004) say that vulnerability arises from system-specific factors such as economic imbalances, disparity in power among social groups, knowledge dissemination, and social protection. They found factors of vulnerability in the ability of systems to cope with, mitigate, and recover from the impacts of disasters. Another example can be seen in Cardona (2003) where he states that vulnerability is tied to social and physical processes. From Cardona's point of view, vulnerability is a result of system fragility, susceptibility, and lack of resilience. He emphasises that those political, economic, and demographic processes that distribute resources among groups of people are the basic roots of vulnerability. The following dimensions of vulnerability have been cited: economic, political, social, physical, environmental, institutional, educational, cultural, and ideological (Villagrán de Léon, J. C. 2006, Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) 2008, Cardona 2011, Wilches-Chaux 1993).

A second way of looking at vulnerability defines it as the likelihood of injury, disruption, and harm. Here, the main elements of vulnerability are conditions which increase the chance of injury (Adger 1999, Downing, Aerts et al. 2006, Gabor, Griffith 1979, Godschalk 1991, Anderson 1995, Cutter 1996, Wisner 2002, Gallopin 2006).

The third approach is dualistic, where vulnerability is a result of interaction between a system's susceptibility to external harm and its internal coping capacity to recover from the impacts of the disaster (Berkes 2007, Bohle 2001, Pelling 2003, Renaud 2006).

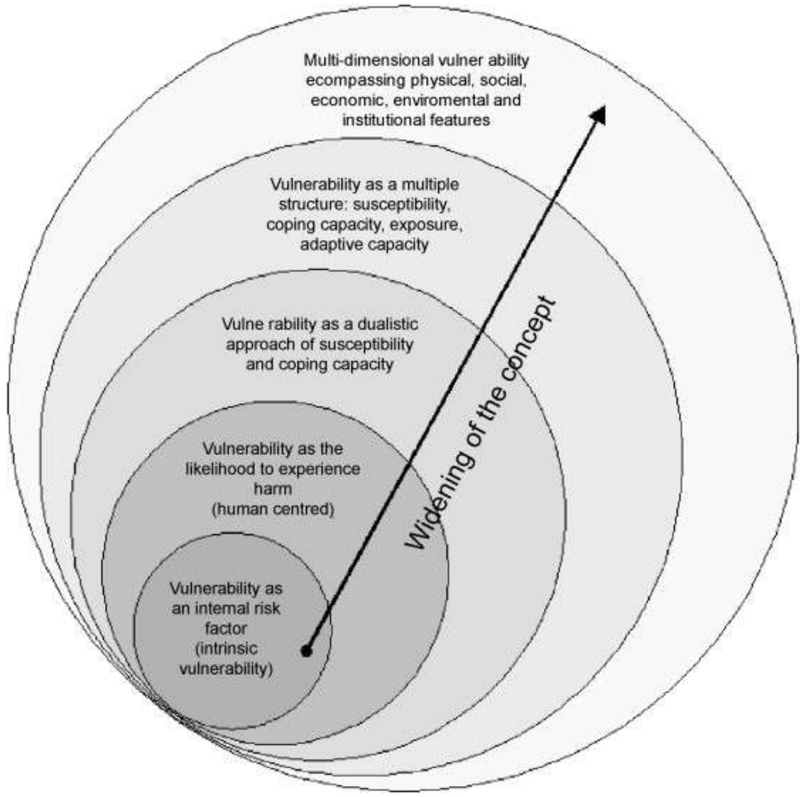

Figure 2-6: Spheres of the concept of vulnerability
Source: (Birkmann 2005)

The next step is to understand the multifaceted nature of vulnerability. Therefore, it is not just the coping capacity and susceptibility of the system which determine vulnerability; factors such as exposure, adaptive capacity, and interaction with stress are also considered (Weichselgartner 2001, Turner, Kasperson et al. 2003)

The most comprehensive approach can be seen in the definition of UN/ISDR, which shows not only the multifaceted nature of vulnerability but also the variety of dimensions which have been set for it (Fussel 2007, Birkmann 2006c, UN/ISDR 2004). In this way, vulnerability is seen as exposure, adaptive and coping capacity, and the susceptibility of the system and external stress in a multi-dimensional environment; physical, environmental, social, and economic.

Having in mind all the above approaches to the extent of vulnerability concept, relative factors, indicators, and dimensions have been proposed. For example, Cardona (2003, 2011) regards vulnerability as an intrinsic property of the elements at risk, but at the same time defines a number of dimensions of vulnerability: physical, environmental, economic, social, political, institutional, educational, cultural, and ideological (Cardona 2011). Adger (1999) belongs to the second circle of Figure 2.6; he distinguishes two levels of assessment: individual and collective. Weichselgartner (2001) (from the fourth circle) mentions hazard, exposure, preparedness, prevention, and response as the factors of vulnerability. The dimensions of vulnerability have been understood by Fussel (2007) as the temporal sphere, knowledge domain, system, hazard, and attribute of concern (for more information please see (Fussel 2007).

Whatever the indicators and factors of vulnerability with regard to the approach and perspective of the research, there are issues to be well thought out (Naude´, Santos-Paulino et al. 2009):

1- act as a predictive quality,
2- explain vulnerability in relation to a socially accepted level of results,
3- give an insight into the causes of vulnerability,
4- hazard specific,
5- appreciate dynamic nature of vulnerability, and
6- introduction of coping tools.

2.4.6. Vulnerability frameworks

In this section some of the most fundamental and well-known frameworks of vulnerability will be discussed. These have been proposed by experts from diverse perspectives and disciplines. Birkmann (2006) has put forward six schools of thought in vulnerability assessment. This proposal has been adopted to describe the vulnerability frameworks in more detail based on the understanding and review of the author.

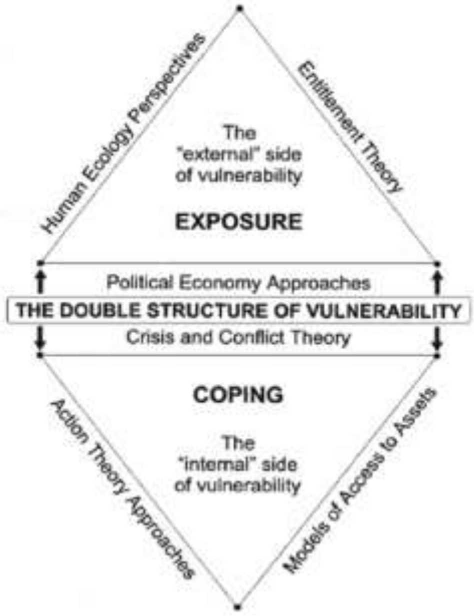

Figure 2-7: Vulnerability framework proposed by Bohle (2001)

First is the double structure of vulnerability. Bohle (2001) defines vulnerability as the internal factors of the system, such as the ability to anticipate, cope with, resist, and recover from the disadvantageous effects of the disaster, and an external factor, which is exposure to risk and hazard (Figure 2-7) (Bohle 2001). In this school of thought, the framework proposed by Gabor and Griffith (1979) can also be mentioned. They assessed vulnerability on two scales: large geographic entities (e.g. a metropolis) and local disaster planning (e.g. states). In their perspective, vulnerability is defined as the result of hazard, risk and system preparedness (Gabor, Griffith 1979). The sustainable livelihood model is another contribution in this school of thought (Chambers, Conway 1992).

The second approach is the analysis of vulnerability within a hazard and risk framework. In this school, vulnerability is seen as an element participating in risk, where risk is generally seen as a result of hazard, exposure, vulnerability, and coping capacity (Davidson 1997).

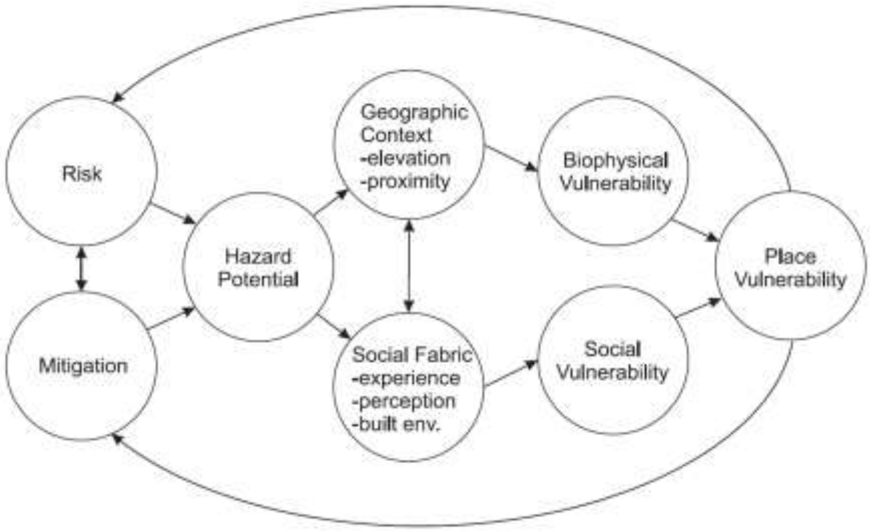

Figure 2-8: Cutter's framework of vulnerability
Source: (Cutter, Boruff et al. 2003)

Weichselgartner (2001) describes vulnerability as a combination of a pre-existing condition (i.e. physical vulnerability) and tempered response (i.e. social vulnerability) within a set of geographic conditions. He intends vulnerability analysis to contribute towards disaster damage reduction (Weichselgartner 2001). In the USA, Cutter (1996) made an attempt to develop a conceptual framework with regards to hazard mitigation strategies, considering interaction between nature, society and technology with an explicit focus on the locality of analysis. She also considered vulnerability as a result of interaction between social and biophysical elements (Figure 2-8) (Cutter 2003, Cutter 1996, Cutter, Boruff et al. 2003).

In addition, Brooks (2003) introduced the concept of adaptive capacity in the school of disaster risk reduction (Brooks 2003). Furthermore, Roberts and colleagues developed an especially interesting model of vulnerability in the context of a natural science paradigm. They highlighted the importance of scale in vulnerability analysis and took advantage of both social and biophysical parameters (Roberts, Nadim et al. 2009).

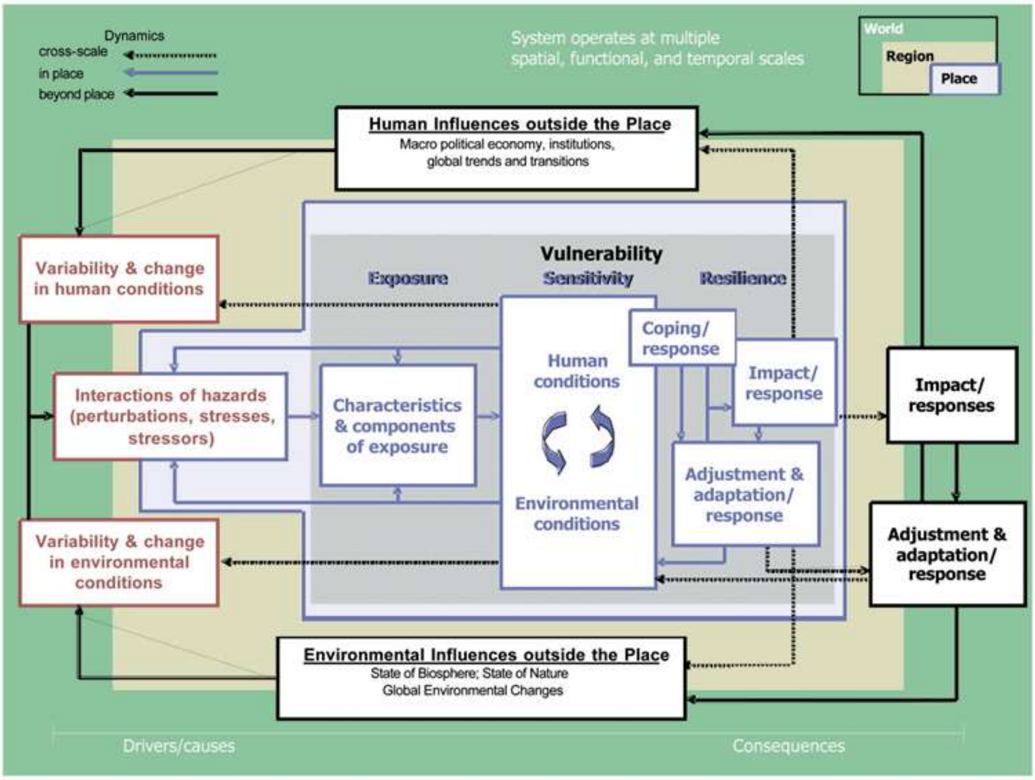

Figure 2-9: Turner's conceptual model
Source: (Turner, Kasperson et al. 2003)

The third school is global environmental change, where vulnerability and risk are seen in the broad global context and notions such as global environmental change are respected (Adger 1999, Liverman 1990). As Figure 2-9 demonstrates, Turner et al. (2003) developed a complex vulnerability framework which sets in global environmental change community. In their framework vulnerability is defined as a coupled human–environmental system comprising exposure, sensitivity, coping response, impact response, and adaptive response (Turner, Kasperson et al. 2003). Another decent work in this school is by Fussel (2007), who clearly discriminated between existing conceptual models and offered a new framework for global environmental change society. He stated that for vulnerability analysis we need to be specific about the system in question, hazard type, attribute of concern, and temporal reference (Fussel 2007).

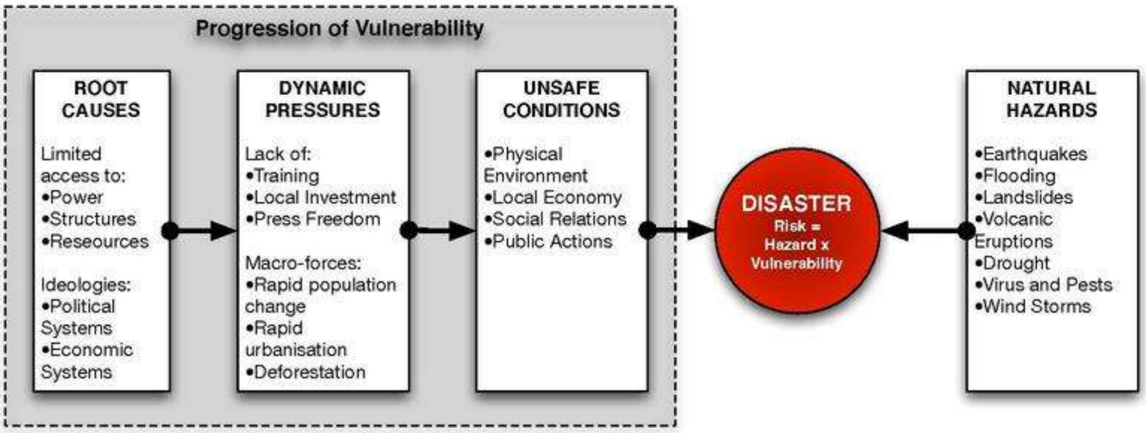

Figure 2-10: Pressure and Release (PAR) model
Source: (Blaikie, Cannon et al. 2004)

The fourth school is political economy. One of the best-known vulnerability frameworks, Pressure and Release (PAR), belongs to this school of thought (Figure 2-10). Blaikie and colleagues defined disaster as a result of two sources of pressure: a natural hazard and a vulnerable situation. The PAR model is based on the common risk module:

$$Risk = Hazard \times Vulnerability$$

Equation 2-1: Pressure and release (PAR) model

This model illustrates how a disaster forms when natural hazards strike vulnerable people. In this model, vulnerability consists of three progressive processes: root causes, dynamic pressure, and unsafe conditions. Basically, in this framework they look for vulnerability reduction in a change in the political and economic system.

Another example from this school is the sectoral approach by Villagrán (2006) (Villagrán de Léon, J. C. 2006). He developed a simplified model of vulnerability for policy makers using a quantitative weightening system. Three pillars were set for vulnerability: geographical level, sector level, and components level.

The fifth school is the holistic approach to risk and vulnerability assessment. As Figure 2-11 shows, this framework emphasises the dynamic (time dependent), complex, and multi-dimensional nature of vulnerability studies. Two categories of risk have been defined within the concept of vulnerability: hard risk, which is hazard-dependent, and soft risk, which is non-hazard-dependent. Hard risk consists of exposure and physical susceptibility. Soft risk comprises socio-economic fragilities and lack of resilience (Cardona 2003, Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) 2008, Cardona 2011, Cardona 2001, Cardona 1999). In addition, Carreno et al. (2005) expanded a revised version of the holistic approach in seismic risk reduction (Carreno, Cardona et al. 2005).

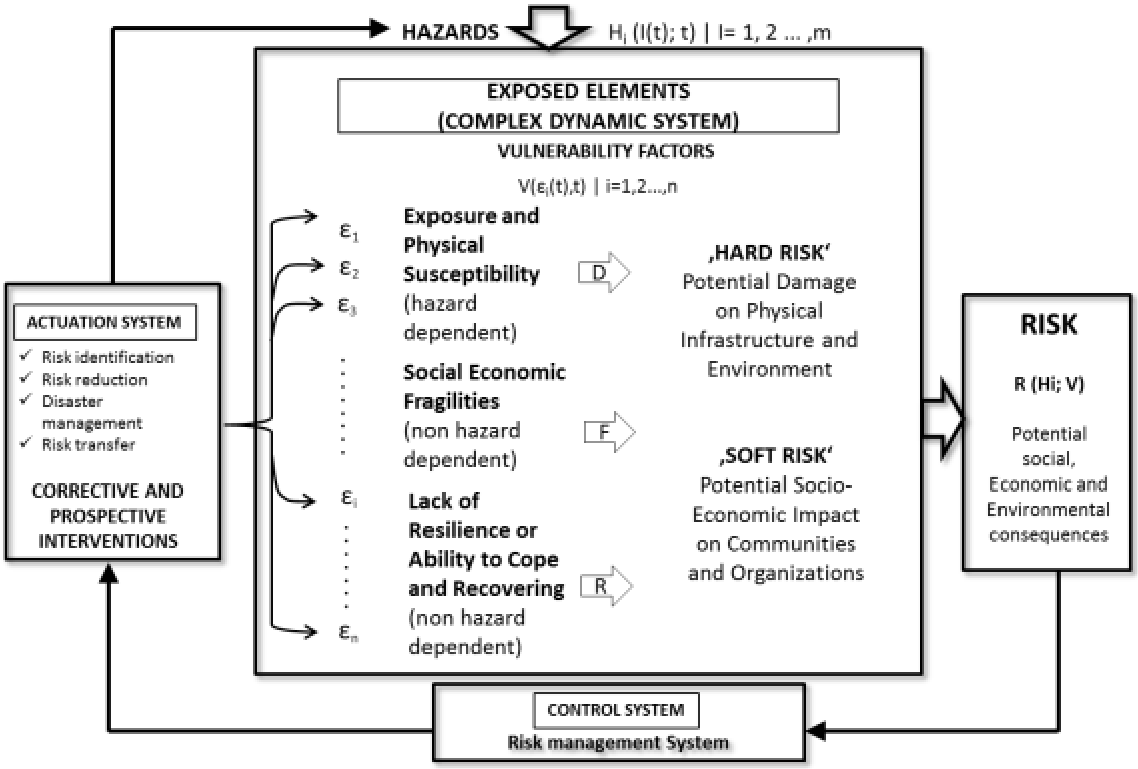

Figure 2-11: The holistic approach to disaster risk management
Source: (Cardona 2003)

The fifth and last school of thought proposed by Birkmann (2006) is the BBC (Birkmann 2006c, Birkmann 2006b, Bogardi, Birkmann 2004, Birkmann 2007, Birkmann, Fernando et al. 2006). This model is based on works by Bogardi and Birkmann (2004) and Cardona (1999-2001). It makes use of elements from other frameworks and aims at vulnerability reduction in sustainable development. Exposed/susceptible elements and coping capacity as the main factors of vulnerability and the three pillars of sustainability (environmental, economic, and social) are the main theme of this model

(Figure 2-12). The authors declare that understanding of vulnerability should go beyond damage reduction. They initiated intervention systems as a vulnerability reduction tool (Birkmann 2006c).

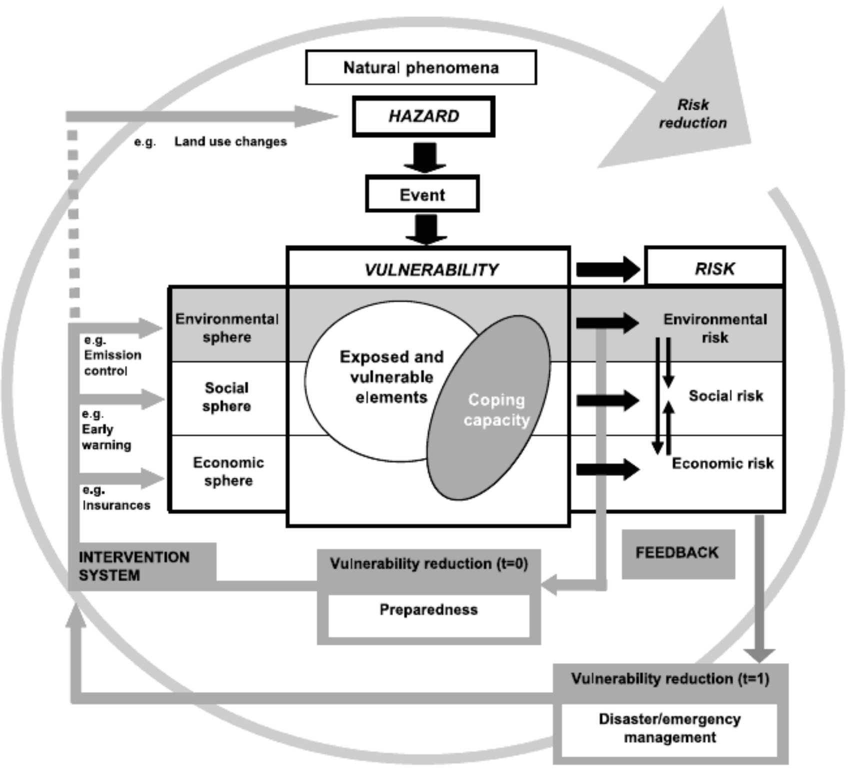

Figure 2-12: BBC Framework
Source: (Birkmann 2006c)

2.4.7. Classification of vulnerability methodologies

There are great numbers of vulnerability frameworks associated with methodologies for assessing and measuring vulnerability. There is no need to unify the concept of vulnerability, and in fact it is not feasible to do so, because specialists have reviewed and considered it according to their perspectives and goals. However, Anderson (1995) states that a framework should be simple enough to grasp, complex enough to capture the reality, comprehensive enough to capture all the critical factors for understanding the roots of vulnerability, and able to picture essential relations and interactions between factors.

Turner et al. (2003) explained some ways to improve vulnerability analysis:

1. considering vulnerability in a coupled human-environmental system

2. identification of the complexity, inter-connectedness, and interactive nature of components
3. reflection on the location and scale of the problems
4. detection of dynamics within the human-environmental system which give rise to new hazards
5. recognition of critical interactions in the system that suggest response opportunities for decision makers
6. openness to both qualitative and quantitative analysis
7. assistance in the development of metrics and new models.

There is a fascinating classification of vulnerability methodologies presented by Birkmann (2006) which will be used as the basis of the following discussion (Birkmann 2006b). The first issue is quantitative versus qualitative approaches. In fact, deciding whether to use qualitative or quantitative methods depends on the focus and scale of the approach. Examples of qualitative approaches are (Weichselgartner 2001, Naude´, Santos-Paulino et al. 2009, Luers 2005, Wisner 2006), and examples of quantitative approaches are (Pelling 2006, Peduzzi 2006).

Secondly, we may classify the methods as hazard-specific or hazard-independent. Some scholars insist that vulnerability assessment should be holistic and should aim at preparedness for multiple hazards. Decision making and policies need to be based on a multi-stressor situation (Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) 2008, Cutter, Boruff et al. 2003, Pelling 2006, Greiving 2006). In contrast, other scientists believe that vulnerability is characteristic of a specific hazard and should be validated with regard to the factors of a related hazardous situation (Downing, Aerts et al. 2006, Fussel 2007, Villagrán de Léon, J. C. 2006, Brooks 2003, Metzger, Leemans et al. 2005).

Thirdly, global assessment may be evaluated in comparison to local assessments. Global analyses give us an overview and method of comparison for countries worldwide (Turner, Kasperson et al. 2003, Cardona, Ordaz Schroder et al. 2010, Dilley 2006). However such analyses have revealed that countries should be assessed with regard to their characteristics. For example, developing countries have higher numbers of people killed or injured while developed countries have higher economic losses, which shows that indicators that determine vulnerability vary among nations. Therefore context-specific approaches which consider the importance of time and scale may produce better results (Adger 1999, Gabor, Griffith 1979, Fussel 2007, Villagrán de Léon, J. C. 2006, Brooks 2003, Roberts, Nadim et al. 2009, Luers 2005, Dixit 2003).

Fourthly, there is the question of whether to use reliable loss estimation or fuzzy context interpretation. Some methods use the losses and damage experienced and recorded to assess vulnerability (Pelling 2006, Peduzzi 2006, Dilley 2006), implying a retrospective view, while the alternative way is a forward-looking assessment using broader perspective indicators such as population growth or literacy rate (Carreno, Cardona et al. 2005, Birkmann, Fernando et al. 2006). Points to bear in mind are, firstly, that not all historical datasets are reliable, and secondly, that some of the indicators of vulnerability are really important for revealing the pattern of vulnerability in society.

The fifth issue is the notion of a simplified or complex framework. Anderson (1995) has mentioned that a framework should be simple enough to be understandable and complex enough to capture the reality. This is one of the major issues for every specialist in developing a model. For quantitative approaches, having a simple model is beneficial in order to take measurements and to avoid mistakes. In addition, the scale of the approach plays a role in how complex a framework can become. For global approaches there are not many datasets available. Furthermore, the thematic scope and focus of the approach determine the level of simplification.

Finally, the importance of having goals and targets for a vulnerability assessment should be noted. It is proven that efficiency of analysis and reliability of results will be dramatically improved by establishing a set of goals for analysis.

2.4.8. Vulnerability vs. related terms

In this section, the concepts which are related to vulnerability and are often misunderstood or confused with vulnerability are clarified and their working definitions are stated. It is of essential importance to be clear about the terms which will be used in the thesis to prevent any distortion.

2.4.8.1. Vulnerability vs. hazard

Hazard is the starting point for disaster risk reduction and sustainability. A variety of definitions have been offered for 'hazard' (Birkmann 2006c, Cardona 2003, Cardona, Ordaz Schroder et al. 2010, Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) 2008, Roberts, Nadim et al. 2009, Ologunorisa 2004, UN/ISDR 2002). However, in this context 'hazard' is defined as:

"A potentially damaging physical event, phenomenon and/or human activity, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation." (UN/ISDR 2002)

Hazard has a socio-natural origin, and is defined generally as the potentiality of a particular threatening event occurring during a particular period. Hazard is often seen from the risk reduction perspective and is a factor of risk (Equation 2-1). Hazards are characterised by indicators such as location, magnitude, frequency, probability, depth, duration, and velocity (Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) 2008, Ologunorisa 2004). In addition, the Centre for Research on the Epidemiology of Disasters (CRED) (2011) mentions that hazard is a totally different concept from disaster. Hazard is defined as: "threatening event or probability of occurrence of a potentially damaging phenomenon within a given time period and area" (Centre for Research on the Epidemiology of Disasters - CRED 2011).

2.4.8.2. Vulnerability vs. disaster

"Instead of defining disasters primarily as physical occurrences, requiring largely technological solutions, disasters are better viewed as a result of the complex interaction between a potentially damaging physical event (e.g. floods, droughts, fire, earthquakes and storms) and the vulnerability of a society, its infrastructure, economy and environment, which are determined by human behaviour." (Birkmann 2006c)

In addition, the Centre for Research on the Epidemiology of Disasters (CRED) (2011) has made a glossary of all the terms related to disasters. It has defined disasters as "a situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering. Though often caused by nature, disasters can have human origins. Wars and civil disturbances that destroy homelands and displace people are included among the causes of disasters. Other causes can be: building collapse, blizzard, drought, epidemic, earthquake, explosion, fire, flood, hazardous material or transportation incident (such as a chemical spill), hurricane, nuclear incident, tornado, or volcano."

In fact, numerous scholars have emphasised the fact that disasters are not just natural events, but that the social context should also be counted (Weichselgartner 2001, Weichselgartner, Berten 2000, Cardona 2003, Blaikie, Cannon et al. 2004, Anderson 1995, Cardona 2011). Blaikie et al. (2004) explained that disasters are the result of risk and vulnerability.

2.4.8.3. Vulnerability vs. risk

"The term risk encompasses the probability and the amount of harmful consequences or expected losses resulting from interactions between natural or human induced hazards and vulnerable conditions." (UN/ISDR 2002)

Even though some people use the term 'risk' when they are referring to vulnerability or hazard, there is a difference between the terms. In the briefest case, risk has been defined as the threat of hazards (Gabor, Griffith 1979), or the physical characteristics of the hazardous event (Blaikie, Cannon et al. 2004). However, most scholars regard it as a hazard and its consequences (Kron 2005, Birkmann 2007). Risk, vulnerability and hazard are intertwined to create the damage and losses caused by a disaster; therefore, an understanding of the risk of disaster can greatly improve policy planning and the tools we apply for damage reduction (Blaikie, Cannon et al. 2004, Cardona, Ordaz Schroder et al. 2010).

In addition, risk is the "expected losses (of lives, persons injured, property damaged and economic activity disrupted) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the function of hazard and vulnerability" (Achilleos 2005). The United Nations Disaster Relief Co-ordinator (UNDRO) (quoted in (Cova 1999): 848) defined risk as:

$$\boldsymbol{Risk} = \boldsymbol{R}(\ \boldsymbol{H}(\boldsymbol{E_h}).\boldsymbol{V}(\ \boldsymbol{E_v}))$$

Equation 2-2: Risk formula

Where hazard is a function $\boldsymbol{H}$ derived from hazard elements, vulnerability is a function $\boldsymbol{V}$ derived from vulnerability elements, and risk is a function $\boldsymbol{R}$ derived from the results of functions $\boldsymbol{H}$ and $\boldsymbol{V}$. Cova (1999) describes the difference between vulnerability and hazard as the inherent classification of the human/physical environment. However, later studies on vulnerability consider both social and bio-physical indicators at specific places and applications (Weichselgartner 2001, Cutter, Mitchell et al. 2000). An example of the formula above can be found in the work by Chung et al. (2005). They have designed a three-step procedure and software to support the model for decision makers. At the first step, a potential hazard map is constructed, while the second step is about validation of the probability of occurrence of each hazard level. Finally, a risk map can be generated by combining hazard prediction and socio-economic factors (Chung, Fabbri et al. 2005).

Risk is generally accepted as the interaction of physical hazards and social vulnerability (Birkmann 2006c, Cardona 2003, Cardona, Ordaz Schroder et al. 2010, Brooks 2003, Roberts, Nadim et al. 2009, Cardona 2011, Cardona 1999, Birkmann 2007, Ologunorisa 2004). Consequently there is no risk where a natural hazard occurs in a place with no exposed values. Kron (2005) provides a broader definition where he states that risk is a function of hazard, values at risk, and vulnerability (Kron 2005).

2.4.8.4. Vulnerability vs. coping capacity

"Coping capacity is a combination of all strengths and resources available within a community or organization that can reduce the level of risk, or the effects of a disaster." (UN/ISDR 2002)

Coping capacity emerged from the discourse on vulnerability where scholars realized that vulnerability is more than exposure, susceptibility, and sensitivity, but also includes the capacity of the system to cope with disaster (Bohle 2001, Birkmann 2006c, Blaikie, Cannon et al. 2004, Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) 2008, Carreno, Cardona et al. 2005, Chambers, Conway 1992, Cutter, Boruff et al. 2003, Cardona 1999, Dixit 2003). Therefore, coping capacity has been seen as a subcomponent of vulnerability, although it has been acknowledged that distinguishing between indicators is problematic (Roberts, Nadim et al. 2009).

It is noteworthy to mention a different concept named 'adaptive capacity' (Brooks 2003, Intergovernmental Panel on Climate Change (IPCC) 2001, Adger, Brooks et al. 2004). Adaptive capacity can reduce social vulnerability and hence the disaster risk. It has been defined as the "ability or capacity of a system to modify or change its characteristics or behaviour so as to cope better with existing or anticipated external stresses" (Brooks 2003). The adaptive capacity of a human system represents the potential of the system to reduce its social vulnerability and thus to minimize the risk associated with a given hazard.

2.4.8.5. Vulnerability vs. resilience

"Resilience describes the capability of a system to maintain its basic functions and structures in a time of shocks and perturbations and can continue to deliver resources and ecosystem services that are essential for human livelihoods." (Birkmann 2006c)

This is a general definition of resilience, but there are various perceptions of the term where some define it as the opposite of vulnerability and lack of human security (Adger, Hughes et al. 2005, Bogardi, Brauch 2005). In addition, resilience could be related to the concepts of coping and adaption. Resilience is a characteristic of a system which is desirable among the decision making and management practices where the aim is for vulnerability reduction and disaster-resilient societies.

2.4.8.6. Vulnerability vs. Sustainability

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."
(World Commission on Environment and Development 1987)

Concepts of sustainability and vulnerability are interconnected. Sustainable development is not possible without explicit policies to reduce vulnerability, and vulnerability reduction is not achievable without approaches to sustainable development (Anderson 1995). The increase in the number of disasters and the number of extreme events worldwide, higher vulnerability of societies, global environmental changes, natural resource degradation, and the rise in human and economic losses due to disasters are some of the warnings calling for vulnerability and risk reduction which aims at sustainable development. Birkmann (2006) has made an interesting description of sustainability in his book (in Chapter 1), where he has comprehensively introduced two schools of thought on sustainability: The Triangle of sustainability (Serageldin 1995) and the Egg of sustainable development (Busch-Luty 1995).

2.4.9. Intermediate conclusion

The main purpose of this section is to explain and clarify the concept of vulnerability and related terms. There have been many key facts and figures discussed in this chapter which will be of great importance to this work.

Everybody is vulnerable to some degree. It is the job of vulnerability analysis to reveal the pattern of vulnerability within society. Table 2-3 provides some definitions of vulnerability extracted from reading on the literature. This table shows the variety of disciplines and perspectives from which scholars approach vulnerability. There is no benefit in unifying the definition but it is of vital importance to clarify the definition used in the work. The definition in this research is from UN/ISDR (2004):

> "Vulnerability is the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards."

In addition it is important to differentiate between terms normally associated with vulnerability such as 'disaster', 'hazard', 'risk', and 'coping capacity'.

There are three origins of vulnerability: social, biophysical, and socio-physical (i.e. vulnerability of places). Vulnerability of places is particularly compatible with the objectives and associated tools of this research. This stratum of vulnerability emphasises the geography of the place.

In the spheres of vulnerability proposed by Birkmann (2006), the hierarchical progress of the vulnerability concept has been demonstrated. Based on the concept, the factors and causes of vulnerability have been defined. However, it is important to bear in mind the complex, dynamic, cumulative, self-compounding, irreversible, and borderless characteristics of vulnerability.

Five schools of thought on vulnerability have been explained: double structure, hazard and risk, global environmental change, holistic, and BBC. Among the frameworks discussed for each school, BBC has much potential for a noble vulnerability analysis. It defines three dimensions of vulnerability, which are based on three pillars of sustainable development. In addition, the BBC framework explicitly emphasizes the factors of vulnerability, which are exposure, susceptibility, and coping capacity. Another distinction of this model is the interactive loop which has been designed to cover the dynamic nature of vulnerability. The complexity of the concept and its interaction with risk, hazard, natural phenomena, and human systems of vulnerability are well considered. In addition, the initiative of putting intervention systems which reduce vulnerability into the model is outstanding. This framework stands out from those of the other schools by considering time scale and emergency management phases. Therefore, the BBC framework was selected as the platform for vulnerability assessment of this work.

2.5.Conclusion

In this chapter, three main fundamentals of my research have been explained: emergency management, flood as a hazardous event, and vulnerability. Comprehensive Emergency Management (CEM) is a four-phased system which attempts to mitigate, prepare for, respond to, and recover from disasters. Sustainable development is an ideal that cannot become reality without disaster disk reduction.

Vulnerability is a multi-faceted concept viewed from diverse perspectives by various scholars. Social and biophysical vulnerability and vulnerability of places are three origins of the concept. This research has taken the “vulnerability of places” viewpoint where geography of place is the main concern. Within this perspective, many frameworks have been developed on the basis of the authors’ various disciplines, such as global environmental change or risk community. The BBC framework (Bogardi and Birkmann (2004) and Cardona (1999-2001)) is a framework promoted by the United Nations which is based on sustainable development. It comprises three pillars: social, economic, and environmental. This model takes into account the complex, dynamic, hazard-dependent, multi-faceted, multi-dimensional, interactive nature of vulnerability.

Climate change is affecting our environment in a number of ways. Its greatest impact can be seen in the frequency and intensity of climate extremes, especially floods. Floods are the most hazardous event in the UK both economically and in human terms.

Various strategies have been undertaken to manage the effects of floods. Integrated flood management is the most recent and robust strategy. Flood risk management is part of this strategy, which also includes vulnerability analysis. From the points above, an inter-connected system of sustainability, emergency management, disaster risk reduction, flood management, flood risk management, and flood vulnerability analysis can be extracted. This is the main aim of this work: *Flood Vulnerability Assessment.*

3. General Methodology

3.1. Introduction

The aim of this chapter is to provide an overview of the methods applied throughout this work. Owing to the structure of the work, some contexts are repeated in chapters 4, 5, and 6. Therefore, the basic and general discussions are outlined here and will be referred to in the following chapters. However, the specific methods and topics will be further expanded if necessary. The topics discussed are the study area, the conceptual framework of the research, the developed land stratification sectors, indicator development, and visualisation of the results.

3.2. Case study area- East Riding of Yorkshire, England

The case study area is the eastern part of the Yorkshire and Humber region of the Government Office Regions (GOR). The study area comprises two unitary authorities: the City of Kingston upon Hull and the East Riding of Yorkshire. However, for the purpose of simplicity we use the term "East Riding of Yorkshire". This area has been chosen for the following reasons: (a) parts of the region are prone to flooding, according to the historical flood records and the Environment Agency flood risk maps; (b) the area is characterised by a diverse landscape which makes it appropriate to the objectives of a GIS-based work; (c) the East Riding is close enough, should the work need any field observation; (d) the vulnerability analysis requires a great number of variables, and a good number were available for this region; (e) the area is a European administrative NUTS3 unit and appropriate for further extension and transformation.

The administrative geographic division of England is illustrated in Figure 3-1. There are 49 electoral wards within the area. Wards are the building blocks from which other units are constituted. In addition, the study area includes 172 parishes; English parishes are a very old form of local unit and have very limited functions in the present (Office for National Statistics 2011a).

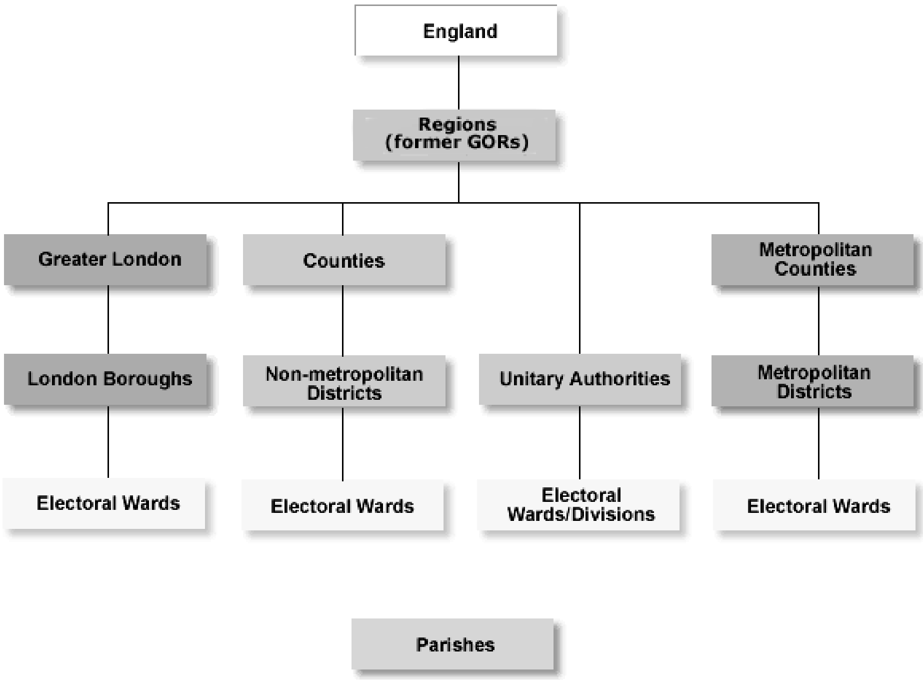

Figure 3-1: The hierarchy of administrative geographic divisions in England
Source: (Office for National Statistics 2011b)

The East Riding of Yorkshire covers more than 248,000 hectares of land and has more than 557,000 residents according to the 2001 census (Office for National Statistics 2011a). Over half of the population live in rural communities and more than 98 per cent of the population have white ethnic origins. Agriculture occupies most of the land use within the East Riding of Yorkshire. The industry of the region mostly relies upon agriculture, agricultural businesses, fishery, and gas terminals. The East Riding of Yorkshire's principal settlements include the heavily populated cities of Hull, the coastal towns of Bridlington, Hornsea and Withernsea, the free-standing market towns of Beverley, Howden, Market Weighton, Pocklington and Driffield, and the inland port of Goole. Figure 3-2 shows the extent of the East Riding of Yorkshire and its location in England. The Land Cover Map (LCM2007) has been used in order to give a preliminary picture of land cover. In addition, Ordnance Survey Land-Form PROFILE DTM was used to demonstrate the elevation within the region. Other features such as large urban areas, roads and rail tracks have also been highlighted (Figure 3-2).

The geology of the area is characterised by clay, sand, and silt to the west and Middle and Upper Chalk in the remainder of the area. The East Riding of Yorkshire is a low-lying, undulating countryside. The area is bounded to the south by the Humber Estuary, and to the east by the North Sea, where its 60 km of coastline is subject to the fastest rate of coastal erosion in Europe. The Yorkshire Wolds are rolling chalk hills running approximately north-south through the heart of the region, and a major aquifer used for public water supply. On either side of the Wolds are low-lying vales and plains. The region is drained by a great number of channels and rivers as well as man-made mechanisms such as sluices, and gates. East of the Yorkshire Wolds is the River Hull, which flows south from Driffield, past Beverley, and into the Humber at the City of Kingston upon Hull. The western boundary of the East Riding is defined by the River Derwent. The Derwent joins the Ouse, Aire and Don immediately west of Goole. The Trent joins the Ouse just east of Goole. The Market Weighton Canal/River Foulness drains much of the area between the Derwent and the Wolds (East Riding of Yorkshire Council 2011b).

A great proportion of the area of the East Riding of Yorkshire has been at significant risk of flooding owing to the low-lying nature of the area and its many watercourses. The flood hazard arises from various sources, including tidal, fluvial, and ground-water flooding, and surface run-off. The East Riding has a significant history in terms of flooding; the last one was the nationally significant flooding in June 2007. Appendix 1 provides a comprehensive history of the floods which have happened in the East Riding of Yorkshire (East Riding of Yorkshire Council 2011b). The area last flooded extensively in the summer of 2012.

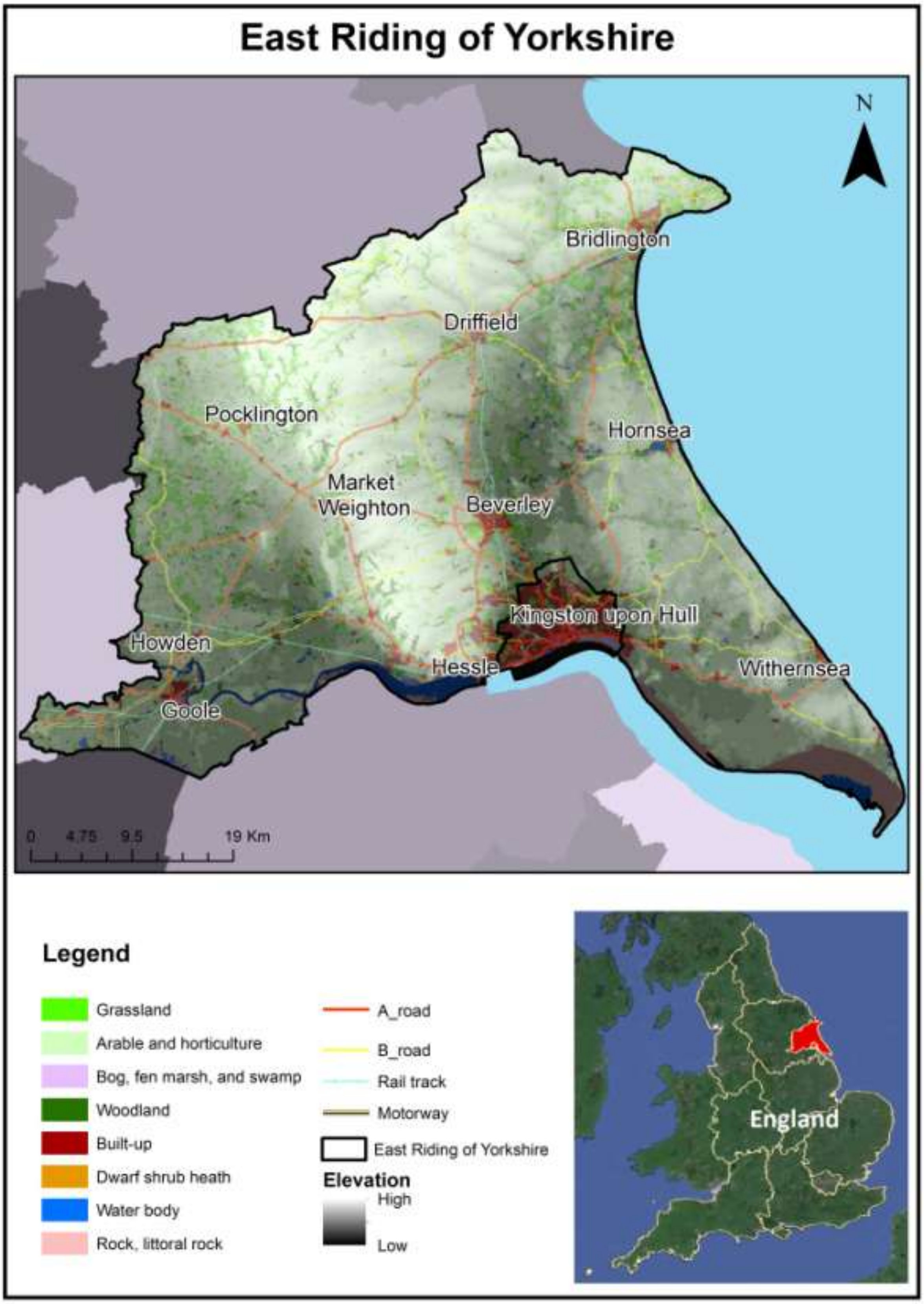

Figure 3-2: The location of the study area: the East Riding of Yorkshire

3.3. The conceptual framework

In order to achieve the objectives of the work, it is of great importance to identify a vulnerability framework. The framework has to facilitate the work operationally, it has to be sound conceptually and valid in practice, and it has to guide the scientific work.

Vulnerability is one of the most ambiguous terms in the field of risk and disaster management. A comprehensive discussion on vulnerability has been put forward in Chapter 2. For vulnerability assessment and examination, the preliminary step is to define the conceptual framework. BBC is a vulnerability framework derived from the United Nations University-Institute for Environment and Human Security (UN-EHS) (Cardona 2001, Cardona 1999, Bogardi, Birkmann 2004).

The BBC framework encompasses elements from all the other frameworks introduced in Chapter 2. It grows from three basic issues: the linkages between vulnerability, human security, and sustainable development, the necessity of a holistic approach to disaster risk assessment, and the development of a causal framework for measuring environmental degradation in the context of sustainable development (Renaud 2006). In such a holistic framework, vulnerability relates to the characteristics of people or groups that influence the impact of hazard events on them. These characteristics depend on the unsafe conditions of people in relation to a set of dynamic pressures caused by another set of indicators (Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) 2008). BBC takes a problem-solving perspective and accounts for all aspects of vulnerability. It incorporates the perspective of sustainable development and tries to bridge the gaps between theory and day-to-day decision making.

Since the framework of BBC is comparatively new, not much work has been carried out on it. Renaud used the framework to evaluate the environmental dimension of vulnerability in the case study of the December 2004 earthquake in Sri Lanka (Renaud 2006). Fekete used the BBC framework to compare the social vulnerability to river floods in Germany at county and household level (Fekete 2009). Other examples of research carried out on the basis of the BBC framework can be found in (Sumernet

2013, Post, Zosseder et al. 2007, UN/IEHS and NNGASU 2006, UN/IEHS and NNGASU 2006, Kienberger 2007)

The BBC framework has been revised with regard to the objectives of this research. Figure 3-3 illustrates a modified version of the framework. The modified BBC framework incorporates the principles of risk and vulnerability analysis of all other schools of thought. Unlike the previous frameworks, the modified BBC sets up four elements of sustainable development defined by UN-ISDR as the pillars of assessment: environmental, physical, economic and social. These components highlight the multi-dimensional characteristics of vulnerability and are emphasised throughout the analysis. In addition, the framework realises that there are two ways to reduce vulnerability, by addressing coping capacity and exposure/susceptibility, in addition to the use of intervention tools. Examples of intervention systems could be providing insurance to reduce economic vulnerability, setting up early warning systems to decrease social vulnerability, and imposing waste management policies to reduce environmental vulnerability. There is a certain overlap between coping capacity and exposure/susceptibility, and one can classify an indicator as either of these components. The relations make use of the formulas below:

$$Risk = Vulnerability + Hazard$$

Equation 3-1: Risk, vulnerability and hazard

$$Vulnerability = Exposure + Susceptibility - Coping\ capacity$$

Equation 3-2: Vulnerability formula

The BBC framework promotes a proactive approach to vulnerability reduction. It differentiates between actions before (t=0) and after (t=1) an event strikes. Taking a dynamic approach to vulnerability provides two opportunities to reduce vulnerability, via preparedness and via response activities. In addition, a dynamic perspective allows for feedback and revision within the vulnerability reduction loop.

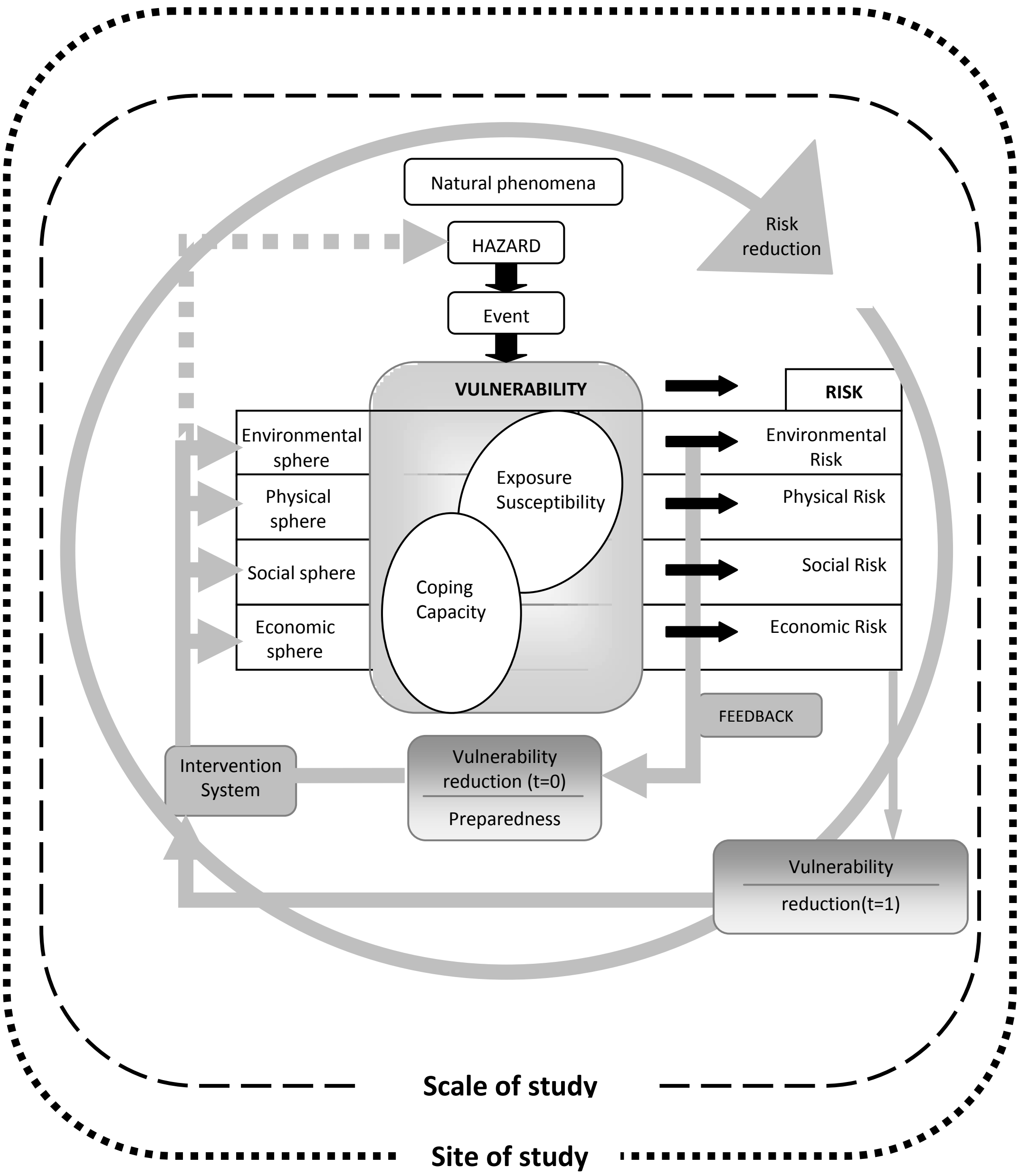

Figure 3-3: The modified BBC framework
Source: Author, Based on (Birkmann 2006c), Page 34

The modified BBC framework puts the overall loop of risk and vulnerability reduction into the nutshell of scale and site specification. This part is based on the scale-dependent and site-specific attributes of the vulnerability. For example, access to TV might a social indicator for a country like Malaysia but not for England. GDP is an economic indicator if the scale of work is national but not a considerable factor for regional analysis.

On the basis of the modified framework displayed in Figure 3-3, four components and two sub-components of vulnerability could be defined. Components of vulnerability are:

- environmental
- physical
- social
- economic

Table 3-1: Working definitions in this research

Term	Definition
Risk	Risk is the probability of damage and depends on two elements of hazard and vulnerability.
Vulnerability	"The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards." (UN/ISDR 2004) Exposure and coping capacity are the two elements of vulnerability.
Hazard	"A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. Hazards can include latent conditions that may represent future threats and can have different origins: natural (geological, hydrometeorological and biological) or be induced by human processes (environmental degradation and technological hazards). Hazards can be single, sequential or combined in their origin and effects. Each hazard is characterised by its location, intensity, frequency and probability." (UN/ISDR 2004)
Exposure	"Elements at risk […] that are exposed to a hazard." (UN/ISDR 2004)
Coping capacity	"A combination of all strengths and resources available within a community or organization that can reduce the level of risk, or the effects of a disaster." (UN/ISDR 2002)
Sustainable development	"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development 1987)

Exposure and coping capacity are the two sub-components of vulnerability. Distinction of vulnerability fundamentals is of great importance in terms of indicator development and vulnerability reduction strategies. There are diverse definitions of terms related to vulnerability and risk assessment. For the sake of clarification, Table 3-1 lists the working definitions of the terms used in this research.

3.4.Geographical stratification of the land

The context of work can greatly affect the vulnerability assessment. Although the context dependency characteristic of vulnerability has been mentioned in most of the literature, few studies have actually implemented it. An example of a study which considers the context of vulnerability is the work by Damm (Damm 2010). She analysed flood vulnerability of agricultural and woodland sectors in relation to German rivers using Turner's vulnerability framework (Turner, Kasperson et al. 2003).

A geographical stratification of land by human activities is introduced in this research. This approach is an annotation from the sectoral vulnerability assessment (Villagrán de Léon, J. C. 2006). The East Riding of Yorkshire has been geographically stratified on the basis of the present maps and datasets and three strata of vulnerability have been distinguished:

1. arable
2. urban
3. wildlife.

Each sector is separately analysed in terms of flood vulnerability, using its own criteria; this analysis forms Chapters 4, 5, and 6 respectively. The modified BBC framework has been applied to develop lists of indicators for each sector through the vulnerability components and sub-components. This contribution makes this research distinct from other studies in that users interested in a specific field can choose to look only at the relevant sector (i.e. arable, wildlife, or urban) with its associated variables. In addition, indicators and assessment criteria are more specific and target-oriented.

3.5.Unit and scale of the research

The unit and scale of research are of importance in mapping vulnerability and related factors. Terms such as scale and unit often connote different aspects of time and space and therefore their meaning needs to be clarified. Table 3-2 illustrates the definitions of the terms 'scale', 'unit', and 'study area' in this work.

Table 3-2: Definition of space-related terms

Term	Definition
Scale	The level of geographical detail of the analysis.
Unit	Homogeneous spatial divisions like pixels, or administrative boundaries.
Study area	Total area of study observation.

For a better understanding, Figure 3-4 illustrates some examples of the terms from a work by Fekete (2009). The unit of analysis could be grid cells or administrative boundaries such as postcode areas. In contrast, the scale of analysis would be defined differently for social or ecological systems (see Figure 3-4).

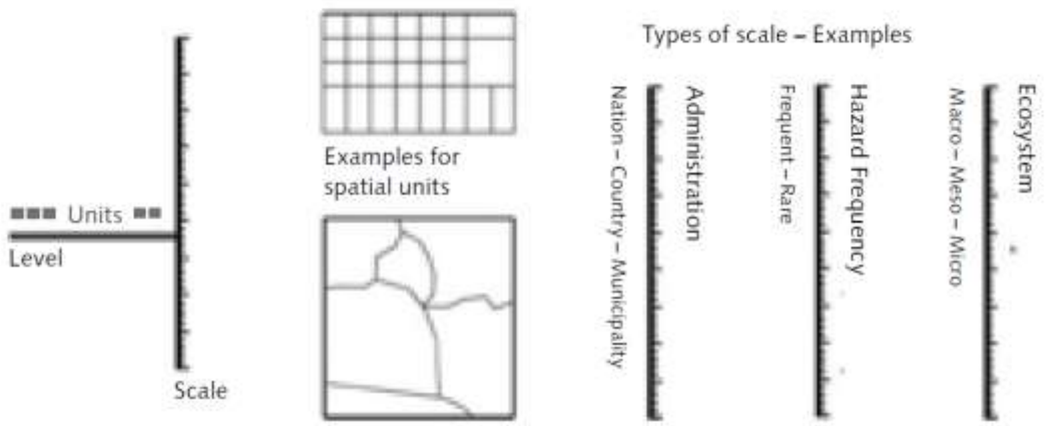

Figure 3-4: Visual interpretation of the terms 'scale' and 'unit'
Source: (Fekete 2009)

The selection of methodology depends on the scale and unit of the work. The Millennium Ecosystem Assessment (MEA 2003) states: "The choice of scale is not politically neutral, because the selection may intentionally or unintentionally privilege certain groups. The adoption of a particular unit of analysis limits the types of problems that can be addressed, the modes of explanations that are allowed, and the generalizations that are likely to be used in analysis.”

In terms of the selection of the scale and unit of analysis, there are some points which should be taken into consideration. Firstly, there is a certain cross-scale interaction among the scales existing in the current work. There are scale mismatches between social and ecological systems. In terms of cross-scale interaction, there is a high level of complexity of system dynamics which leads to difficulties in cross-scale analysis as people perceive the concept of scale differently (Cash, Adger et al. 2006). An example of cross-scale interaction is when land-use management influences a group of species belonging to the ecosystem of a landscape; changes in the ecosystem feed back to the social system which in turn triggers some further reactions by the decision makers.

Secondly, there are issues in dealing with up- and down-scaling when trying to convert all the data into a common unit of analysis (Cash, Adger et al. 2006, Wilbanks 2002, Wu, Li 2006, Kasperson, Kasperson et al. 1995, Cash, Moser 2000, Rogan, Miller 2006). Challenges include data availability on a specific scale, complexity of relationships between scales, capturing conceptual details of reality, computational capacity, ensuring that modelled data reach defined standards, and representing the stochastic and geographic variability of the original data. Some solutions have been addressed by Wilbanks (2002) and Fekete et al. (2009) for both up- and down-scaling issues.

Thirdly, data integration is a well discussed data-related concern, especially in the field of geography. “If the aim is to attain an integrated understanding of processes, simply converting numbers to a common spatial scale does not necessarily assure conceptual integration, as contrasted with computational integration” (Wilbanks 2002). The problem has its roots in theoretical foundations, process assumptions, and standards behind individual datasets. Furthermore, the existence of different disciplinary traditions increases the complexity of data integration (Wilbanks 2002, Wu, Li 2006). Further investigations and clarifications could be found in (Cash, Adger et al. 2006, Wilbanks 2002, Wu, Li 2006, Kasperson, Kasperson et al. 1995, Cash, Moser 2000, Rogan, Miller 2006, Gibson, Ostrom et al. 2000).

Scholars have introduced various approaches to selecting the most appropriate choice of unit and scale for a particular context. Wilbanks (2002) tried different methods, from minimising statistical errors amongst data to evaluating the gains of aggregating/disaggregating data compared to difficulties in analysis (Wilbanks 2002) (further examples can be found in Fekete et al. (2009)).

In order to pick out the most appropriate unit and scale, the objectives of the work should be considered. In addition, the end-user and their requirements and the type of available data are issues of concern (Cash, Adger et al. 2006). The East Riding of Yorkshire has been chosen as the study area according to the criteria discussed above (see part 3-2). The East Riding is one district of European administrative units NUTS3, and therefore the scale of this work is sub-regional. In addition to the reasons for choosing the East Riding described in part 3-2, it is noteworthy that decision-making processes occur at this administrative level, and therefore analysing the data within the boundary would be most useful. The unit of analysis has been defined as a 1 km grid cell on the British National Grid projection coordinate system. This unit was selected for several reasons: (a) to provide an overview of vulnerability at an intermediate rasterised surface, (b) to provide a distinctive unit of vulnerability analysis, (c) to go beyond the always-used administrative boundaries, and (d) to have a homogeneous unit.

The selection of the study area, the scale, and the unit of analysis has always been a cause for debate. Further work to this research could be the investigation of different choices of study area, scale, and unit.

3.6. Indicators as measurement tools

When dealing with the complex concept of vulnerability assessment, it is essential to reduce the number of available data sets to selected indicators which should qualitatively and quantitatively present an insight into the concept of vulnerability. The final document of the World Conference on Disaster Reduction, the *Hyogo Framework for Action 2005-2015*, stresses: "Develop systems of indicators of disaster risk and vulnerability at national and sub-national scales that will enable decision-makers to assess the impact of disasters" (UN/ISDR 2005).

There is rarely a perfect indicator. The explanation lies in the fact that indicators are designed as a balanced outcome of technical feasibility, societal usability, and systematic consistency (Damm 2010).

3.6.1. Definition

The definition of an indicator varies among the authors of different disciplines (for more definitions see (Birkmann 2006b, Damm 2010)); however, Gallopín defines an indicator as a sign that summarises information relevant to a particular phenomenon (Gallopín 1997). An indicator for assessing vulnerability with regard to natural hazard can be defined as:

> *"A variable which is an operational representation of a characteristic or quality of a system, able to provide information regarding the susceptibility, coping capacity and resilience of a system to an impact of an, albeit ill-defined event linked with a hazard of natural origin."* (Birkmann 2006a): 57)

Indicators have been widely recognised as measurement tools which transform raw data into information. Their usefulness lies in how well they communicate the socio-economic, physical, and environmental trends, monitor the conditions, measure the management policies, and in sum achieve the objectives and functions of the proposed research. In terms of vulnerability assessment, the main concern of the research is the identification and understanding of vulnerability and its underlying factors.

3.6.2. Strengths and weaknesses

There are advantages and disadvantages of indicators. Indicators are sufficient tools for simplifying the complex reality. They facilitate visualisation and judgment of vulnerability within the study area. In addition, indicators basically enhance communication and information between academia, the public and politicians. Furthermore, they are a powerful tool for evaluating a specified process over time.

Despite all the advantages of indicators and indices, there are limitations. Indicators and indices model reality imperfectly. In terms of simplification, there are serious risks of loss of information. They are greatly contingent upon their sources and data collection processes. Finally, even with a good understanding of the indicators and objectives, they are only relevant at a certain time and therefore cannot cover dynamic processes.

3.6.3. Selection criteria

Various criteria have been proposed by researchers in order to select the most relevant and applicable indicators. Damm (2010) identified three groups of criteria:

- Standard criteria (technical considerations):
  - validity/accuracy
  - relevance
  - reproducibility
  - sensitivity
  - transparency
- Participatory-relevant criteria (methodological considerations):
  - simplicity of interpretation
  - understandability
- Practitioner-relevant criteria (practical considerations):
  - data availability
  - cost-effectiveness
  - policy relevance.

The relation between indicators and vulnerability assessment goals needs to be explicitly examined; the usefulness of indicators can be judged by how well they attain the vulnerability objectives. The indicator development process is discussed in the next part.

3.6.4. Indicator development

Adger et al. (2004) proposed two fundamental approaches for indicator development: deductive and inductive. The deductive approach is a theory-based approach which develops indicators derived from framework, theory and relationships. The steps involved in a deductive approach are: (a) full understanding of the phenomenon of the study, (b) identification of the main processes to be outlined in the work, and (c) selection of the best possible indicators. The inductive approach is data-based and identifies the most statistically significant indicators out of a large list of datasets.

The current work uses both approaches. Firstly, after an understanding of vulnerability, the proposed framework, and underlying factors, a potential list of indicators is developed, and then statistical methods are used to extract the most significant indicators.

In addition, there are two types of indicators, qualitative and quantitative. As the main goal of this work is measuring vulnerability, a quantitative approach is selected. However, there are some indicators which have a qualitative basis (see Chapters 4, 5, and 6). Also, experts' opinions were involved in developing indicators, which means a semi-quantitative approach is used in this study. The process of indicator development taken in this work is as follows:

1. The goals of the study are defined
2. A conceptual framework is then developed
3. The scale of work is decided
4. The categories of vulnerability and related underlying factors are then identified
5. The selection criteria for the indicators are highlighted
6. A potential list of indicators is extracted
7. The proposed indicators are evaluated
8. The final list of indicators is proposed

3.7.Development of composite indicator and visualisation

There are many approaches to the visualisation of data; however, any decision should be based on the intended purpose, proposed audience, level of interactivity, and degree of abstraction (MacEachren, Bishop et al. 1994). The purpose of visualisation may vary from data exploration and visual thinking to presentation of ideas and mass audience communication, so the end-users of such visualisations range from single individuals (researchers) to a specified team or the public (DiBiase 1990). Demand for visualisation has grown, thanks to improved technology, developments in computer graphics, and increases in the volumes of data (Dykes 1994). However, a risk of unclear visualisation due to unprocessed or ill-processed data persists. Much literature exists on visualisation methods and applications, from inventing new models to the assessment of its relationship to spatial statistics (DiBiase 1990, Kraak, Ormeling 2010, Hearnshaw, Unwin 1994, Taladoire 2001, Taladoire 2001, Goodchild, Haining 2004, Yang 2007, Sidjanin 1998).

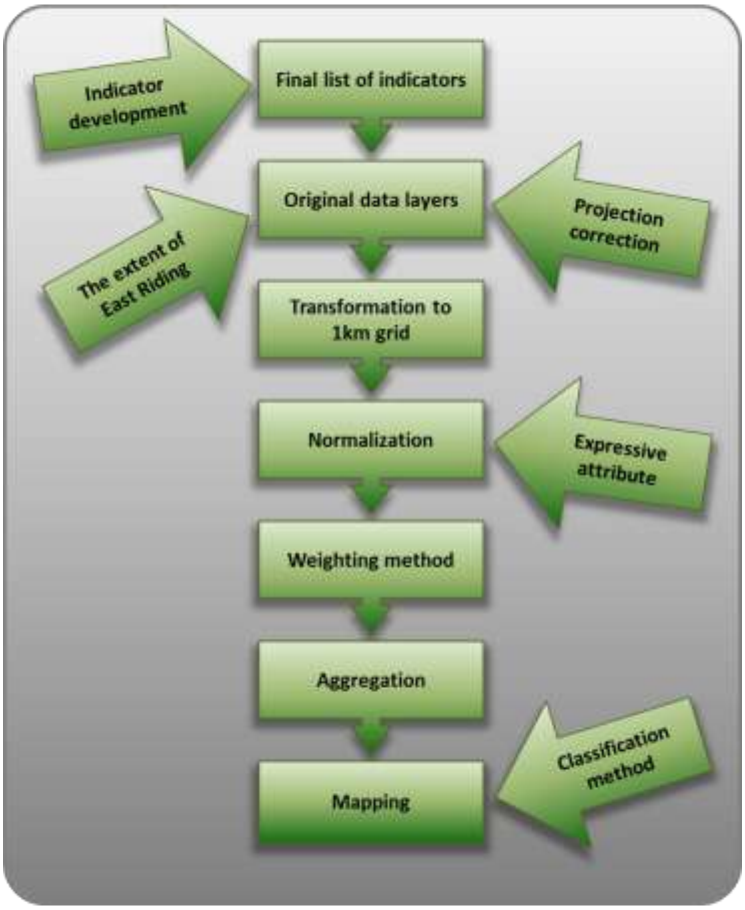

Figure 3-5: Development of composite indicator and visualisation

In addition, the indicators need some work to prepare for further analysis and aggregation for final composite indices. The composite indicator development process described in this part is applied in Chapters 4, 5, and 6. This process is illustrated in Figure 3-5. After the development of the relevant list of indicators for each sector (i.e. agricultural land, built-up areas, and wood lands), the original maps were collected from relevant organisations (metadata and a summary of all transformations of the indicators are presented in factsheets in Appendix 2). All data were projected onto the British National Grid. The layers were then cut to the extent of the study area, the East Riding of Yorkshire. A buffer of 5 km was defined in the “clip” tool of the ArcGIS tool box. The next steps of transformation, normalisation, weighting, aggregation, classification, and mapping are discussed in more detail in the following sections (Figure 3-5).

3.7.1. Data transformation

Transformation is defined as a process of changing form. In everyday life, objects change from one form to another. The same process happens when, owing to the research objectives, operational enquiries, or data compatibility, data need to be transformed from their original units into another. Because of the nature of the vulnerability assessment, many variables are included, with diverse data types and units. This study has transformed all data to the common unit of the research (part 3-5) prior to the analysis rather than transforming the resultant map, as suggested by Kraak ((Kraak, Ormeling 2010): 138).

Data transformation from one unit to another or even from one data type to another is critical. A variety of data types exist (nominal, ordinal, interval, and ratio), each needing its own method of transformation. Many studies have been conducted to find a better way of transforming data from one unit to another or from one type to another. This issue is related to the cross-area estimation of census data (Lo 2008, Foster, Gorr 1986, Fotheringham, Brunsdon et al. 2002, Bracken 1994). There is a comprehensive review of cross-area data estimation in the work by (Rezaee 2010, Saei, Chambers 2003, Wua, Qiua et al. 2005).

As described in section 3-5, the unit of work is a 1 km grid cell. On the one hand, there are both visualisation and integration advantages in this selection. On the other hand, the data transformation hinders the analysis. The process applied to each indicator has been described in the relevant chapter. Further work could address the effects of data transformation on the results.

3.7.2. Normalisation

Having been transformed into the defined unit of the research, the indicators all vary in their data range and distribution. To avoid adding up inconsistent variables, the process of normalisation changes them into dimensionless numbers. ESRI (2011) defines the process of normalisation as "the process of organizing, analysing, and cleaning data to increase efficiency for data use and sharing. Normalization usually includes data structuring and refinement, redundancy and error elimination, and standardization."

Nardo et al. (2005) identified ten approaches to the normalisation of data sets (Nardo, Saisana et al. 2005). The approaches rank from the simplest method, "ranking" the values across the units (Fagerberg 2001), to the cyclical method (Nilsson 2000). The re-scaling method based on minimum and maximum has been chosen for this work.

$$x_N = \frac{x_i - x_{min}}{x_{max} - x_{min}}$$

Equation 3-3: Maximum/minimum normalisation method

where x_N is the normalised value for the cell i, x_i is the original value, and x_{min} and x_{max} are the limits of the values over the whole data set. The re-scaling method is based on the range of the values rather than on other factors such as the standard deviation. The resultant normalised values have a range of (0-1). The disadvantage of this approach is that the limits (minimum and maximum) have a distorting effect on the transformed indicator. However, the benefit of the approach is that the values lying within the range have an increased effect on the composite indicator. This method has also been used for the Environmental Sustainability Index (ESI) (Esty, Levy et al. 2005).

3.7.3. Weighting

Central to the construction of the composite indicator is the need for defining a meaningful weighting system for the components. Different weights may be allocated to indicators to highlight their significance. The weighting system has a substantial effect on the composite index and the resulting ranking, and therefore must be made explicit and transparent.

A great number of methods have been introduced by researchers. The methods range from statistical approaches (such as principal component analysis and factor analysis) to participatory approaches (like analytical hierarchy process and budget allocation). There is not an approved method and individual scholars have advanced their own preferences. One may count on the statistical relationships among the indicators while another may prioritise the opinion of the stakeholders.

The current work, however, favours the use of the equal weighting (EW) system. Equal weighting refers to the equality of importance of all factors and components playing a role in the final composite indicator. This decision implies that for the set of indicators of this research there is no certainty as to which factors would have priority over others. Many other studies use the EW approach (Cutter, Mitchell et al. 2000, Nardo, Saisana et al. 2005, World Economic Forum 2002). The effects of other weighting methods on the composite vulnerability index and resultant maps will be further discussed and assessed in the chapter on sensitivity analysis (Chapter 7).

3.7.4. Aggregation

There is a hierarchical process in making an index out of raw data. Figure 3-6 shows the index pyramid which highlights the level of information density among the terms related to the index. Raw data need processing to be made meaningful and turned into information. The processed information represents a construct or an issue, qualitatively or quantitatively, and is called an indicator (see part 3-6-1). The peak of the pyramid is dedicated to the term “index” which represents the densest state of the information. An index is a result of aggregating several indicators via a function. It is a dimensionless number which is a result of transforming and aggregating data from different units. Vulnerability is such an index and consists of many indicators, each of them representing one aspect of the phenomenon.

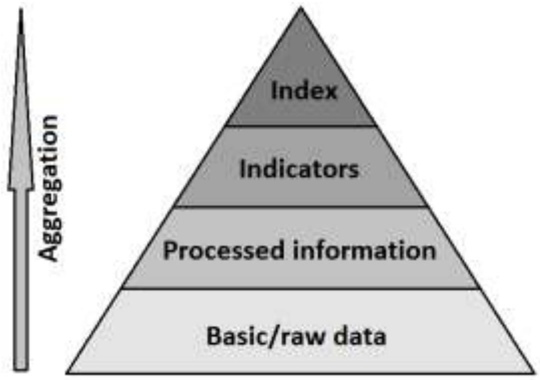

Figure 3-6: The index pyramid
Based on (Adriaanse 1994)

The benefits that composite indicators and indices bring to communities in terms of monitoring and managing the situation have persuaded many researchers to develop composite indicators. However, the comparison between these methods reveals that index development is largely dependent on the choice of study objectives, region, scale, unit, dimensions, and type of hazard. Examples of the development of indices in terms of vulnerability assessment are (Kaly, Pratt et al. 2004, Kaly, Pratt et al. 2004, ESPON 2005, ATEAM 2004).

The literature on composite indicators offers a good number of methods for aggregation. Nardo et al. (2005) have given an excellent review of the existing approaches (Nardo, Saisana et al. 2005). The most common approach is the additive method. Although additive methods are widely used for composite indicator studies, they imply requirements and restrictions. The most serious limitation of this type of approach is the fact that it gives a high level of notation to the sub-indicators and associated weights. Therefore other methods such as geometric and non-linear have been developed which are less well known.

The most common technique of the additive approach is used in this research. This method extracts the composite indicator as the summation of weighted, normalised sub-indicators, as given in Equation 3-4:

$$\boldsymbol{CI_i = \sum_{j=1}^{N} W_j \times I_{ij}}$$

Equation 3-4: Additive aggregation method

where

$\boldsymbol{i}$ = the cell number

$\boldsymbol{CI_i}$ = the composite indicator for the cell $\boldsymbol{i}$

$\boldsymbol{N}$ = the number of indicators

$\boldsymbol{I}$ = the normalised indicator

$\boldsymbol{W}$= the weight.

And therefore with regards to exposure and coping capacity indicators which hold positive and negative weights respectively, the formula can be written as:

$$\boldsymbol{V_i = (\sum_{j=1}^{N} W_j \times EX_{ij}) - (\sum_{k=1}^{M} W_k \times CC_{ik})}$$

Equation 3-5: Additive aggregation method for the BBC model

Where $\boldsymbol{V_i}$ is the final vulnerability index, $\boldsymbol{N}$ is the number of exposure indicators, $\boldsymbol{W_j}$ is the weight of $\boldsymbol{EX_{ij}}$ indicator of exposure. $\boldsymbol{M}$ is the number of coping capacity indicators, $\boldsymbol{W_k}$ is the weight of $\boldsymbol{CC_{ik}}$ indicator of coping capacity.

The choice of aggregation method can greatly affect the resultant index and interpretation. Knowledge of the sub-indicators and components of the analysis is necessary for obtaining meaningful trends and results. The methods chosen for this work are simple and easy to apply. However, the effects of other aggregation methods on the final vulnerability index are discussed in the chapter on sensitivity analysis (Chapter 7).

3.7.5. Classification

The last step before mapping the composite indicators is the classification of the index. Classification is the process of conveniently arranging or systematically grouping data according to one or more characteristics (Kraak, Ormeling 2010).

There are debates on whether classification of spatial data is needed or not. Tobler (1973) stated that the most useful representation of data would have as many grades of shading as data values, and Dykes (1994) declared that regrouping data into classes reduces the communication capability and the potential for personal vagaries in interpretation (Dykes 1994). The main advantages of unclassified maps are that the resulting image is not generalised and extreme values are better isolated.

In contrast, other scholars disagree with Tobler's idea, commenting that an unclassified map does not model or provide any insight into the data (Kraak, Ormeling 2010, Dobson 1973). In addition, the presence of a large number of grey shades reduces the legibility of the map, and it is virtually impossible to perceive the differences between features which are further apart geographically.

So, if we are to classify the spatial data, we need to make sure that the chosen method will give a clear view of the mapped phenomenon. There are conditions to be considered prior to developing a classification method: (a) the purpose of the map needs to be decided; (b) the final representation should mimic the statistical surface of the data; (c) the classification method should display the pattern of the desirable characteristics of the phenomenon; (d) each class needs to cover its share of the observation values; (e) the type of data needs to be considered (qualitative vs. quantitative); (f) the maximum number of classes recognisable by individuals at one glance is 7-8 (Kraak, Ormeling 2010).

Classification methods can be further grouped into graphical and mathematical. Natural breaks, frequency diagrams, and cumulative frequency diagrams are the most common methods in the graphical approach. However, the mathematical approaches have been more favoured by investigators. The most famous mathematical classification techniques are: equal steps, quantile, arithmetic, geometric, harmonic, and nested mean (Kraak, Ormeling 2010).

For the classification of the resultant vulnerability index of three land cover sectors, the quantile classification method is used. All resultant indices (coping capacity, exposure, environmental, physical, economic and social vulnerability, and FVI) in each sector are classified using the quantile method. There are two ways to check if the chosen method is adequate for the pattern of the data: comparing the histogram of the real data with the histogram of the method (Kraak, Ormeling 2010): 130), and comparing the map with the statistical surface of the data.

3.7.6. Cartography

Maps are meant to display the spatial data through a meaningful visualisation. It is the abstraction of data that gives power to maps (Muehrcke 1990, quoted in (Dykes 1994). However, the mapping is the most critical task as the map types and attributes deeply affect the way the mapped phenomena are judged.

In making a map, the initial issues to bear in mind are the characteristics of the attributes to be mapped and the aim of the mapping. The graphic variables need to be specified. Thirdly, a common denominator has to take place. The data variables need to be assessed and their characteristics described. The last aspect of the cartographical process is the information hierarchy: which data aspects are most important, which are least, and which come in between (Kraak, Ormeling 2010). Graphic variables can be classed as discrete or continuous. The discrete class includes point data, linear data (lines and vectors), area data, and volume data. The continuous class consists of surface data and volume data. Nine mapping methods can be discerned: dot map, choropleth map, chorochromatic map, isoline map, statistical surface, diagram map, flow line map, cartogram, and proportional map (Kraak, Ormeling 2010).

The appropriate map type can be selected with regard to the data type (qualitative or quantitative, and nominal, ordinal, interval, ratio, or composite) and graphic variables. The indices for each sector are continuous variables ranging from their minimum to their maximum. As these are continuous surface data, choropleth mapping is used to visualise the results.

3.8.Conclusion

Critical issues in the methodology of this work have been introduced and described in this chapter. Owing to the nature of this research, it is beneficial to set out the methodological processes once and then apply them in the following chapters (Chapters 4, 5, and 6).

The East Riding of Yorkshire has been chosen as the case study area for the work for the following reasons: (a) parts of the region are prone to flooding, according to the historical flood records and the Environment Agency flood risk maps; (b) the area is characterised by a diverse landscape which makes it appropriate for the objectives of a GIS-based work; (c) the East Riding is close enough in case should the work need any field observation; (d) the vulnerability analysis requires a great number of variables, and a good number were available for this region; (e) the area is a European administrative NUTS3 unit and appropriate for further extension and transformation.

The BBC framework derived from the United Nations University- Institute for Environment and Human Security (UN-EHS) has been chosen to provide the conceptual framework for the study. This framework is closely related to vulnerability, risk, human security, and sustainable development. In such a holistic framework, vulnerability relates to the characteristics of people or groups that influence the impact of hazard events on them. These characteristics depend on the unsafe conditions of people in relation to a set of dynamic pressures which are caused by another set of indicators.

However, some modifications are made to the BBC framework in order to make it compatible with the research. The modified BBC framework incorporates principles of risk and vulnerability analysis from all other schools of thought. Unlike the previous frameworks, the modified BBC framework sets out four elements of sustainable development defined by UN-ISDR as the pillars of assessment: environmental, physical, economic and social. In addition, the framework understands that there are two ways to reduce vulnerability, by addressing coping capacity and exposure/susceptibility, as well as by using intervention tools. The BBC framework promotes a proactive approach towards vulnerability reduction. Taking a dynamic view of vulnerability provides two opportunities to reduce vulnerability: before a disaster strikes and after. The modified BBC framework puts the overall loop of risk and vulnerability reduction into the nutshell of scale and site specification.

A geographical stratification of land by human activities is introduced in this research. This approach is an annotation from the sectoral vulnerability assessment (Villagrán de Léon, J. C. 2006). The East Riding of Yorkshire has been geographically stratified on the basis of the present maps and datasets, and three strata of vulnerability have been distinguished: arable, urban, and wildlife.

The unit of analysis has been defined as a 1 km grid cell on the British National Grid projection coordinate system. This unit was selected for several reasons: (a) to provide an overview of vulnerability at an intermediate rasterised surface, (b) to provide a distinctive unit of vulnerability analysis, (c) to go beyond the always-used administrative boundaries, and (d) to have a homogeneous unit.

After the framework of the study, the study area and the unit and scale of analysis have been defined, it is time to develop an appropriate list of indicators. When dealing with the complex concept of vulnerability assessment, it is essential to reduce the number of available data sets into selected indicators, which should qualitatively and quantitatively present an insight into the concept of vulnerability. Numbers of criteria have been proposed by researchers in order to select the most relevant and applicable indicators (Birkmann 2007, Damm 2010, Birkmann 2006a). The relation between indicators and vulnerability assessment goals needs to be explicitly examined; the usefulness of the indicators can be judged by how well they attain the vulnerability objectives. The indicator development process is discussed in the next part. However, the current work uses both approaches. Firstly, after an explanation of vulnerability, the proposed framework, and underlying factors, a potential list of indicators was developed and secondly statistical methods were used to extract the most significant indicators.

Once the final list of indicators is ready, all the data sets need preparation. All data were projected onto the British National Grid. The layers were then cut to the extent of the study area, the East Riding of Yorkshire. A buffer of 5 km was defined in the "clip" tool of the ArcGIS tool box.

Transformation was applied to every dataset where data need to be transformed from their original unit into another, owing to the research objectives, operational enquiries, or data compatibility. Different techniques were used according to the nature of the data, and therefore the processes are described in the relevant sector where the data are used.

Once all indicators have been transformed into the defined unit of the research, they vary in their data range and distribution. To avoid adding up inconsistent variables, the process of normalisation changes them into dimensionless numbers. The re-scaling method based on minimum and maximum has been chosen for this work, as discussed in part 3-7-2.

Central to the construction of the composite indicator is the need for defining a meaningful weighting system for the components. The current work uses the equal weighting (EW) system. Equal weighting refers to the equality of importance of all factors and components playing a role in the final composite indicator.

The final indices are composite indicators which are the result of aggregating the weighted normalised indicators. The additive approach extracts the composite indicators as the summation of weighted, normalised sub-indicators (Equation 3-4).

For the classification of the resultant vulnerability index of three land cover sectors, the quantile classification method is used. All resultant indices (coping capacity, exposure, environmental, physical, economic, social, and FVI) in each sector are classified using the quantile method.With regard to the data type (qualitative or quantitative, and nominal, ordinal, interval, ratio, or composite) and graphic variables, the appropriate map type can be picked. The indices for each sector are continuous variables ranging from their minimum to their maximum. Because of continuous surface data, choropleth mapping is used to visualise the results.

4. Vulnerability of the arable sector to flooding

4.1. Introduction

Great numbers of studies have focused on flooding in residential and built-up areas. This concern is justifiable as these areas are highly valuable in economic and human terms. Messner and Meyer (2006) have claimed that agricultural land has the least potential to suffer flood damage (Messner, Meyer 2006). This might be a fact, but in a region like the East Riding of Yorkshire where agriculture (i.e. arable and grassland) is an important pillar of the region's economy the vulnerability of this sector should be discussed.

Much of the land within the East Riding of Yorkshire is agricultural (split into arable and grassland), which clearly shows the importance of the agricultural industry in the area. Although about 90 per cent of the land in the East Riding is agricultural and there are over 4,000 agricultural workers, only around 2-3 per cent of the area's economy directly depends on agriculture (Coastal Observatory 2012). This industry, however, is under pressure from several trans-national factors such as the reform to the Common Agricultural Policy (CAP) which means farmers are no longer paid for the type of crops grown. Instead, farmers are granted incentives for additional contributions to environmental stewardship, improvements in animal welfare and agricultural land conditions (East Riding of Yorkshire Council 2008).

Having the GVA (Gross Value Added) well below regional and national level, the significance of the agricultural industry has been recognised in the East Riding. Some farm diversification schemes provide some new income for landowners, such as the re-use of buildings for tourism accommodation, workshops, and business spaces. In addition, there are some established manufacturing industries in the region, specifically caravan production, food products, chemicals, and engineering (East Riding of Yorkshire Council 2008).

One of Defra's priorities refocused by the coalition government is supporting and developing British farming and encouraging sustainable food production. 90 per cent of the agricultural lands in the East Riding are classified as excellent, good, or good/moderate in quality, and this industry has been capitalised much better than in other areas, showing a constant and high level of agricultural production (East Riding of Yorkshire Council 2011a). Nevertheless, there has been a dramatic reduction in the agricultural workforce: Defra reports that the total number of agricultural workers (full-time, part-time, and casual) has decreased from 8,414 in 1997 to 7,047 in 2009 (East Riding of Yorkshire Council 2011a).

In the arable industry, there is a mix of crops grown in the East Riding which varies geographically and depends on soil type and topography. The main crops cultivated in the area consist of cereals, oilseed rape, sugar beet, potatoes, and field vegetables. In addition, there are some minor crops grown for the pharmaceutical and niche markets, such as borage, crambe, hemp, and linseed. The mix of crops grown in the region has been changed and influenced by weather, market conditions, structural supply chain, and policy chain (East Riding of Yorkshire Council 2011a, East Riding of Yorkshire Council 2012).

Horticultural production in the East Riding is divided into two sectors: (1) vegetables grown in the open, and (2) crops grown under glass. The livestock industry in the East Riding includes four main sectors: pigs, poultry, dairy and beef cattle, and sheep. In the pig sector, despite increased sales to health-conscious people, there has been a sharp decline in production. The major challenges facing this sector are high prices of raw materials, devaluation of the pound, and subdued feed prices (East Riding of Yorkshire Council 2011a). In the poultry sector, two main producers have helped the industry to develop: highly integrated international processors and localised independent specialist producers of poultry and eggs. Experience shows some key issues in this sector: volatile input costs (energy, water, feed), environmental compliance, disease control, lack of return to encourage investment, and implementation of EU welfare directives (East Riding of Yorkshire Council 2011a). Beef herds and dairy herds are intertwined as about 50 per cent of beef production comes from dairy herds. This sector has shown a period of decline in the past; however, there is an optimistic forecast for the coming years. There has been a decline in sheep flocks recently at both national and local (East Riding) level. Expensive lamb meat is a negative factor; however, improved market conditions are a positive force that slows down the contrast in the sheep flock industry (East Riding of Yorkshire Council 2011a).

The issues discussed above have been presented in order to provide a rough idea about the agricultural situation in the East Riding of Yorkshire. Following this section, the effects of flooding on agricultural land will be discussed. Afterwards, the methodology of flood vulnerability assessment will be introduced, applied, and concluded. This chapter will end with results and conclusions which will be employed in order to discuss and evaluate the weaknesses and strengths of the area in relation to flood management.

4.2.Flood effects on agricultural land

Historically, wetland was seen as wasteland, so humans started to dry the land and draw economic benefits from it without considering the environmental consequences and long-term land sustainability (Porter, Snyder et al. 1992). In the East Riding, most of the agricultural lands are located within wetlands and flood plain areas. As a land-based industry, agriculture is sensitive to flooding. In most cases high rainfall caused problems to the land prior to flooding; however, extreme storms, high surface flow, an overloaded drainage system, and overtopped flood defences also have an effect (Posthumus, Morris et al. 2008). Three types of floods may affect agricultural land (ADAS 2007):

- severe flooding with high water level and duration longer than one week
- flooding which is less prolonged and less deep
- logged water.

The rest of this section discusses the costs and damages which flooding imposes on agriculture. However, there are research studies showing some beneficial gains from flooding (Hansen 1987). Banerjee (2010) argues that although floods decrease yields they offer open access irrigational inputs to the fields. In addition, a larger cultivation area and a higher productivity rate have been observed among flooded fields in Bangladesh (Banerjee 2010).

The farm animal industry also suffers from flooding. Lower production in the dairy industry is the most visible impact. In the sheep, beef, poultry, and pig industries, food and water shortages, increased diseases, and reduced growth rate are primary costs (Posthumus, Morris et al. 2008, ADAS 2007).

4.2.1. Damage

A flood event results in economic loss, social distress, and environmental disruption. Prolonged soil saturation depresses crop growth and yield, depletes the soil of oxygen and increases disease risk (Butzen 2012). The main costs of a flood incident have been recognised as yield loss and crop damage. However, the impact of a flood may last much longer and cause indirect costs and damages. The 2007 flood in England cost the agricultural industry over £50 million (Posthumus, Morris et al. 2008). The following costs and damages imposed on agriculture have been proven by researchers: (Posthumus, Morris et al. 2008, ADAS 2007, Hansen 1987, Butzen 2012, del Carmen Silva-Aguila, Lopez-Caloca et al. 2011, NDSY Extension Services 2010, Borruf 1994, Van Zyl, Groenewald 1984)

1. loss of yield and crop damage
2. loss of fodder supplies
3. additional management time
4. decreased livestock growth rate
5. less milk production
6. cost of land reinstatement
7. damage to buildings and assets
8. personal distress and social impacts
9. ongoing reparation.

Crop damage due to flooding is inevitable, although the degree of damage depends on various factors. The type of cultivation is important; for example, vegetables are more sensitive than crops. The growth stage might help the crop to survive better as the yield is taller and stronger, but at the same time its oxygen consumption is greater, which may make it more sensitive to flood accumulation. Flood duration is another factor: the longer the duration, the higher the crop damage. Warm soil and air temperatures speed up respiration, oxygen consumption and plant death. Water motion is another issue which may help the plant to survive. Finally, soil drainage and weather conditions can be mentioned. Cold and wet weather stresses roots, limits plant recovery, and favours diseases. Hot and windy conditions bake the soil, causing rapid drying and crusting (Butzen 2012, NDSY Extension Services 2010, Thomison 1995, Rao, Li 2003, Wiebold 2007).

The primary damage to crops from flood water is due to lack of oxygen, which is vital for plant growth and development. Studies show that the oxygen content of water is much lower than that of air and soil, and the oxygen level in water approaches zero after 24 hours (NDSY Extension Services 2010, Wiebold 2007). Other factors which cause damage to cultivation are a lack of nitrogen (N), which leads to permanent yield reduction; the presence of silt and residuals on the leaves of crops, which reduces photosynthesis; damaged roots and delayed growth, which increase the risk of disease (such as Fusarium root rot, Phytophthora rot, or Pythium rot); changes in nutrients by availability or leaching; and the accumulation of CO_2, which is toxic for plants (Butzen 2012, NDSY Extension Services 2010, Wiebold 2007).

4.2.2. Management practices

There are some soil and seed management practices which may decrease the impacts of flooding on crops. Firstly, planting dates could be shifted in order to avoid the times when floods occur. Secondly, some soil management practices such as ridging, furrowing, and making raised beds might be applied in order to reduce the risk of flooding and pollution. Thirdly, seed treatments and weed control have shown positive effects on the reduction of flood damage. Fourthly, using chemicals for land amelioration is recommended (Butzen 2012, NDSY Extension Services 2010, Rao, Li 2003, Howe, White 2003). Replanting is an economic decision which might be taken after a flood strike. However, care must be taken as yellow and damaged crops may recover after good management. It is recommended that farmers should check with crop insurers and agronomists before making any decision (Butzen 2012).

4.3.Inconsistency map of the arable sector

The first step towards vulnerability analysis is mapping the extent of agricultural land within the boundary of the East Riding of Yorkshire. There are different data sets available from various organisations which map the extent of arable land. Table 4-1 below gives description extracted from available metadata, direct contact with associated organisations, and online web pages. The extent of agricultural land has been defined by various organisations according to their needs and objectives. For example, arable land and grassland have been mapped by the Centre for Ecology and Hydrology (CEH) in six different land-use classes within the Land Cover Map 2007 dataset, whereas the Rural Payment Agency holds a Single Payment Scheme dataset in a GIS shape file format that shows areas provided with incentives by the Rural Payment Agency in order to assist them in better land management.

According to the sources listed in Table 4-1, there are two comprehensive sources for mapping agricultural lands (arable and grazing), the Land Cover Map 2007 (LCM 2007) and Rural Payment Agency (RPA); two sources for extra arable, MasterMap for orchards and Vector Map District for glasshouses; and one for grazing parcels from Natural England.

Table 4-1: List of data sources for arable lands

Title	Data source	Scale/ Resolution	Data Format	Availability	Temporal resolution
Land Cover Map (2007)	Centre for Ecology and Hydrology(CEH)	25 m	Raster	License agreement	2007
Single Payment Scheme	Rural Payment Agency (RPA)	–	Vector	License Agreement	2012
Coastal and Floodplain Grazing Marsh	Natural England	10-100 m	Vector	Public Domain	2002
Glasshouse from Vector Map District	Ordnance Survey	1: 25000	Vector	License Agreement	2010
Orchards from MasterMap Topography Layer	Ordnance Survey	1:1250-1:10000	Vector	License Agreement	2012

There are always errors and uncertainties in spatial data (Robinson, Fisher et al. 2005). In addition, organisational objectives, rules, methods and tools make them inconsistent with other similar data bases. It is possible to integrate dissimilar data bases to map a phenomenon, depending on the purpose of the study (Comber, Fisher et al. 2004b).

For the sake of consistency evaluation, a 30 m x 30 m grid for the extent of the East Riding of Yorkshire was sketched. Then a binary presence of each data source was recognised. Five datasets presented in Table 4-1 were used. Figure 4-1 shows the final map of arable land within the East Riding of Yorkshire. The darker the grey colour, the more certain the existence of arable land. However, datasets are not much ontologically coincident, although this presentation of them can reveal some facts. The vast majority of parcels of land are claimed by two datasets (medium grey on the map).

The reason behind the inconsistency of data sets could be errors or actual change (Comber, Fisher et al. 2004b). In addition, different datasets put in a nutshell different conceptual views. The type of technology used to extract the data, political variations, and the perspective of the organisation may well affect the result of the survey. Furthermore, in this case, especially, because of the time gap (from 2007 to 2012) there might be real land cover change (Comber, Fisher et al. 2004b, Comber, Fisher et al. 2005).

If the graded shades of grey become unified, a map of arable land in the East Riding of Yorkshire forms. Therefore, we get a map of every possible agricultural parcel from five different datasets. Most of the area is covered by agriculture except for human settlements and woodlands. As a result, it is noticeable how important the agricultural industry is in the region. This is one of the characteristics of the area and the reason behind the idea of this work to consider agriculture as a series of strata in terms of flood vulnerability assessment.

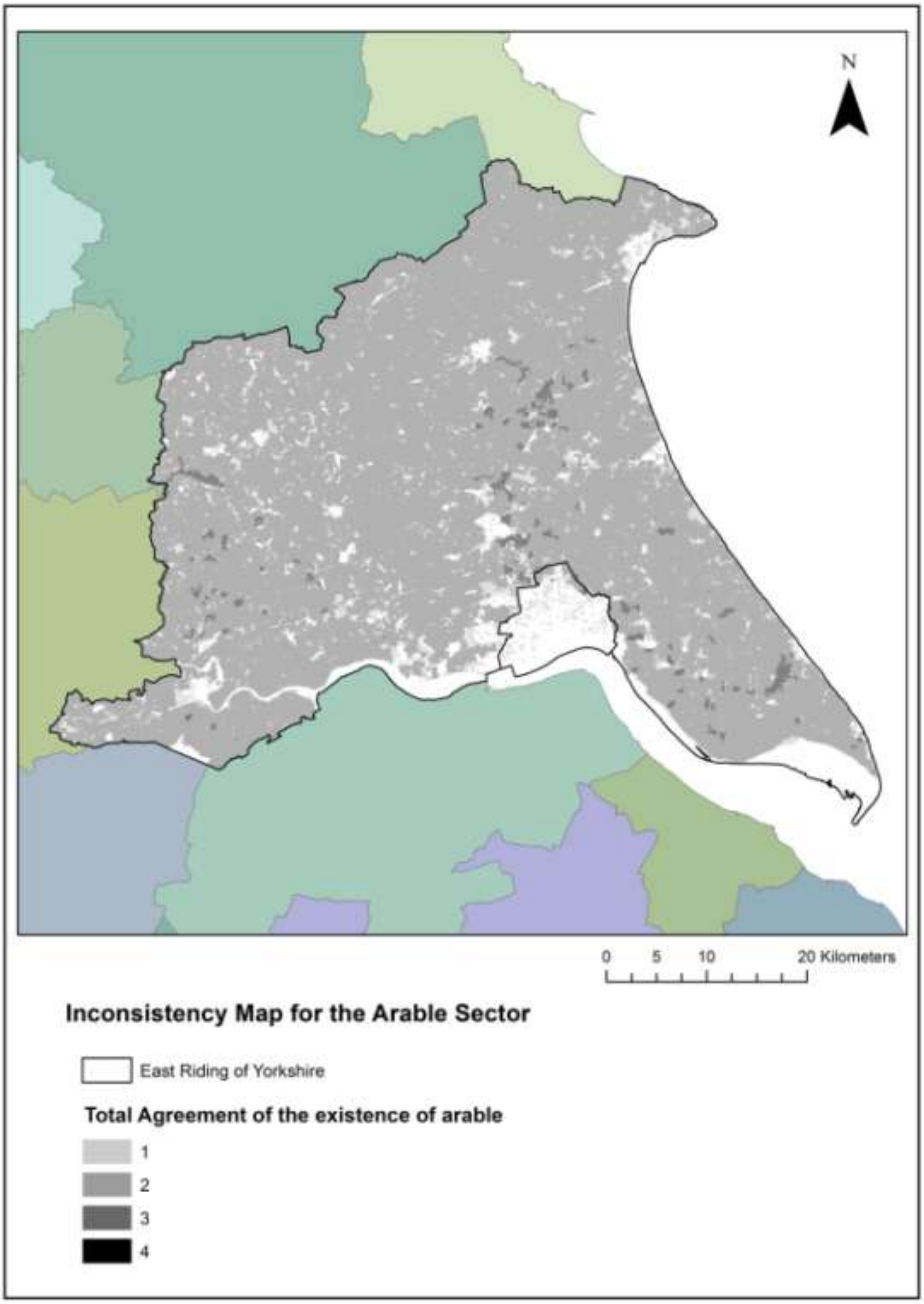

Figure 4-1: Inconsistency map of the arable land

4.4.Indicator selection

The separation of three strata of vulnerability indicates that there are different indicators effective for each strata. In addition, the flood vulnerability assessment is (1) hazard-specific, since it focuses on the factors that are directly relevant to flood hazard and tries to draw a map which shows locations highly vulnerable to flooding; (2) set at a medium-local level, the East Riding of Yorkshire; and (3) inclusive and at the same time simplified. Both qualitative and quantitative factors have been utilised, such as degree of land quality and crop yield for arable lands.

The goal is to map and visualise highly vulnerable farmland. In this section, the analytical processes of vulnerability assessment of the arable sector will be described. GIS has been exclusively used in order to facilitate the work for visualisation and statistical analysis. The social component is absent in this chapter (it is discussed in Chapter 6). Only farm crops, vegetables, animals, assets, and property are accounted in this chapter.

The identification of vulnerability components, sub-components and representative indicators is of great importance. Based on the indicator development flowchart by Maclaren (1996) presented in the methodology chapter, the first step is goal specification (described in the previous paragraph).

The objective of this work is to develop a composite vulnerability index, map highly vulnerable places, and identify some recommendations to overcome shortages in flood vulnerability management. A visualisation of highly vulnerable places within the agricultural land of the East Riding of Yorkshire based on the developed criteria can dramatically help to achieve the aims of the research. The scope of analysis therefore is at a medium-local level, hazard-specific, simplified, and inclusive.

Scholars have proposed a range of indicators for the vulnerability assessment of arable land based on their work's perspectives and objectives. Social and biophysical indicators are involved. Table 4-2 summarises a list of indicators proving the coverage of vulnerability usage from diverse disciplines.

Table 4-2: Potential list of vulnerability indicators for the arable sector

Indicator	Literature
Land area	(Damm 2010) (Kaly, Pratt et al. 2004)
Employed people People engaged with agriculture Non-agricultural workers	(del Carmen Silva-Aguila, Lopez-Caloca et al. 2011) (Cutter, Boruff et al. 2003) (Roy, Blaschke 2011)
Unemployment rate	(Damm 2010)
Soil erosion Erodibility (Non-sealed surfaces with erosion potential)	(Damm 2010) (Scheuer, Haase et al. 2011) (Kaly, Pratt et al. 2004) (Myeong, Hong 2009) (UN/IEHS and NNGASU 2006)
Contaminated sites	(Damm 2010) (Scheuer, Haase et al. 2011)
Soil type (Water retaining capacity, texture, type, filter, soil permeability)	(Damm 2010) (Yahaya, Ahmad et al. 2010) (Myeong, Hong 2009)
Dominating land use Vegetation cover Land cover Land value Vegetation cover rate	(Damm 2010) (Kaly, Pratt et al. 2004) (Yahaya, Ahmad et al. 2010) (Myeong, Hong 2009) (Roy, Blaschke 2011) (Scheuer, Haase et al. 2011) (Chen, Chen 2008)
GDP	(Damm 2010) (Chen, Chen 2008)
% of gross value added agricultural sector	(Damm 2010)
% of farmers with side income	(Damm 2010)
% of protected areas	(Damm 2010)
% of organic farming	(Damm 2010)
Buildings, infrastructure, commercial establishments, available budget	(Cutter, Boruff et al. 2003) (Kaly, Pratt et al. 2004) (Scheuer, Haase et al. 2011) (Chen, Chen 2008)
Hot/cold periods	(Kaly, Pratt et al. 2004)
Wet/dry periods	(Kaly, Pratt et al. 2004)
Sea Temperatures	(Kaly, Pratt et al. 2004)
Dispersion	(Kaly, Pratt et al. 2004)
Isolation (distance to nearest town or...) Distance to major/minor road/town	(Kaly, Pratt et al. 2004) (Roy, Blaschke 2011)

Borders	(Kaly, Pratt et al. 2004)
Intensive farming % of agricultural land that is overused	(Kaly, Pratt et al. 2004)
Fertilizers	(Kaly, Pratt et al. 2004)
Pesticides	(Kaly, Pratt et al. 2004)
Renewable water	(Kaly, Pratt et al. 2004)
Waste production/treatment	(Kaly, Pratt et al. 2004)
Vehicles	(Kaly, Pratt et al. 2004)
Environmental agreement	(Kaly, Pratt et al. 2004)
Average slope of basin Relief Elevation	(Connor n.d.) (Yahaya, Ahmad et al. 2010) (Myeong, Hong 2009) (Chen, Chen 2008) (Kaly, Pratt et al. 2004)
Investment amount	(Connor n.d.) (UN/IEHS and NNGASU 2006)
Annual rainfall Precipitation intensity Frequency of heavy rainfall	(Yahaya, Ahmad et al. 2010) (Myeong, Hong 2009) (Connor n.d.)
Drainage network	(Yahaya, Ahmad et al. 2010) (Chen, Chen 2008)
House Holds owning agricultural lands	(Roy, Blaschke 2011)
Preparedness for possible flood occurrence	(Adelekan 2011)
Distance to a river	(Adelekan 2011)
Transport (rail/road)	(Scheuer, Haase et al. 2011)
Farming income	(Chen, Chen 2008)
Distance to a river	(Adelekan 2011)

Indicators have been selected from Table 4-2 on the basis of the criteria proposed by Birkmann (discussed in detail in Chapter 3). Extra care should be taken in selection of relevant indicators as there are differences between this study and the ones done before. From BBC perspective some indicators may be assigned to hazard category rather than vulnerability, or some may differ in components which they belong to. The context, scope, goal, and characteristics of the research are important in indicator development.

Table 4-3 reveals the final list of indicators selected for vulnerability assessment of the arable sector. Indicators are allocated to vulnerability components and sub-components. The abbreviations for indicators used throughout the work are introduced as well.

4.5. Development and evaluation of a composite indicator

Development of a flood vulnerability index (FVI) for the arable sector requires a set of steps. The relevant flowchart is provided in Chapter 3 along with a comprehensive description. Firstly, the components and sub-components of vulnerability have been identified and appropriate indicators have been assigned to them (Table 4-3).

Table 4-3: Final list of arable flood vulnerability indicators

Component	Sub-component	Indicator
environmental	Exposure/ susceptibility	Geological indicators of flooding (GIF)
	Exposure/ susceptibility	Flood zones (FZ)
	Coping Capacity	Permeability (PRB)
	Exposure/ susceptibility	Pollution Incidents (PI)
	Exposure/ susceptibility	Groundwater areas (SPZ)
	Exposure/ susceptibility	Landfill sites (LFS)
	Exposure/ susceptibility	Contaminated land (CL)
	Exposure/ susceptibility	Surface water (SWF)
Physical	Coping Capacity	Construction and Repair services (CONS)
	Coping Capacity	Central and local government (RESC)
	Coping Capacity	Train stations (TRN)
	Coping Capacity	Roads (ROAD)
Economic	Exposure/ susceptibility	Agricultural workers (AGWR)
	Exposure/ susceptibility	Farm location (FARM)
	Exposure/ susceptibility	Land productivity (ALC)
	Exposure/ susceptibility	Farm livestock (DFR)

Secondly, variables have been transformed into a 1 km grid and normalised. Thirdly, a descriptive approach has been taken to evaluate the statistical characteristics of indicators. Fourthly, a correlation analysis has been carried out to evaluate the relationship between the indicators. Fifthly, the composite index has been calculated. Sixthly, the final flood vulnerability index (FVI) of the arable sector is visualised by means of FVI maps and discussed.

4.5.1. Data transformation and normalisation

There are, overall, sixteen indicators of vulnerability in the arable sector. The original maps of indicators, their metadata and a description are provided in Appendix 2, while the metadata presented in Appendix 2 are summarised in Table 4-4. For the sake of simplicity, abbreviations have been assigned to variables. Environment-related indicators are mostly provided by the Environment Agency; Ordnance Survey, Natural England, and CASWEB are the other sources of data sets. It is essential to have a good understanding of indicators before making use of them. Spatial resolutions of indicators vary as demonstrated in Table 4-4. This work has been carried out in a raster theme and at medium administrative level. A grid with 1 km cells has been sketched and all indicators have been remapped into this theme. The transformation method varies among the indicators according to their characteristics. The normalisation method, however, is min/max, as described in detail in Chapter 3.

4.5.1.1. Environmental indicators

There are eight indicators of environmental vulnerability for the arable sector. In this section, the map and the process of transforming data from the original format to 1 km grids are presented.

- Geological Indicators of Flooding (GIF):

Figure 4-2 shows both zone 1 and zone 2; coastal and fluvial categories are dissolved since the probability of occurrence, not the cause of flooding, is the matter of importance. Since analysis is done on 1 km grid cells, the original map of GIF-

Table 4-4: Summary metadata of the arable indicators

Indicator	Variable	Organisation	Resolution / scale	Data format	Availability	Date
Geology of land	Geological indicators of flooding (GIF)	British Geological Survey (BGS)	1:50 000	Vector polygon	License agreement	2011
Permeability	Permeability Index (PRB)	BGS	1: 50 000	Vector point data	License agreement	2010
Flood zone	Flood zones 2 and 3 (FZ)	Environment Agency	1: 10 000	Vector polygon	License agreement	2012
Pollution	Pollution incident (PI)	Environment Agency	1: 10 000	Vector point data	License agreement	2001-2012
Groundwater areas	Source protection zones (SPZ)	Environment Agency	-	Vector point data	License agreement	
Polluted lands	Landfill sites (LFS)	Environment Agency	-	Vector Polygon	License agreement	1975-2011
Contaminated lands	Contaminated lands (CL)	Environment Agency	-	Vector Polygon	Vector Polygon	
Surface water	Flood Map from Surface Water (SWF)	Environment Agency	-	Vector Polygon	License agreement	2010
construction services	Points of Interest-Construction (CONS)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Rescue services	Points of Interest-rescue services (RESC)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Train stations	Points of Interest-Train stations (TRN)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Roads	Roads from Vector Map District (ROAD)	Ordnance Survey	1:25 000	Vector polyline	License agreement	2011
Agricultural workers	Industry of employment (AGWR)	CASWEB	Output Areas	Vector polygon	Public domain	2001
Land productivity	Agricultural Land Classification (ALC)	Natural England	1:1250 - 1:10000	Vector polygon	Public domain	2002-2009
Farm locations	Points of Interest-Farms (FARM)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Farm livestock	DEFRA (DFR)	DEFRA	2 km	Vector grid	License agreement	2010

(presented in Appendix 2) is converted to a 1 km grid. Scores are given to each cell based on the area of zone 1 and zone 2 within them. Weights of 1 and 0.5 were given to zone 1 and zone 2 to show the level of importance respectively. Normalised scores are the final rank of each cell, as illustrated in Figure 4-2. Compared to the original map of GIF, the rasterised version represents a good visualisation of the data. Areas around rivers and water bodies are especially highly remarkable.

- Permeability Indicator (PRB):

Bedrock and superficial permeability are two outstanding layers of permeability derived from British Geological Survey (BGS) maps which cover the area. In some places they overlap and therefore a merged layer called surface permeability has been extracted by the author (Appendix 2). From the resultant layer, two scenarios are proposed: maximum permeability and minimum permeability (classified in the shapefile attribute table). Generally, a flood happens after massive rainfall, when the soil is almost saturated; hence minimum permeability has been utilised. There are five levels of permeability for each scenario: very high, high, medium, low and very low. A final score is given to each grid by multiplying the area of each level of permeability by 5, 4, 3, 2, or 1 respectively and then adding up the areas. Figure 4-3 shows the extent of permeability scores in 1 km grid cells. As visualised by Figure 4-3, the Yorkshire Wolds are an area of permeable land whereas Holderness and Humberhead Levels are least permeable.

- Flood Zones (FZ):

There are three zones of flood plains in England: Flood Zone 1, Flood Zone 2, and Flood Zone 3. Flood Zone 1 is everywhere in England and Wales not covered by zones 2 and 3. Flood Zone 2 shows areas of land with an annual probability of flooding of 0.1% or greater from rivers and the sea, but with an annual probability of flooding of less than 1% from rivers and less than 0.5% from the sea. Flood Zone 3 shows areas of land with an annual probability of flooding of 1.0% or greater from rivers, and 0.5% or greater from the sea.

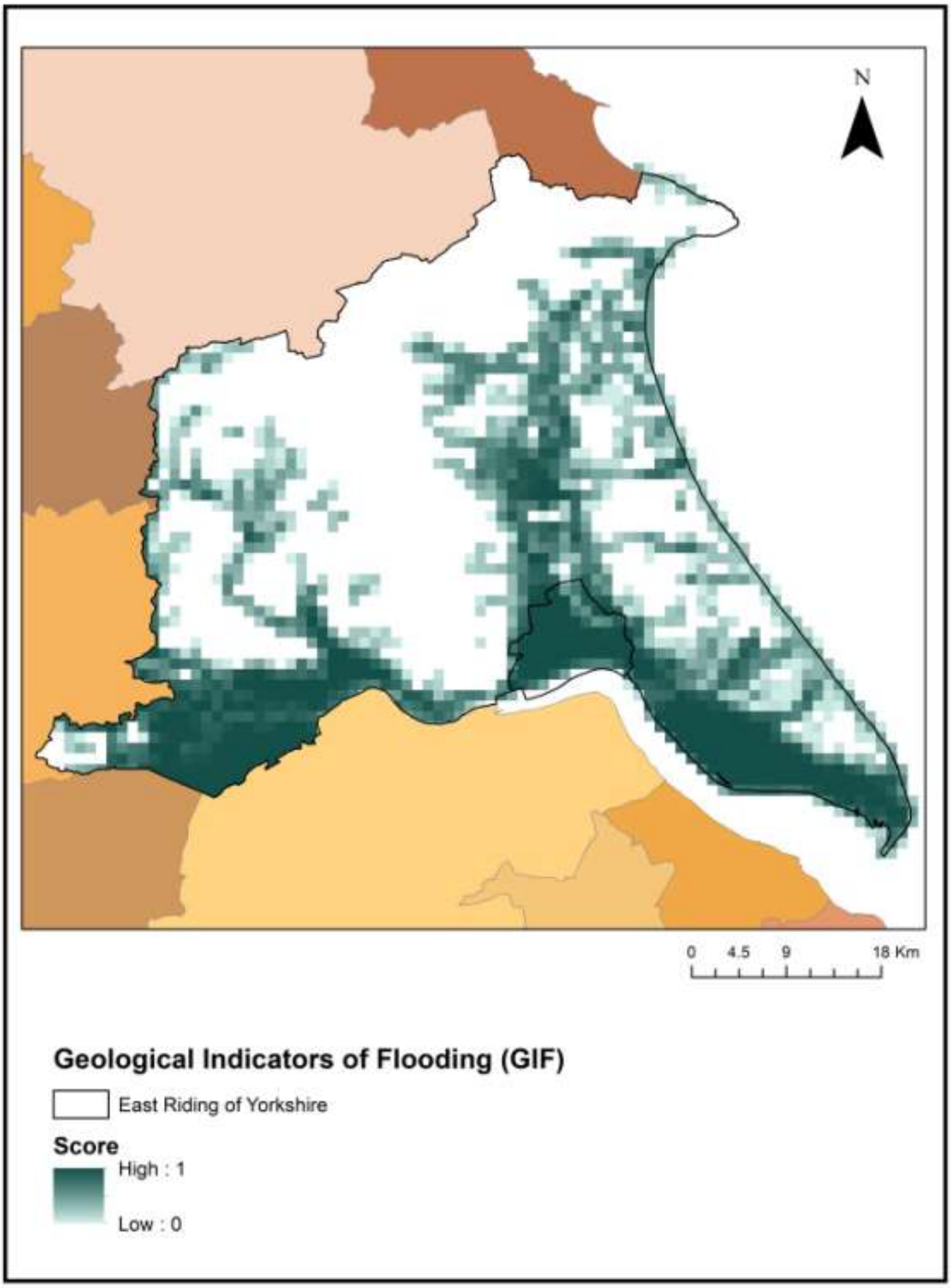

Figure 4-2: Transformed and normalised geological indicators of flooding,
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In addition, there are two sources of flooding in each zone: tidal and fluvial. Since the probability of flood occurrence, not the source of flooding, is important, the calculation was based on the chance of flooding in each grid cell. Normalised values have been assigned to cells as the FZ score. Two separate grids were developed for each source of flooding (i.e. tidal and fluvial). The areas of Zone 2 and Zone 3 were given weights of 1 and 2 respectively and added together to give the rank of the grid. Finally, for each grid, the score was calculated by adding together both the fluvial and the tidal score. Normalised values were the final ranks to be given to grids (Figure 4-4).

- Pollution incidents (PI):

The data present a filtered version of all incidents held on the National Incident Recording System (NIRS2). Data supplied include only substantiated environmental protection incidents, where the environmental impact level is category 1 (major), category 2 (significant), category 3 (minor), or category 4 (no impact) in relation to at least one of the environmental components: air, water or land.

In order to project this indicator onto 1 km cells, a severity rank was given to each incident point based on its impact on air, land and water, then the number of incidents (holding their severity rank) in each cell was calculated. The darkest green grids hold a higher number of pollution incidents with greater effects on the environment (air, land, or water) (Figure 4-5).

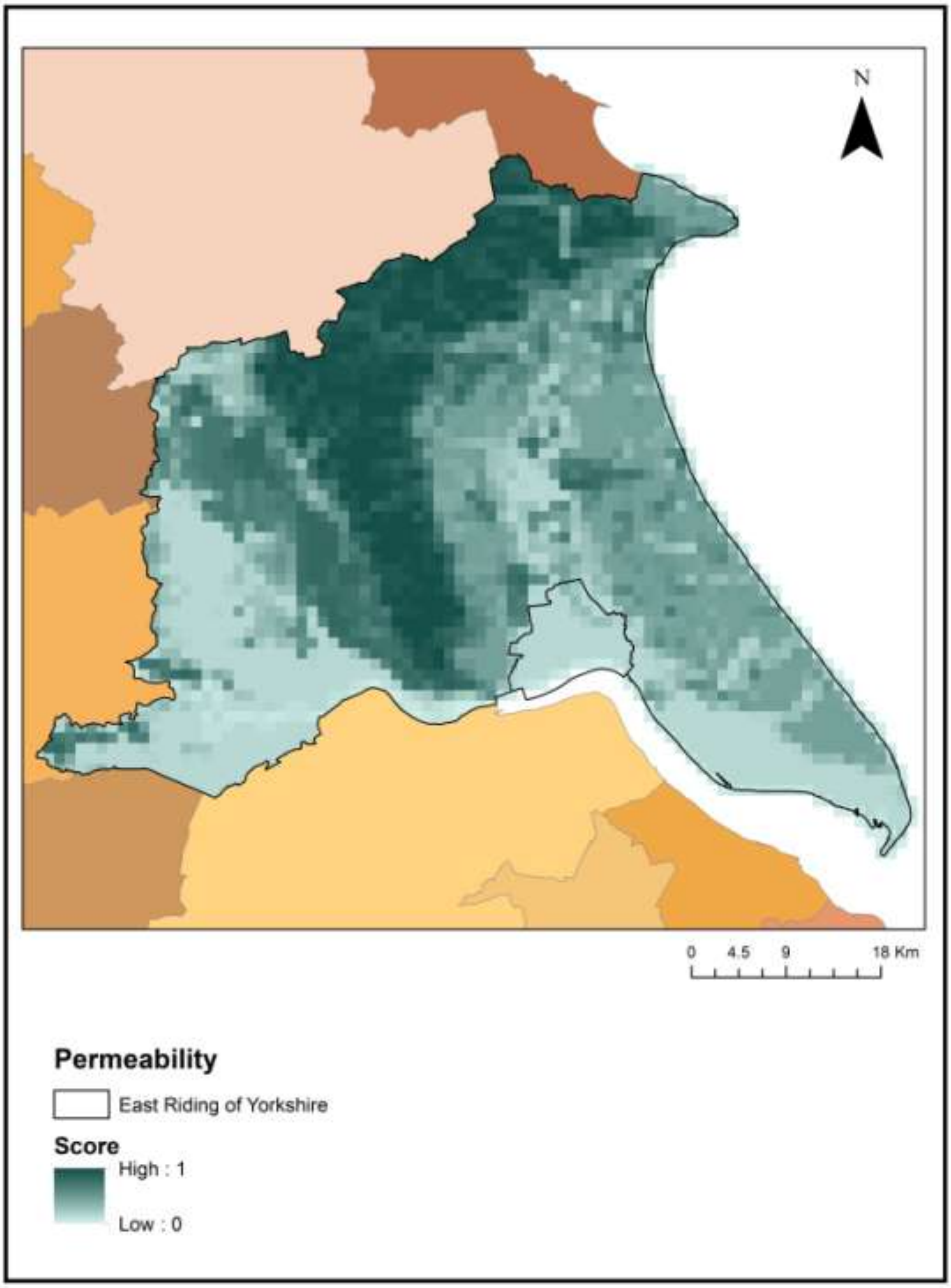


Figure 4-3: Transformed and normalised permeability

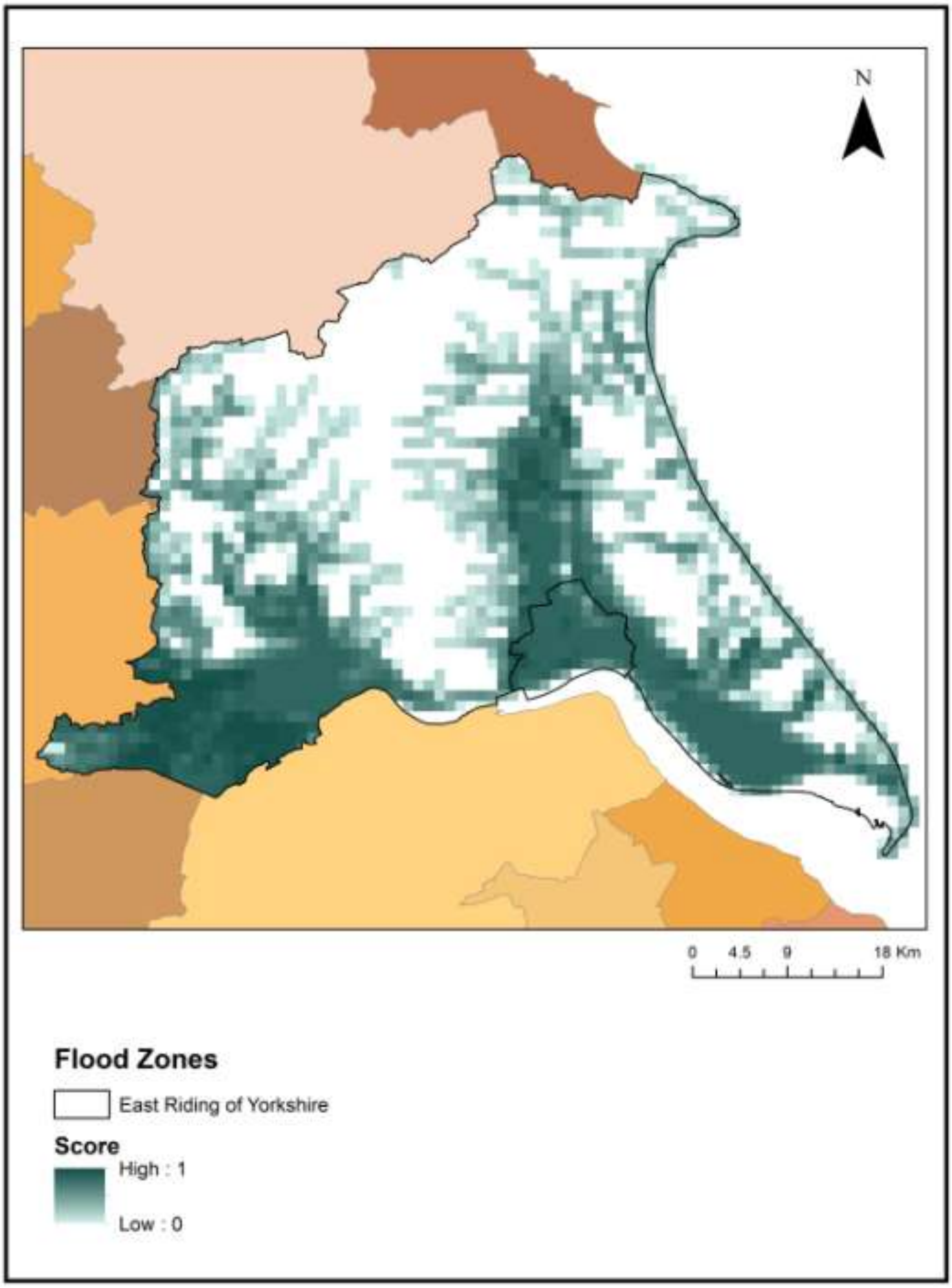


Figure 4-4: Transformed and normalised flood zones
Contains Environment Agency information © Environment Agency and database right

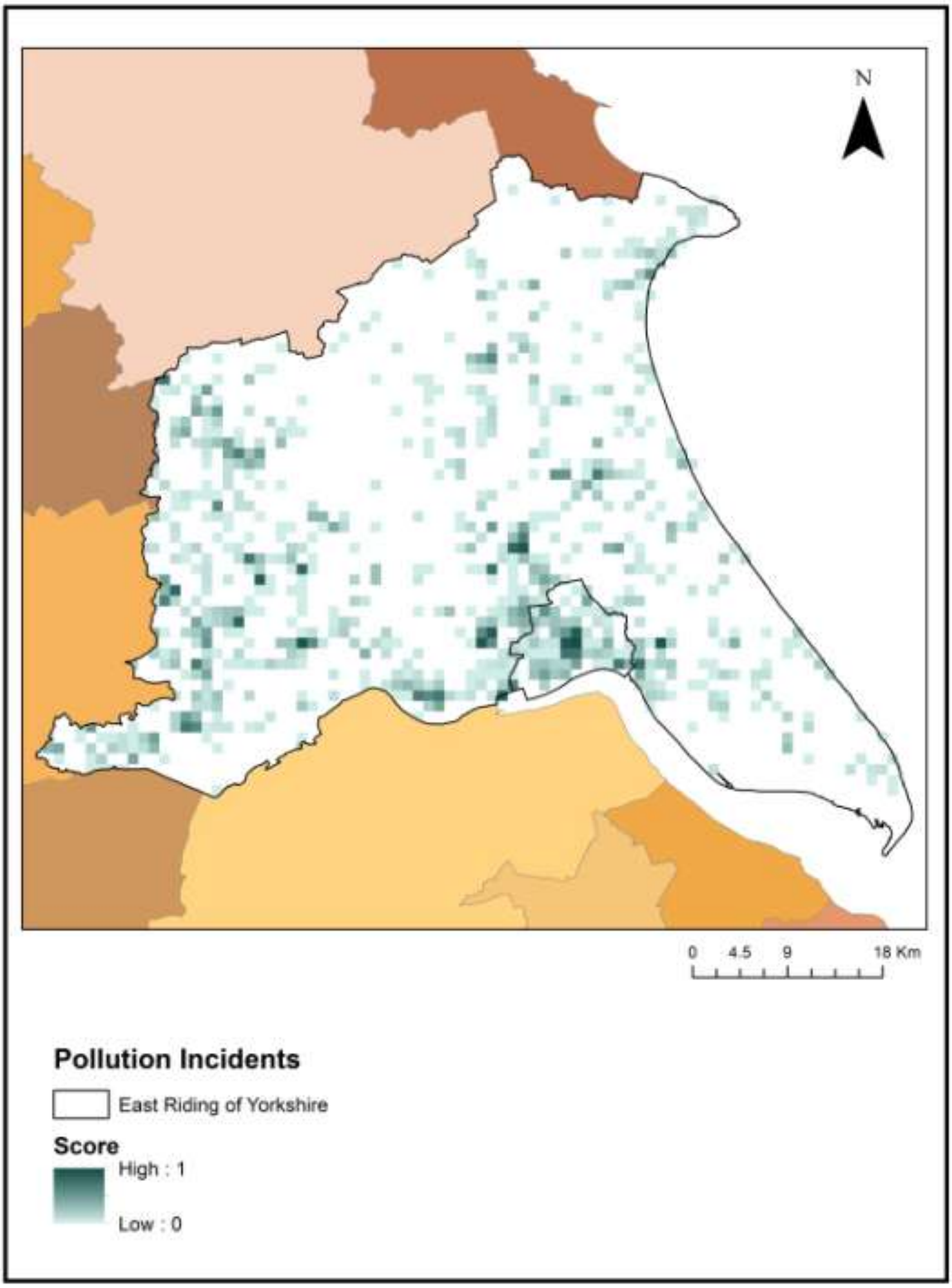


Figure 4-5: Transformed and normalised pollution incidents
Contains Environment Agency information © Environment Agency and database right

- Source Protection Zones (SPZ):

Source Protection Zones (SPZs) have been defined for groundwater sources. These zones show the risk of contamination from any activities that might cause pollution to the groundwater. The closer the activity, the greater the risk. The shape and size of a zone depends on the condition of the ground, how the groundwater is moved, and other environmental factors. In order to project the data into 1 km cells, weights of 3, 2, and 1 were given to zone 1, zone 2, and zone 3 respectively. The score of each cell was calculated according to the formula below, where C_i is the SPZ score in a cell, $zone_{1i}$ is the total area of zone 1 in cell i, $zone_{2i}$ is the total area of zone 2 in cell i, and $zone_{3i}$ is the total area of zone 3 in cell i (Figure 4-6).

$$Score\ of\ C_i = (3 \times\ zone_{1i}) + (2\ \times zone_{\ 2i}) + (1 \times\ zone_{3i})$$

- Landfill sites:

There are two types of landfill sites: historic and authorised (active). Historic landfill sites are locations where there are records of waste being buried but which are now closed or covered. Authorised landfill sites are where local authorities and industry can take waste to be buried and compacted with other wastes (The Environment Agency 2011). The Environment Agency licenses and regulates landfill sites to ensure that their impact on the environment is minimised. A buffer of 250 m was given to landfill site areas. The area of LFSs within each grid was calculated and normalised as the final LFS score (Figure 4-7).

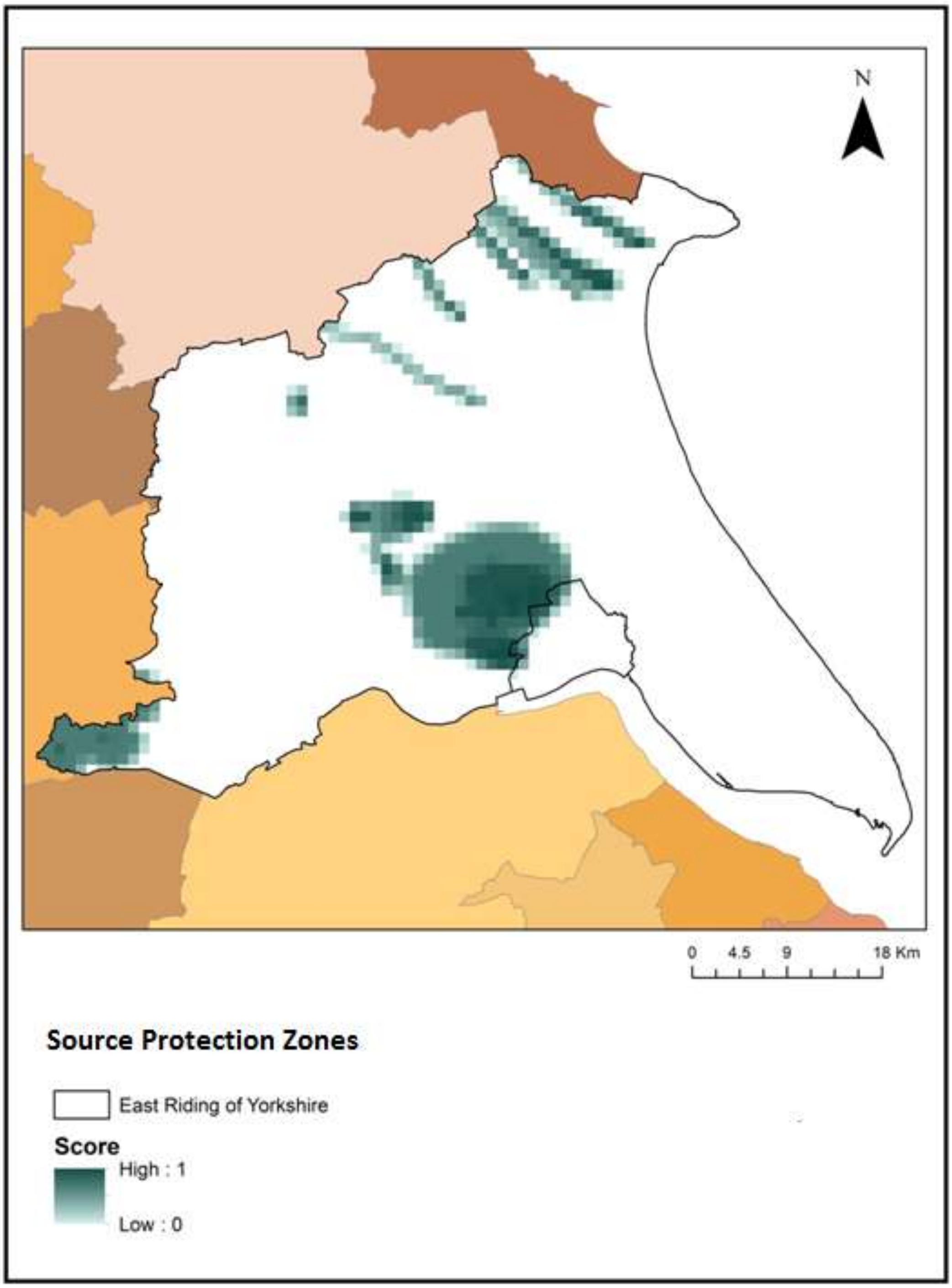


Figure 4-6: Transformed and normalised source protection zones
Source: The Environment Agency

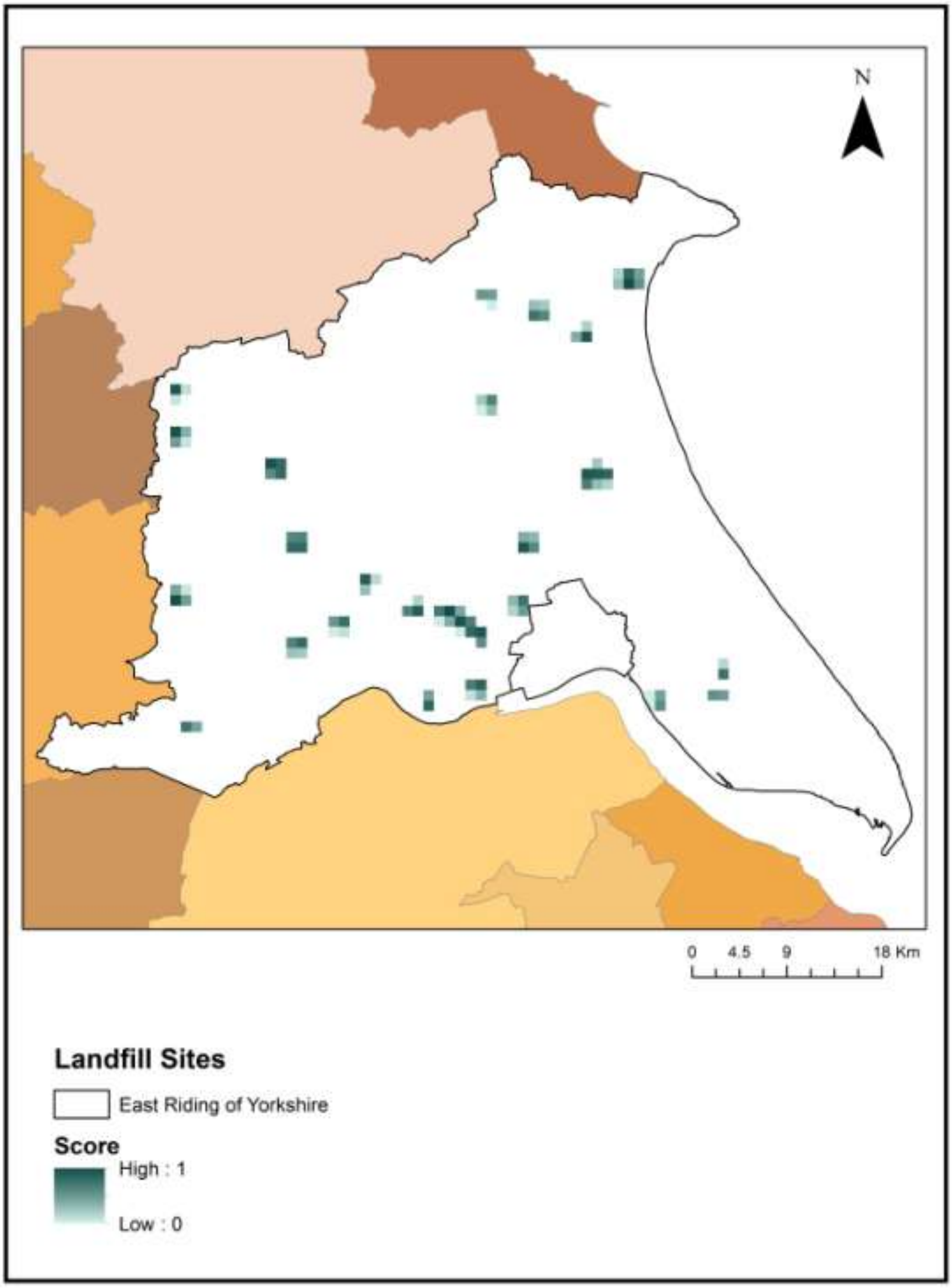


Figure 4-7: Transformed and normalised landfill sites

- Contaminated Lands (CL):

Non-radioactively contaminated land is defined in section 78A(2) of the Environmental Protection Act 1990 as “any land which appears to the local authority in whose area it is situated to be in such a condition, by reason of substances in, on or under the land, that (a) significant harm is being caused or there is a significant possibility of such harm being caused, or (b) pollution of controlled waters is being, or is likely to be caused”.

In order to project the dataset into a 1 km cell grid, a buffer of 250 m was given to the polygons, and the area of contaminated land (CL) within each cell was calculated and normalised. Figure 4-8 shows the final score for each cell.

- Surface water flooding (SWF):

‘Flood Map from Surface Water’ is a database from the Environment Agency which is based on DEM and elevation data. It shows water flow and water accumulation pathways. Although it uses simulated data, it corresponds well to the real river beds and channels. Polygons showing surface water flooding over thirty years were used in order to estimate the susceptibility of each grid cell to flooding from accumulated water flow. Two categories, ‘30 year SWF’ and ‘30 year deep SWF’, are presented in the database. Weights of 2 and 1 were given to 30 year deep SWF and 30 year SWF respectively. The normalised accumulated area of both SWF categories was the final score given to each grid cell (Figure 4-9).

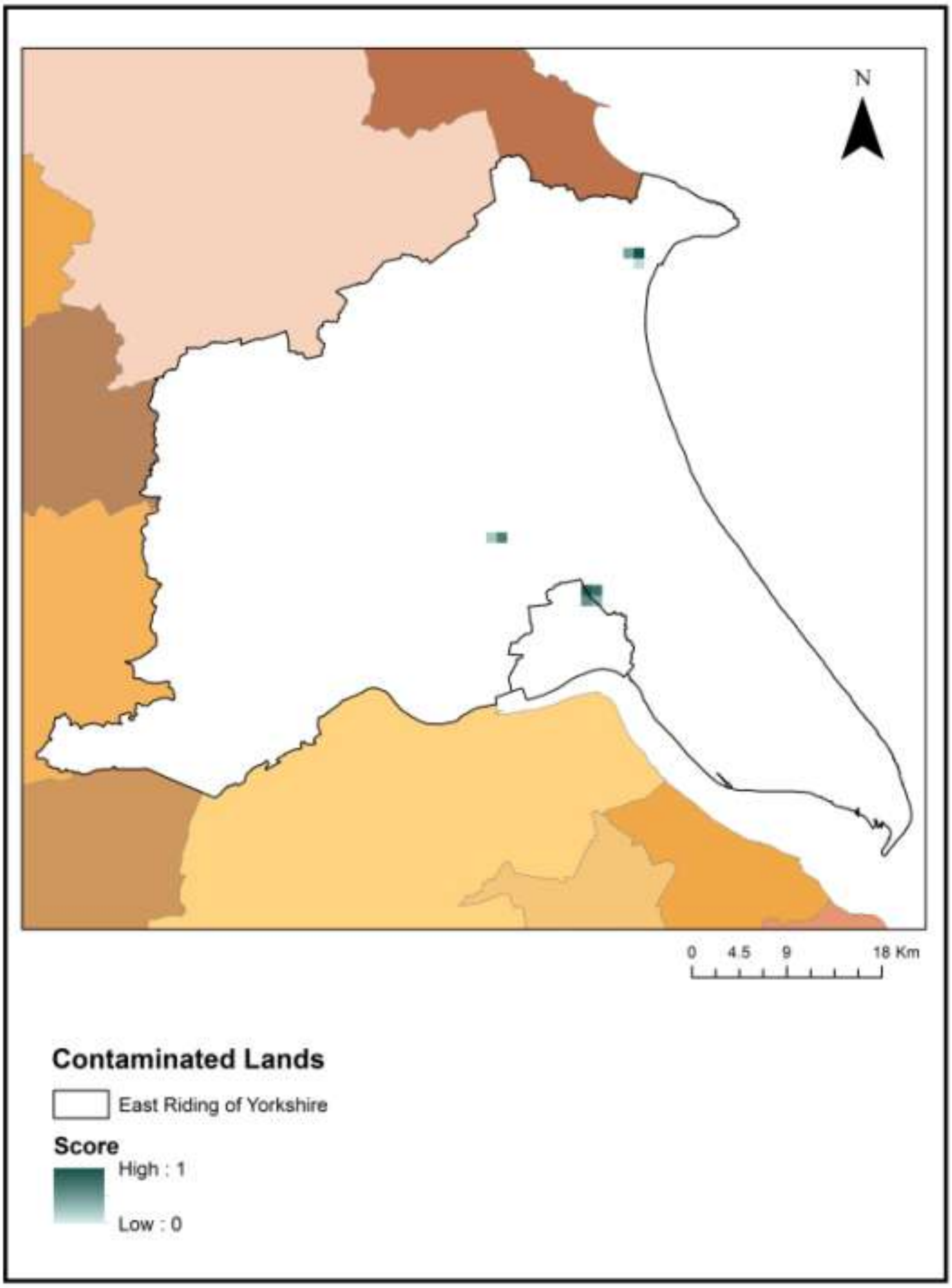


Figure 4-8: Transformed and normalised contaminated lands

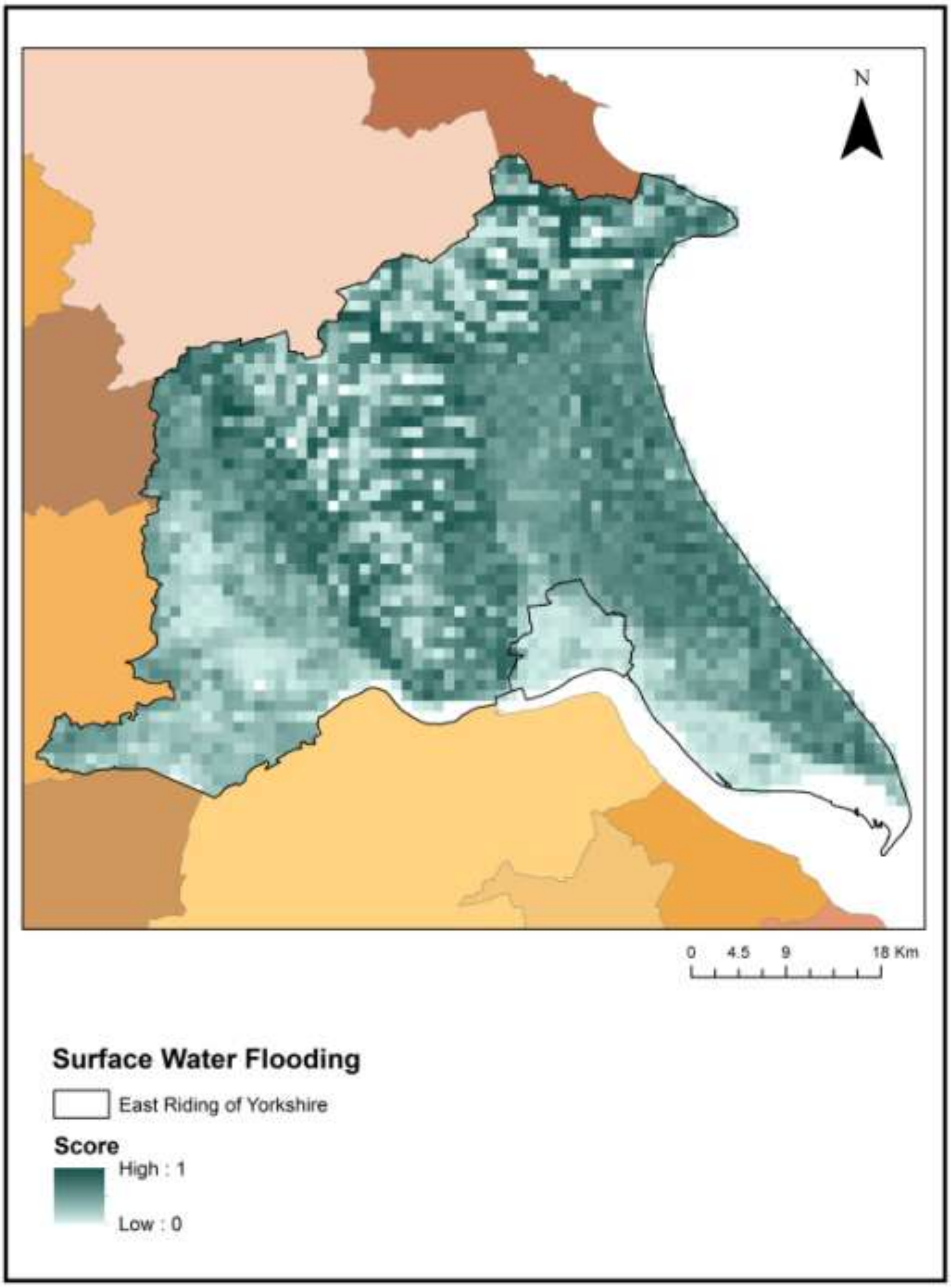


Figure 4-9: Transformed and normalised surface water flooding

4.5.1.2. Physical indicators

There are four indicators of physical vulnerability which all have been classified as coping capacity sub-components of vulnerability. In this section, the transformation and normalisation processes of the physical indicators are presented.

- Repair and construction services (CONS):

These are point data from the Ordnance Survey (Points of Interest (POI)) which show commercial services related to construction, repair, and servicing. In emergencies such as extreme floods, local repair and construction services are potential resources. The "kernel density" operation in ArcGIS has been used in order to calculate the score of each cell in terms of proximity to repair and construction services within a radius of 5 km. Figure 4-10 shows the resultant grid.

- Rescue services (RESC):

The Ordnance Survey "Points of Interest" shows locations of government-related rescue services including police stations, armed services, coastal safety, fire brigade stations, social service activities, and local government. These are government posts in charge of public help and rescue in the case of extreme events. Point data have been converted into 1 km cells using the "kernel density" operation. A radius of 30 km was applied to the calculation to project point data into grids representing the distribution of central and local government services. Figure 4-11 shows the resultant grid scores.

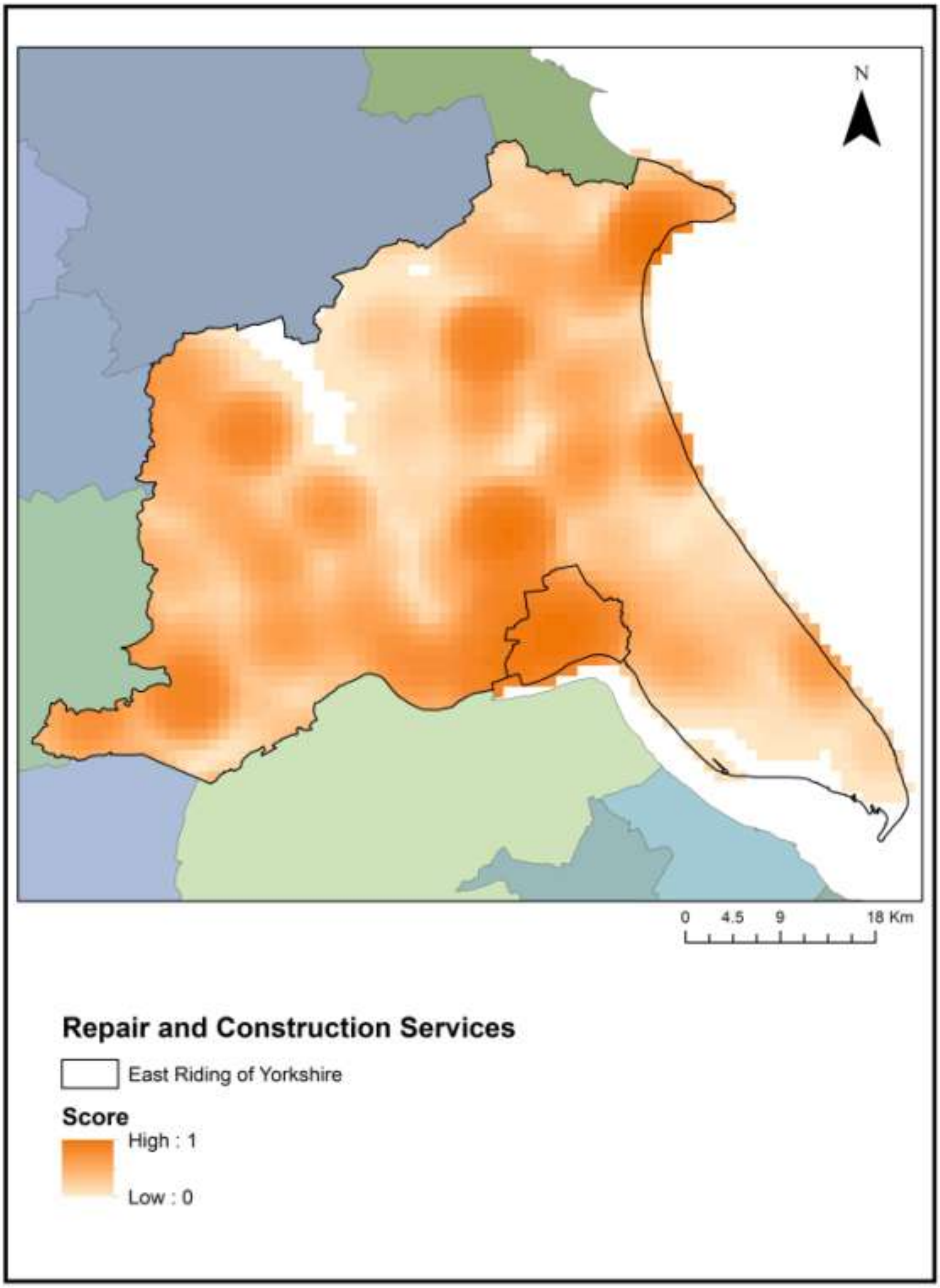


Figure 4-10: Transformed and normalised repair and construction services
Contains Ordnance Survey data © Crown Copyright and database right [2012]

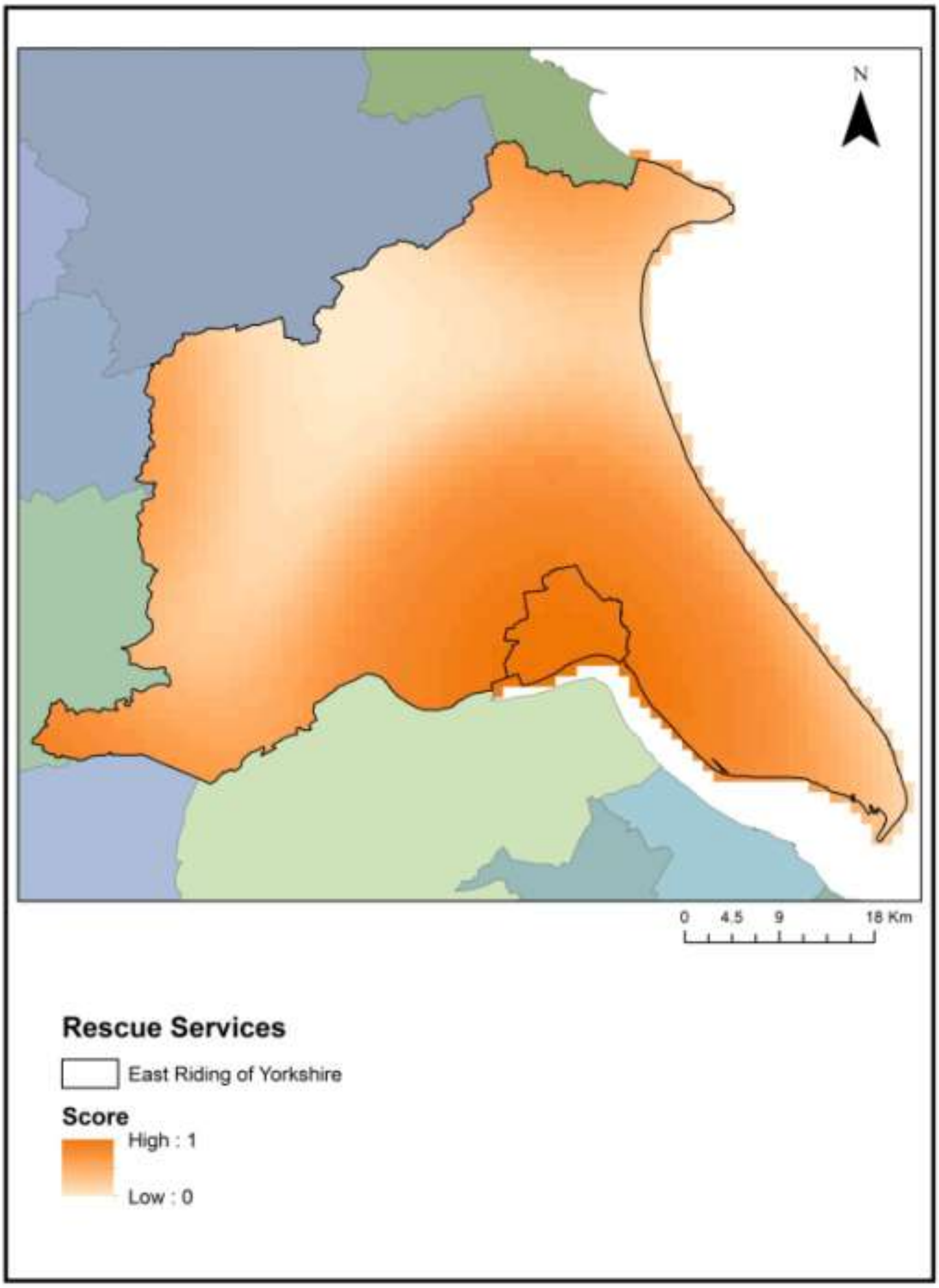


Figure 4-11: Transformed and normalised rescue services
Contains Ordnance Survey data © Crown Copyright and database right [2012]

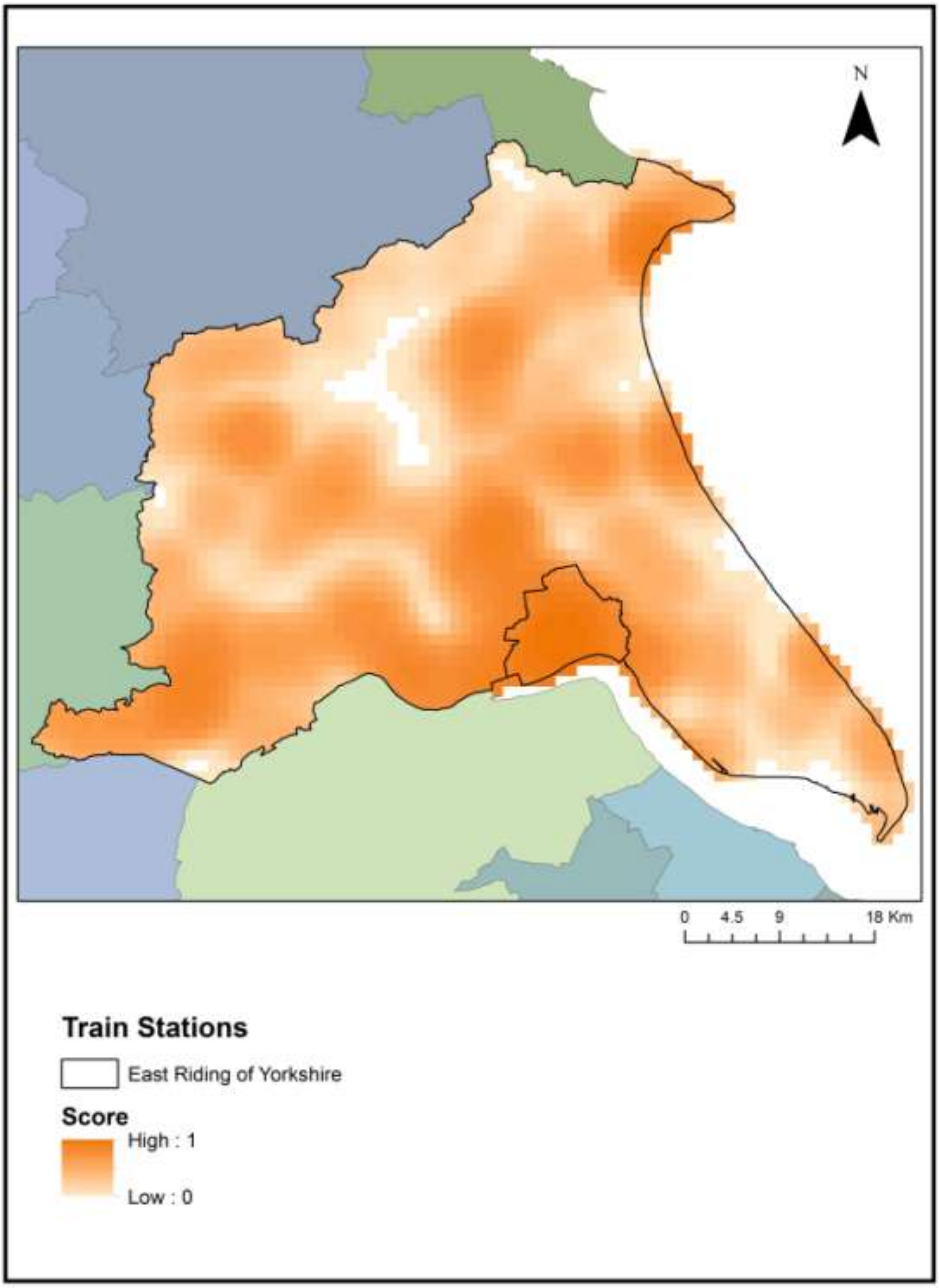


Figure 4-12: Transformed and normalised train stations
Contains Ordnance Survey data © Crown Copyright and database right [2012]

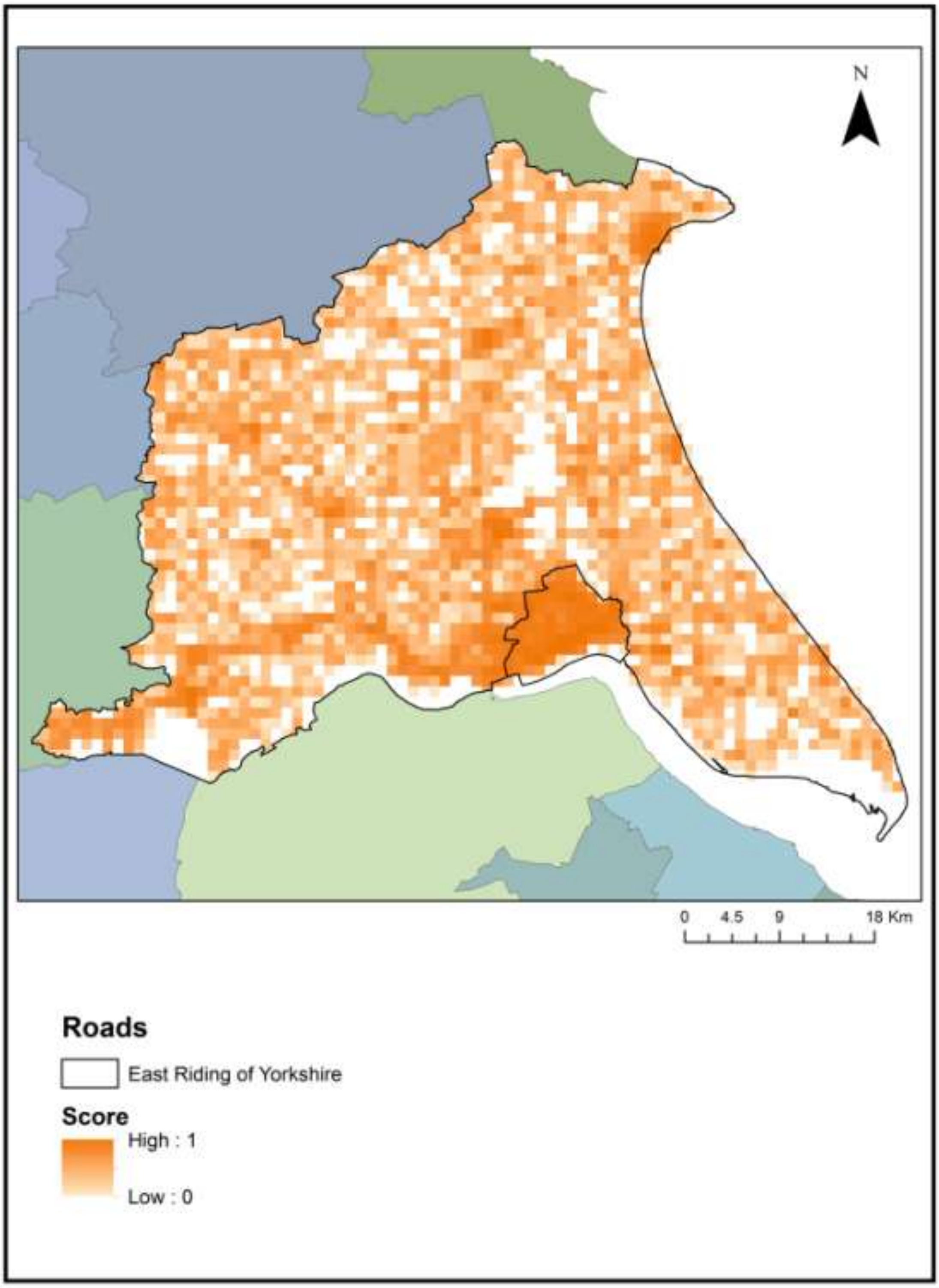


Figure 4-13: Transformed and normalised road network
Contains Ordnance Survey data © Crown Copyright and database right [2012]

- Train stations (TRN):

This indicator has been developed using train station points from Ordnance Survey Points of Interest (POI). The "kernel density" operation with a 5 km radius was applied to the point layer in order to extract a rasterised grid of the distribution of locations of train stations in the East Riding of Yorkshire. Normalised values were the final scores to be assigned to grids (Figure 4-12).

- Roads (ROAD):

This indicator has been developed using the roads network from the Ordnance Survey Vector Map District. The categories of roads in Vector Map District are much more comprehensive than MasterMap or Strategi, and include A roads, B roads, minor roads, local streets, motorways, primary roads, private roads, and pedestrian roads. Using Hawth's Tool in ArcGIS, line in polygon analysis was applied and the sum of the length of roads in each grid cell was calculated and assigned to them as the roads score. Figure 4-13 shows the resultant grid map. It might be suggested that the roads should be given weights according to their importance or primarily (e.g. motorways get a higher weight than B roads) or a greater kernel radius should be applied to the analysis.

4.5.1.3. Economic indicators

There are four indicators of economic vulnerability to flooding in arable land. All four indicators belong to the exposure component of vulnerability.

- Agricultural workers (AGWR):

Census data for 2001 are accessible from the CASWEB website. There are various spatial resolutions available from online webpage, from county level to output areas (OA) (i.e. postcode areas). Census data for the East Riding of Yorkshire at OA level were downloaded. In the "Industry of employment" category, agricultural workers' data are of importance to this chapter. Density of agricultural workers is a measure of economic exposure/susceptibility because these are people who may be injured physically or affected financially by a flood event. In addition, a higher number of agricultural workers shows greater economic importance of the OA. A "Polygon to Raster" tool was used to project the density of workers in each OA (i.e. agricultural workers/hectares) to grid cells. Figure 4-14 shows the resultant map illustrating the normalised density of agricultural workers in each cell.

- Land productivity (ALC):

Natural England has proposed a map of land classification based on land productivity called the "Agricultural Land Classification” (ALC). There are non-agricultural lands which are not of use in this sector (grade 6). Grades 1 to 5 show the productivity of land, where grade 1 is excellent and 5 is the poorest land. In practice, only grades 1 to 3 are cultivated and scored as agriculture. Since the economic importance of agricultural land corresponds to this classification, weights of 3 to 1 have been given to grades 1 to 3 respectively. Figure 4-15 shows the final map of normalised scores of land productivity.

- Farm locations (FARM):

The POI dataset has a group of points classified as "Manufacturing and Production" including a class called "Farms" which shows the location of farms within the area. A kernel density of 5 km can satisfactorily show the agricultural parcels, including arable, vegetable, bees, dairy, horses, activities. Figure 4-16 shows the final normalised scores of farm locations.

- Animal report (DFR):

The livestock report from Defra includes sheep, cattle, poultry, horses, goats, deer, and pigs. The density of livestock population on a 1 km grid was calculated. Normalised scores are the final ranks to be assigned to grids (Figure 4-16).

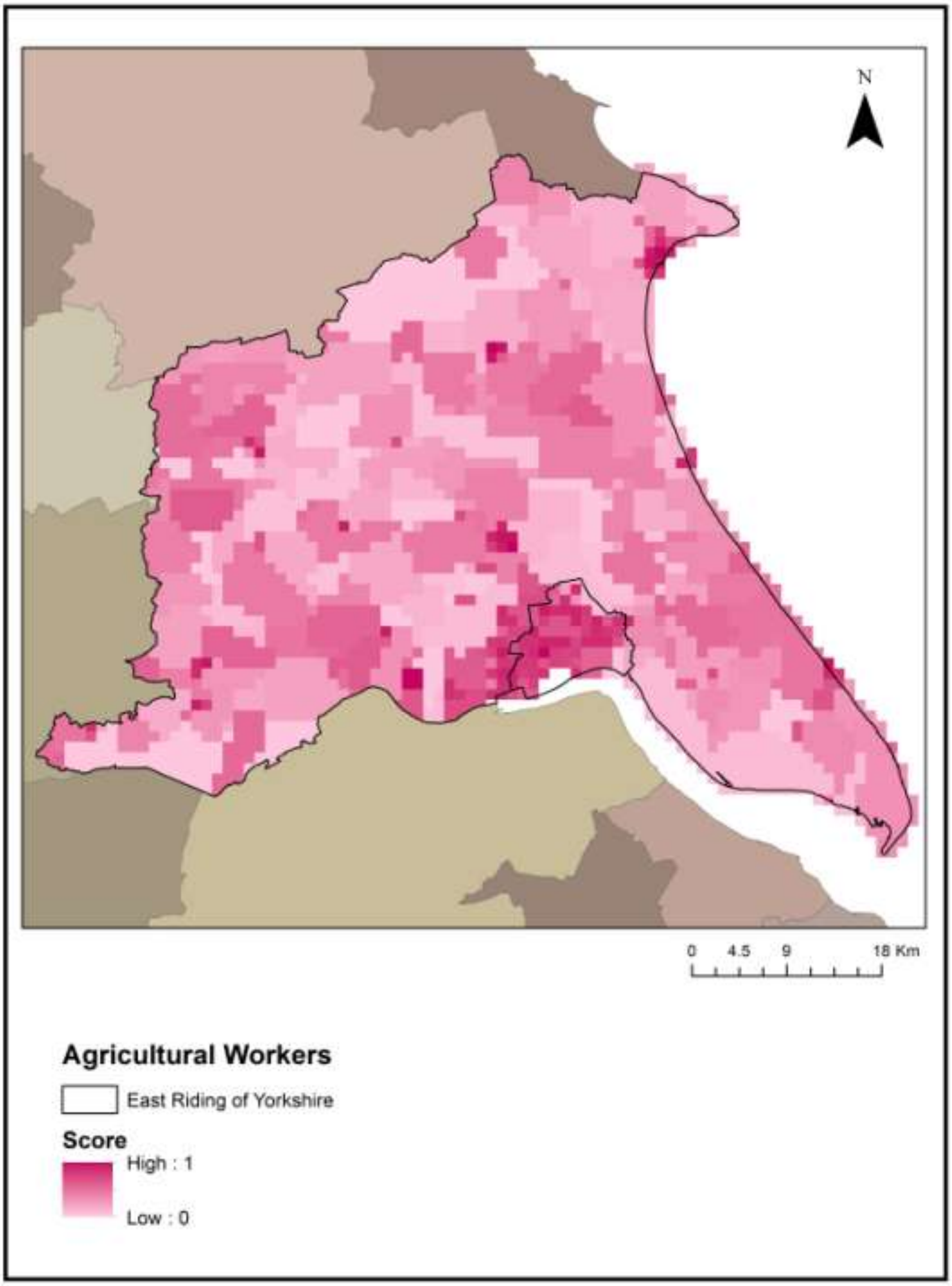


Figure 4-14: Transformed and normalised agricultural workers

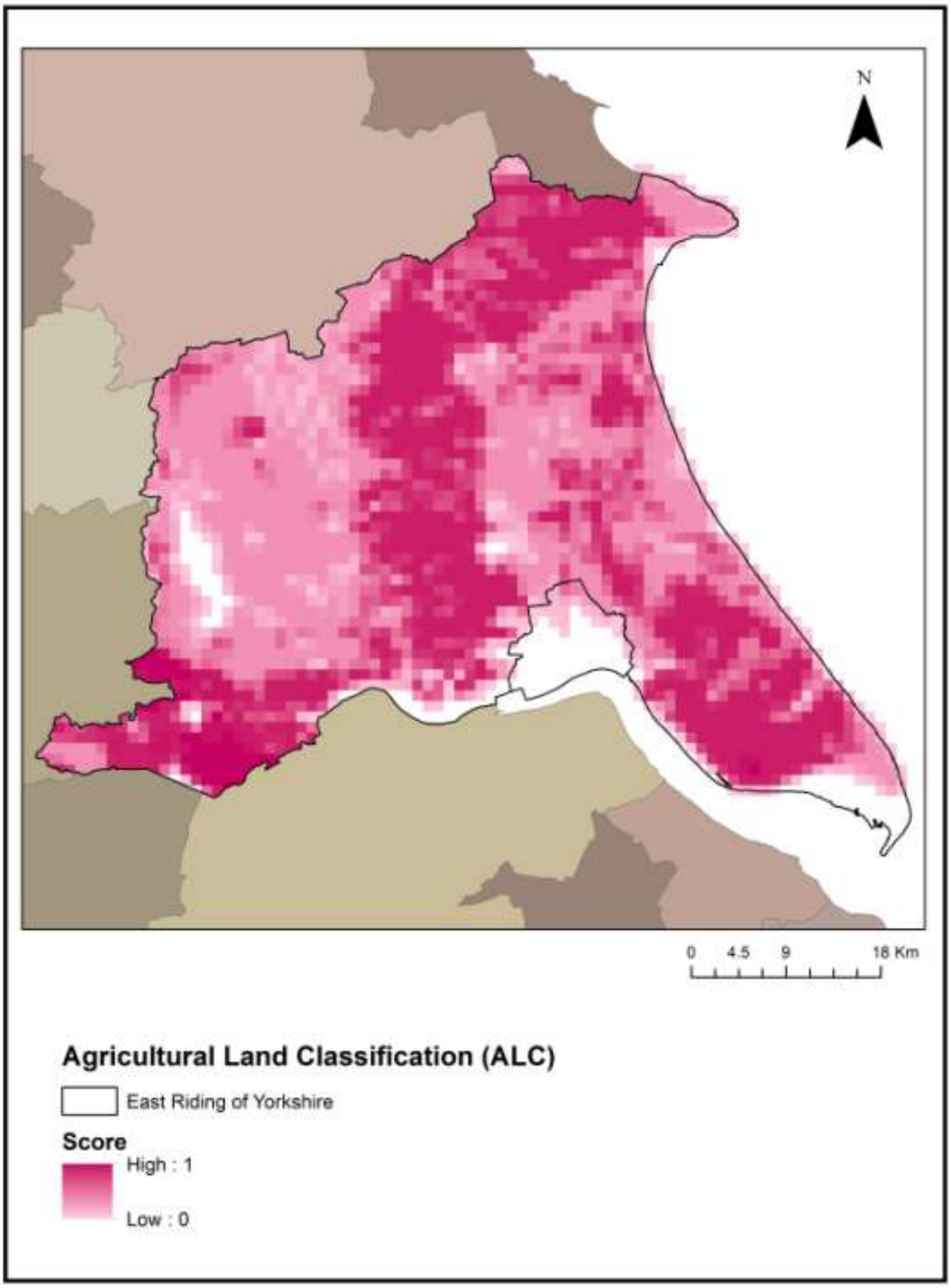


Figure 4-15: Transformed and normalised land productivity (ALC)

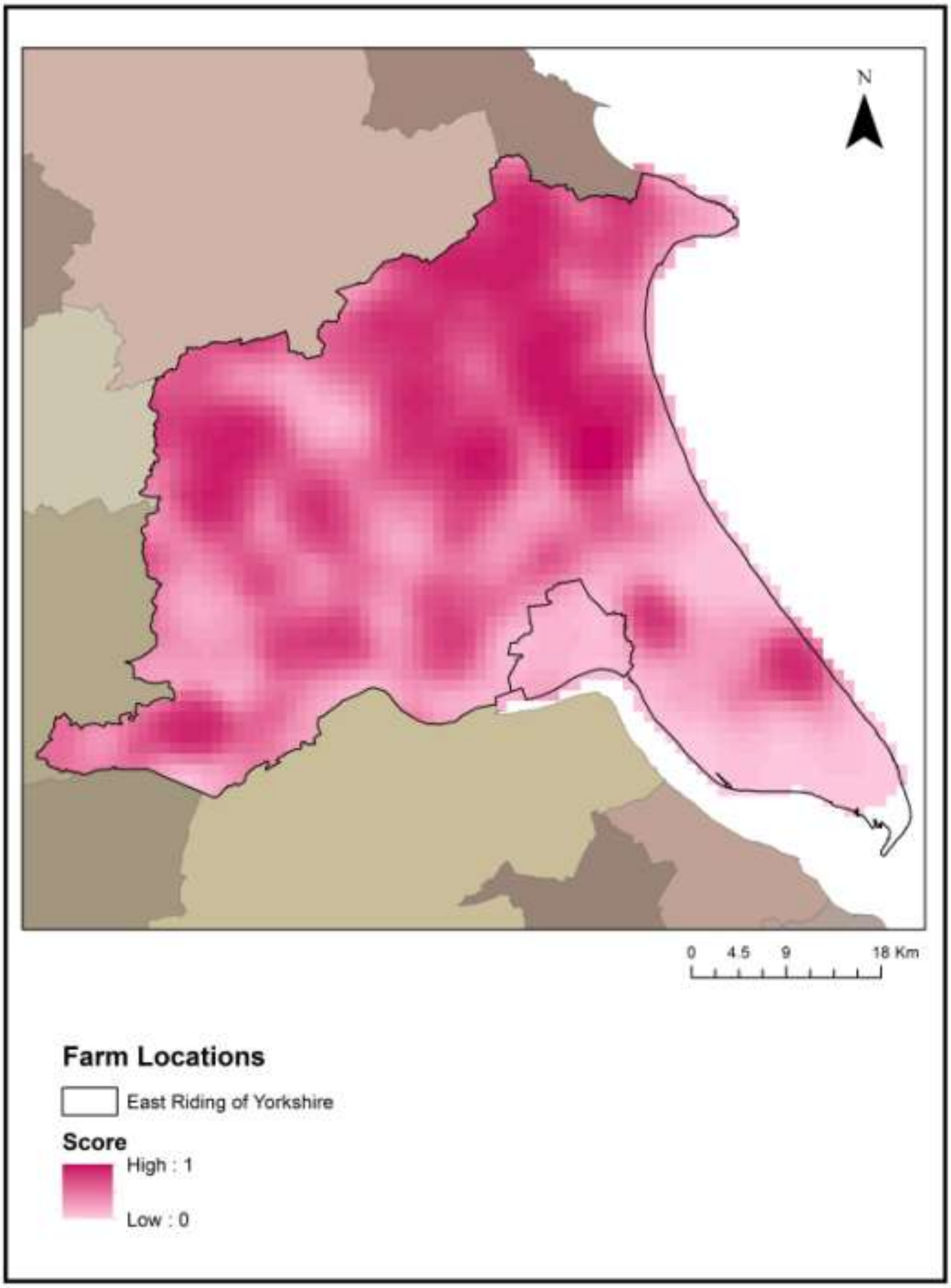


Figure 4-16: Transformed and normalised farm locations

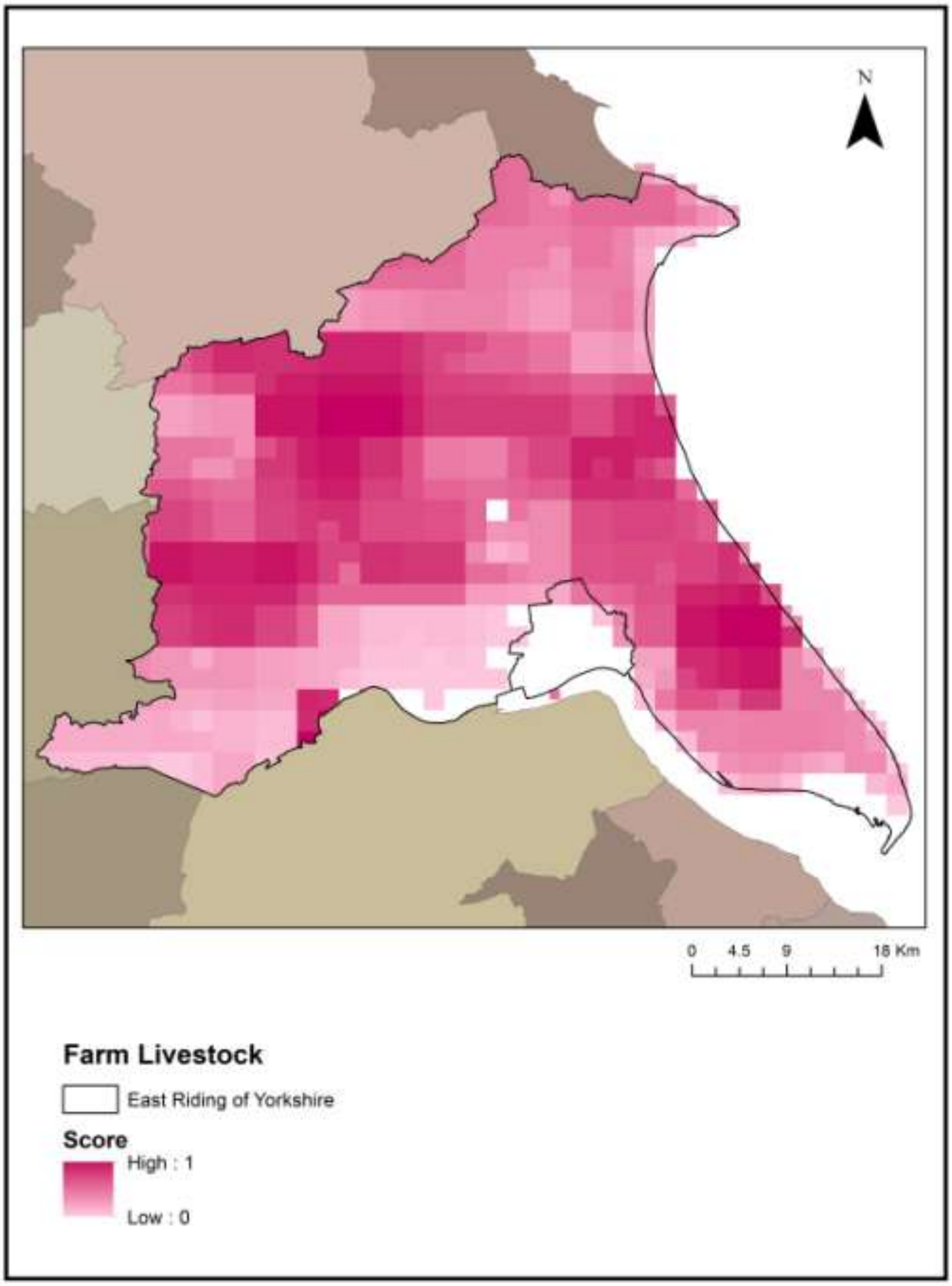


Figure 4-17: Transformed and normalised farm livestock

4.5.2. Data analysis

To evaluate the vulnerability indicators of the arable sector, a descriptive and explorative approach was employed. This means that all the statistical characteristics of indicators within and between them have been examined. This section has been structured around three vulnerability components: environmental, physical, and economic. Firstly, for each component, tables of the information on all the indicators have been presented (section 4-5-1). Secondly, statistical characteristics have been explored. Thirdly, a correlation analysis has been carried out using EViews statistical software. The correlation coefficient measures the linear relationships among the variables and is a good gauge of dependency of variables. All coefficients above the threshold of r = 0.50 indicate a high correlation and are therefore assessed.

The preliminary correlation matrix of arable indicators is provided in the "sensitivity analysis" chapter and is not repeated in this part. Table 7-1 shows the correlation coefficients of the arable vulnerability indicators. The correlation analysis of the indicator set for the arable sector delivers the following results:

- The construction indicator is highly correlated with two other indicators: train stations (+0.86) and roads network (+0.65). Because all three indicators belong to the component of physical and the sub-component of coping capacity the exclusion of one or two of them might be considered. However, a high coefficient does not always mean that both parameters are indicating the same issue. Since the indicators of train stations, roads and construction stand for three different sources of coping for the community, none of them has been removed from the list.
- Train stations and the roads network show a degree of correlation of +0.64. However, the same argument put forward in the previous point applies here and therefore both variables are kept.
- Flood zones and GIF indicators are significantly correlated (+0.79). In addition, both are derived from similar roots and therefore the GIF indicator is taken out of the analysis.

4.5.3. Weighting and aggregation

Central to the construction of a composite indicator is the need to combine the indicators in a meaningful way, which in turn implies a decision on a specific weighting and aggregation model. The weighting and aggregation methods which have been applied on the final fifteen indicators of the arable sector are described in the methodology chapter (Chapter 3).

4.6. Results

The flood vulnerability index (FVI) of the arable sector which has emerged from the analysis has been developed at 1 km grid resolution. In this part, the outcomes are mapped and discussed. The vulnerability index is described in terms of its three components – environmental, physical, and economic – and its two sub-components (i.e. exposure and coping capacity). The final arable FVI is the main result of this chapter and is investigated in the final section.

4.6.1. Components of vulnerability

4.6.1.1. Environmental vulnerability index (EnVI)

Seven factors play a role in shaping the final index for environmental vulnerability in the arable sector. All factors were projected onto 1 km grid cells and scored as described in the previous section. There is a pattern of vulnerability in the region, with high scores (dark green) near the Humber Estuary and River Hull (Holderness, Humber Estuary, and Humberhead Levels), whereas the least vulnerable places are in the Yorkshire Wolds, where the vulnerability score is negative, showing the high permeability of the soil (coping capacity factor) and the absence of exposure/susceptibility factors (Figure 4-18). Summary statistics in both table and histogram report that great numbers of cells fall within the low vulnerability class (Table 4-5 and Figure 4-19). There are negative scores in places where there is no exposure/susceptibility factor but there is a coping capacity indicator (permeability index).

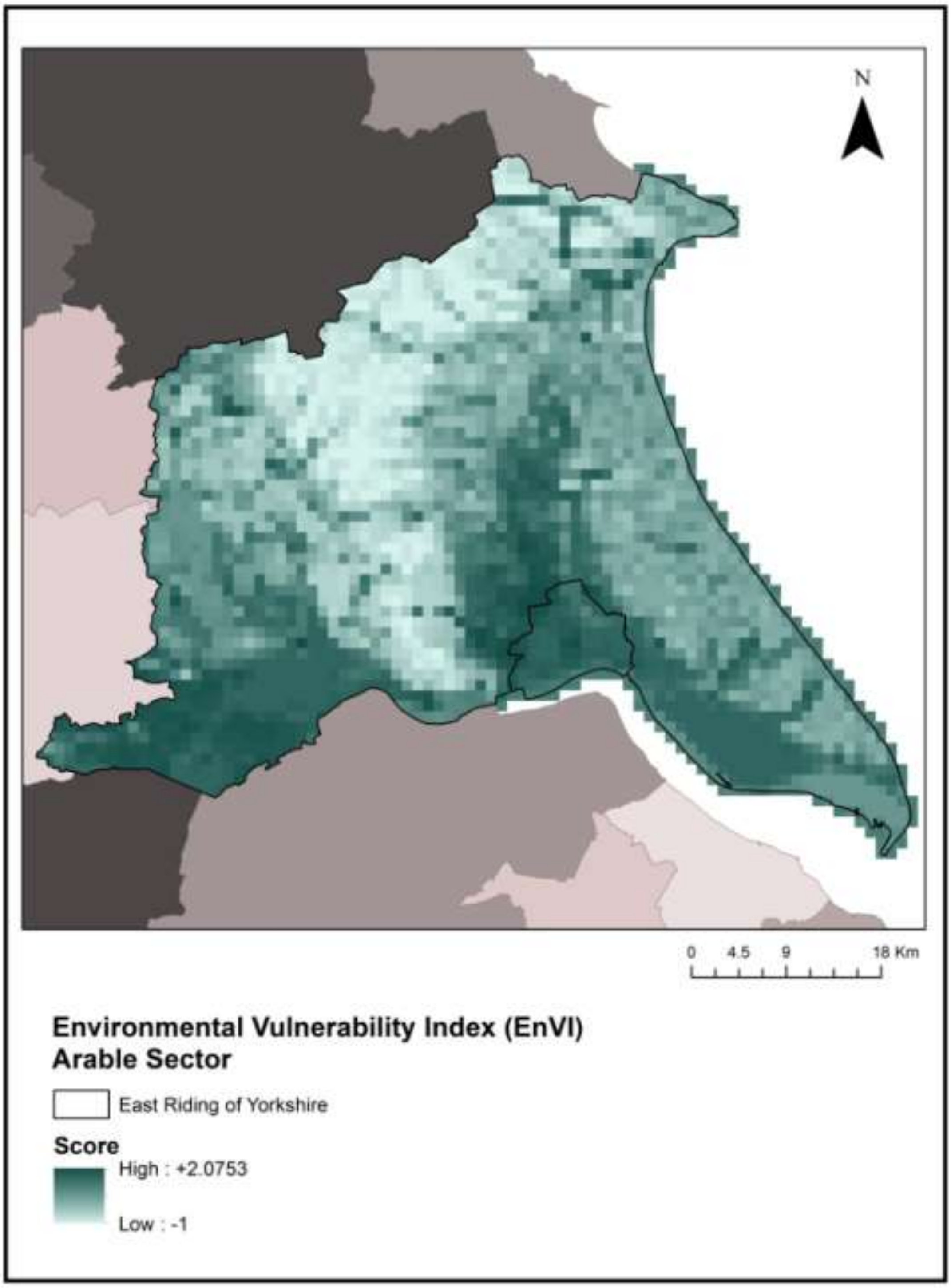


Figure 4-18: Environmental vulnerability index (EnVI) for the arable sector

Table 4-5: Summary statistics of the arable EnVI

Descriptive Statistics for the Environmental Vulnerability Index						
	Number of cases	Range	Minimum	Maximum	Mean	Standard deviation
EnVI	2780	3.075	-1	2.075	-0.1671	0.4593

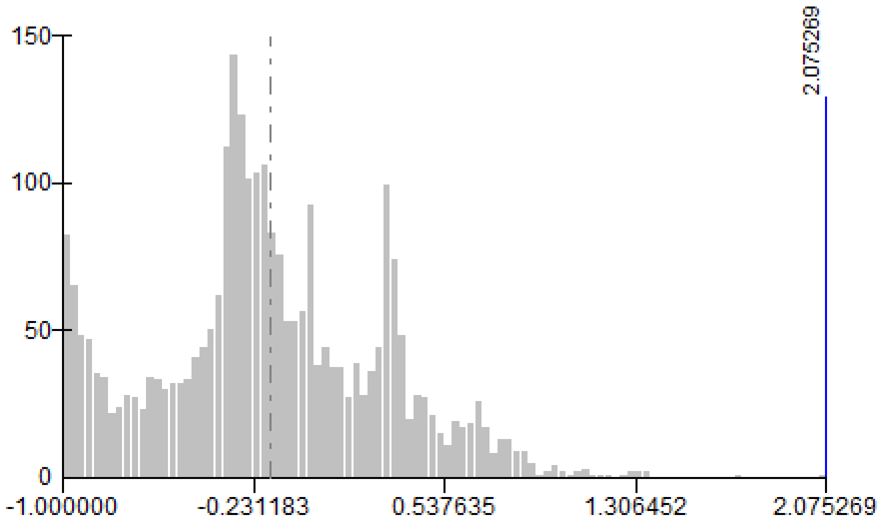


Figure 4-19: EnVI histogram of the arable sector

4.6.1.2. Physical vulnerability index (PhVI)

There are four factors in the physical component of vulnerability, all of which have been classified as coping capacity factors. Figure 4-20 is the resultant map showing physical vulnerability within the East Riding of Yorkshire. According to this map, the higher the score, the lower the vulnerability. Areas around cities are noticeably less vulnerable, and the overall picture of the area shows a lack of physical coping factors in the north-west. Applying a greater buffer for kernel density calculation may improve the situation. In addition, summary statistics (Table 4-6 and Figure 4-21) report that many cells are in the low vulnerability class, which is another indication of a lack of coping factors.

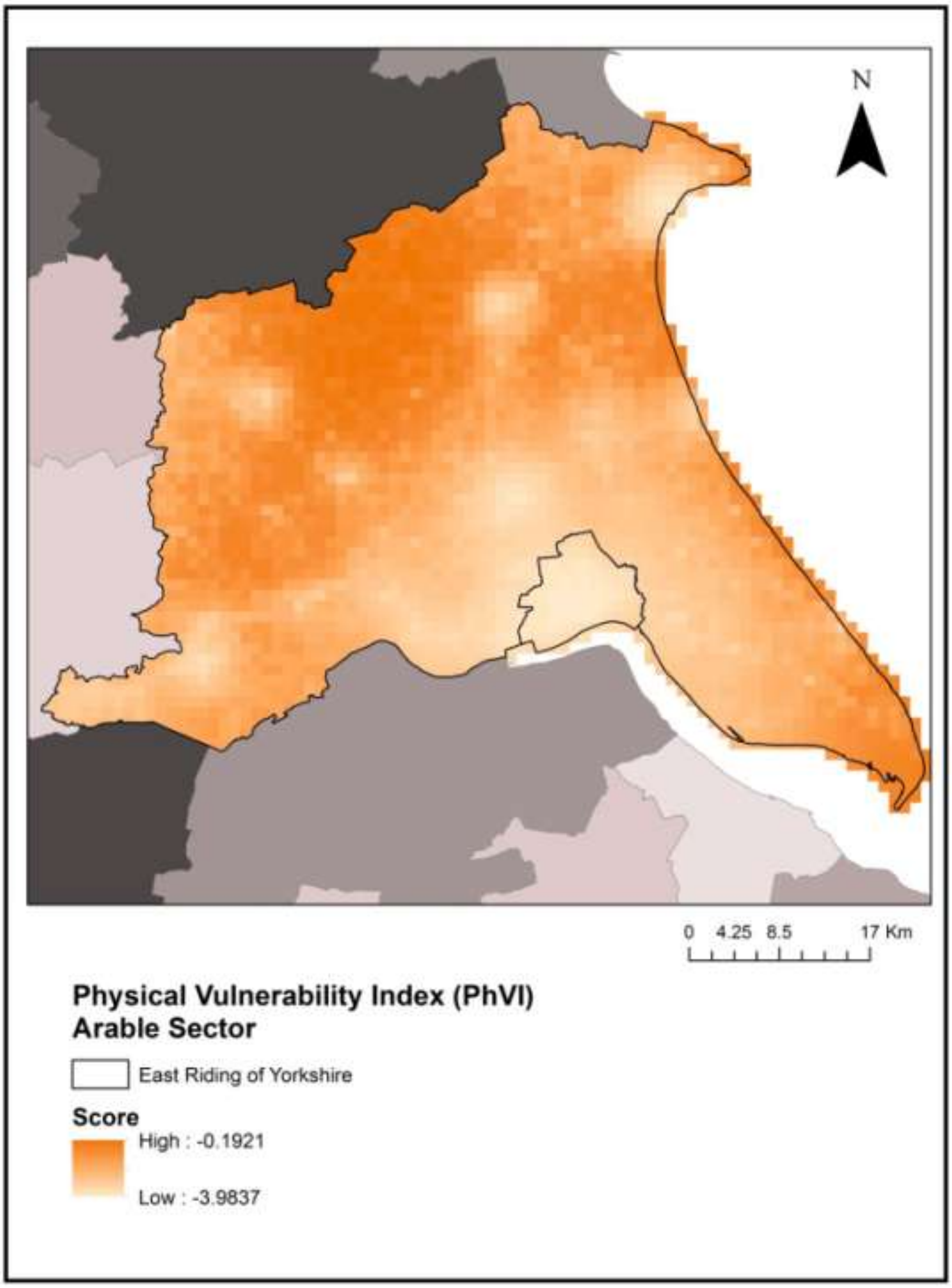


Figure 4-20: Physical vulnerability index (PhVI) for the arable sector

Table 4-6: Summary statistics of the arable PhVI

Descriptive Statistics for the Physical Vulnerability Index						
	Number of cases	Range	Minimum	Maximum	Mean	Standard deviation
PhVI	2780	4.1758	0.1921	3.9837	0.7335	0.4649

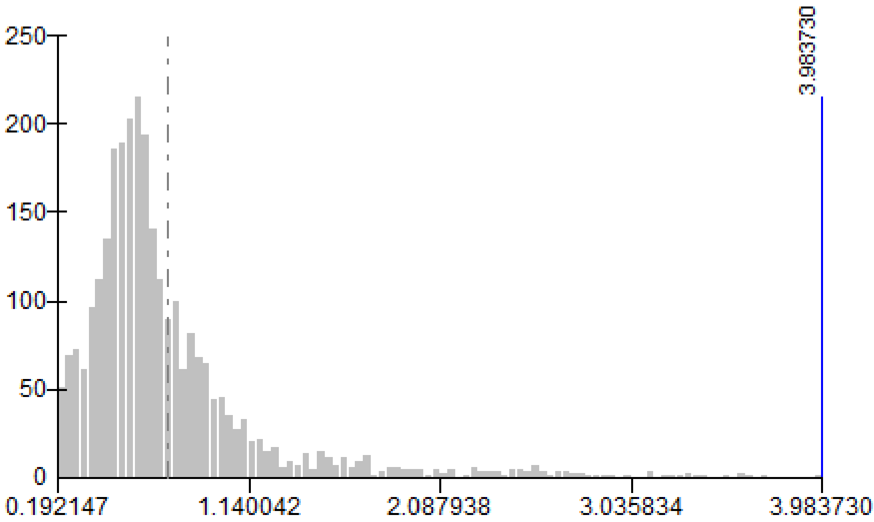


Figure 4-21: PhVI histogram of the arable sector

4.6.1.3. Economic vulnerability index (EVI)

The third component of vulnerability concerns valuable and economically important assets. In particular, the economic component includes farm crops and animals which may be damaged by a flood event (more detail in section 4-2). All economic indicators are a measure of the exposure/susceptibility of agricultural land to flooding. Arable incentives have not been involved in the vulnerability analysis because they vary in expiry date, grant duration, spatial resolution, and terms and conditions (see concluding chapter). Figure 4-22 shows the map of the final EcVI of the arable sector. The summary statistics table and histogram (Table 4-7 and Figure 4-23) report that most of the cells fall within the medium vulnerability class. However, there are areas in the north and middle of Holderness, the north of the Yorkshire Wolds, and the middle of Humberhead with high level of economic vulnerability to flooding.

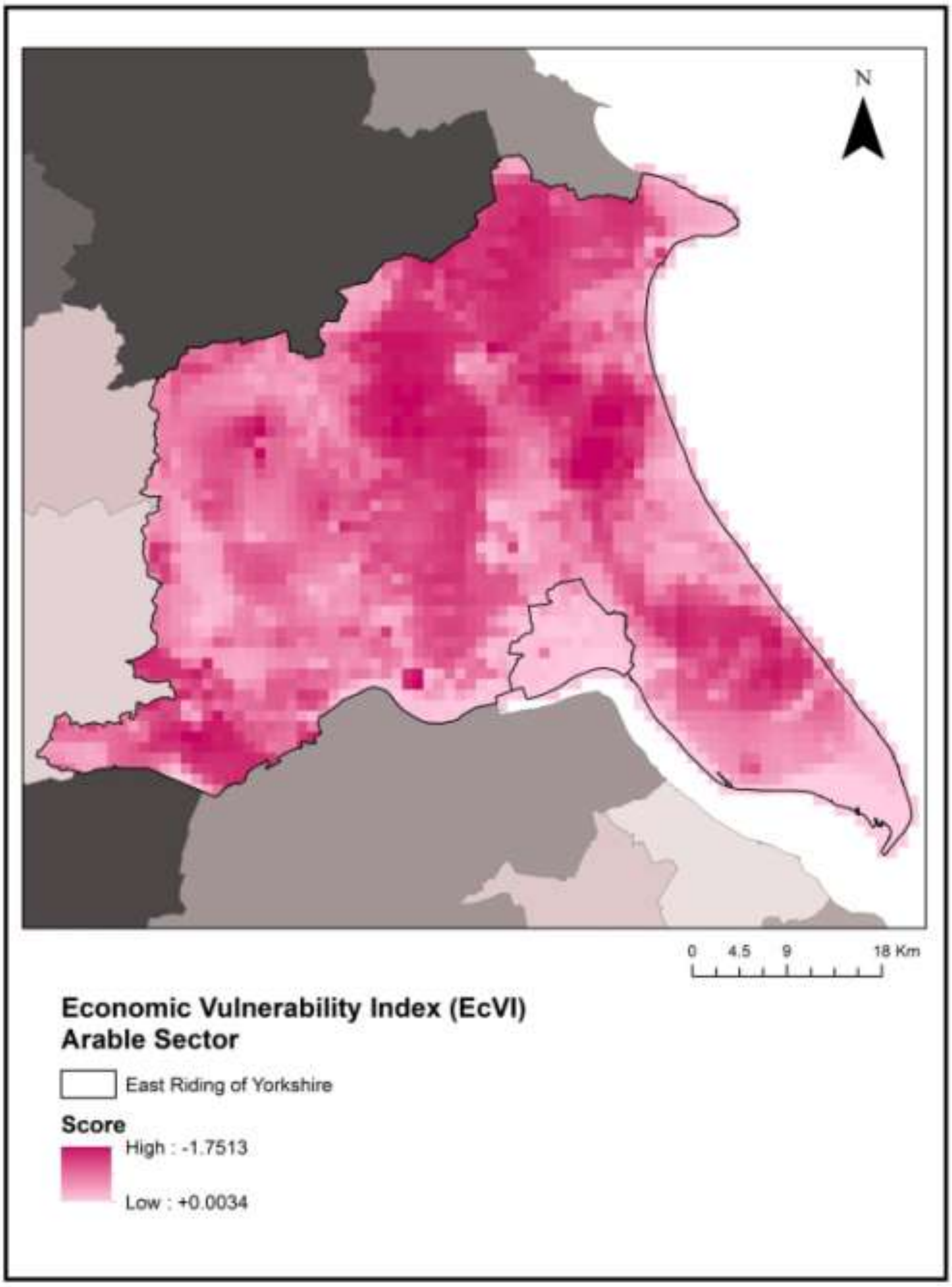


Figure 4-22: Economic vulnerability index (EcVI) for the arable sector

Table 4-7: Summary statistics of the arable EcVI

Descriptive Statistics for the Economic Vulnerability Index						
	Number of cases	Range	Minimum	Maximum	Mean	Standard deviation
EcVI	2780	1.7547	0.0034	1.7513	0.9204	0.3524

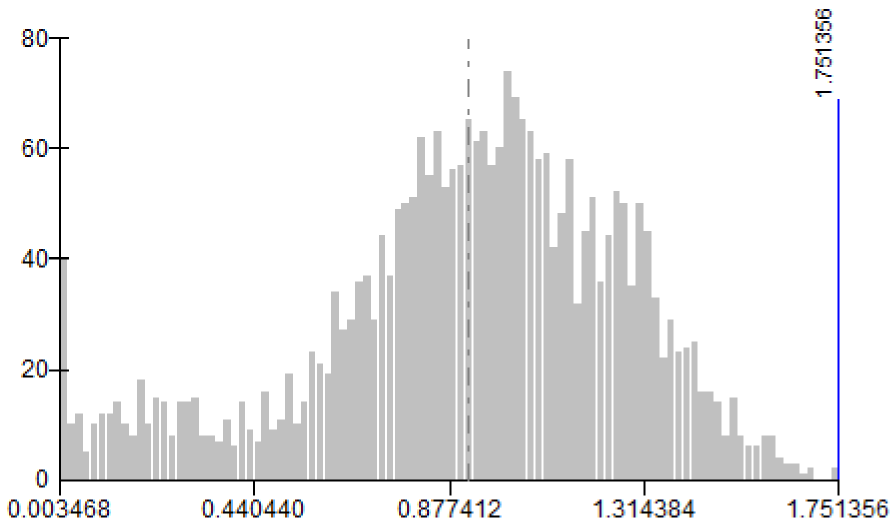


Figure 4-23: EcVI histogram of the arable sector

4.6.2. Sub-components of vulnerability

4.6.2.1. Exposure/Susceptibility

Another way of looking at the FVI is through its sub-components. The sub-component of exposure is an index of all variables which make the area more susceptible to the impacts of flooding. Figure 4-24 demonstrates the exposure index within the extent of the East Riding of Yorkshire. The Humberhead Levels and the area north-west of the City of Kingston upon Hull are the most exposed and susceptible to the impacts of flooding. In addition, there are clusters of cells with a high exposure index in the west and south of Holderness, and the northern, eastern and central Wolds. The urbanised areas have a considerably lower exposure index.

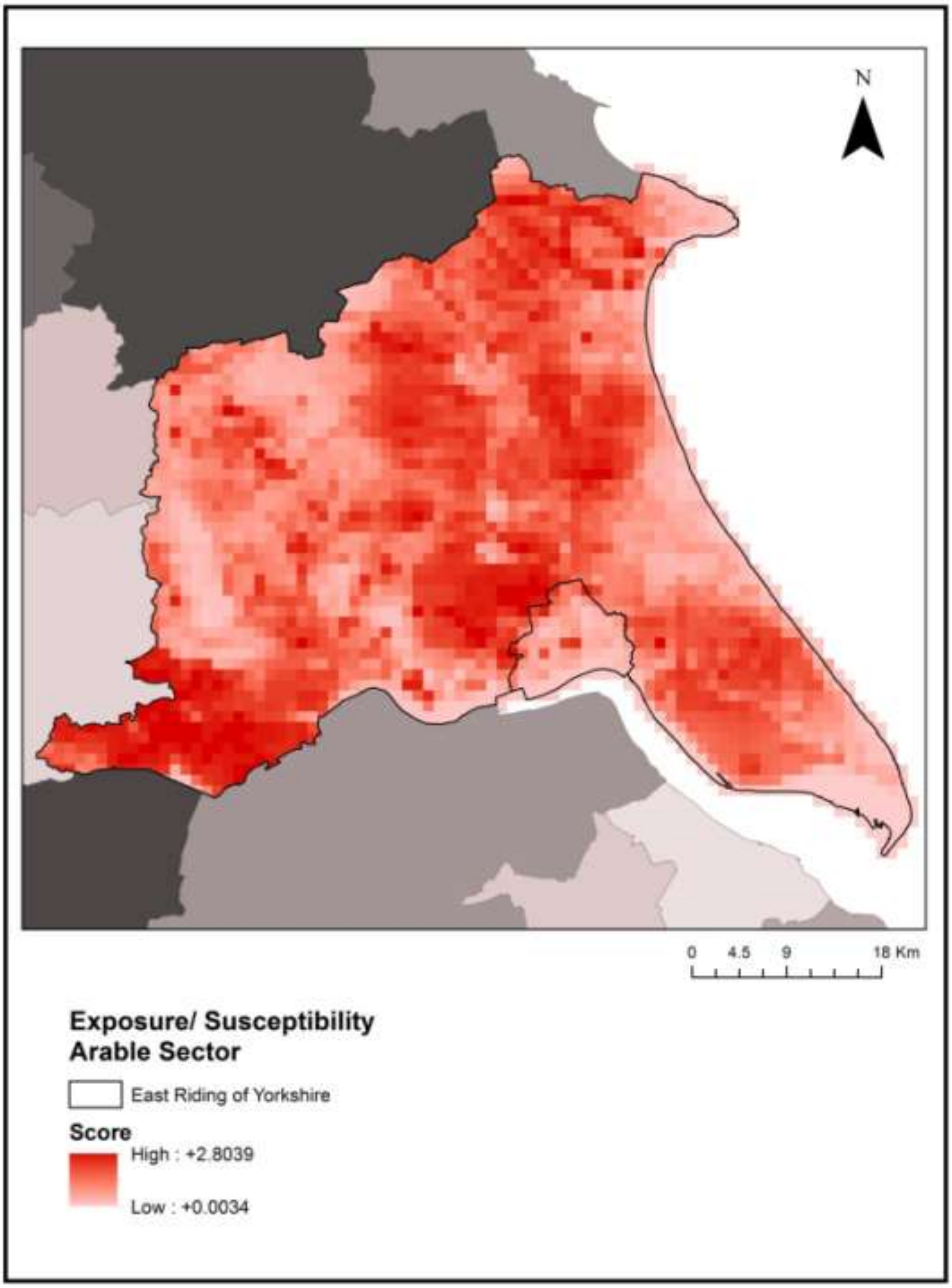


Figure 4-24: Exposure/susceptibility index of the arable sector

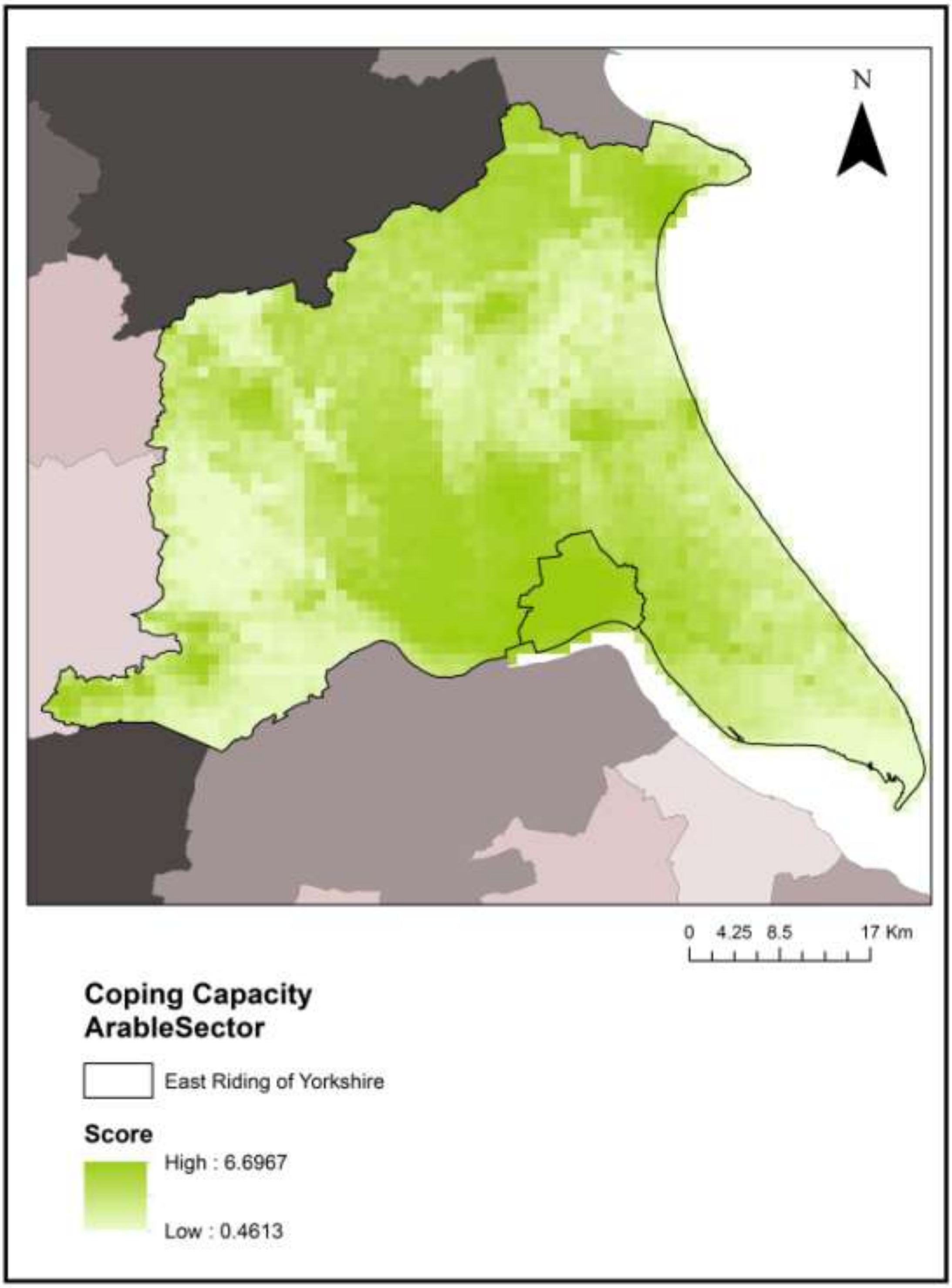


Figure 4-25: Coping capacity index for the arable sector

4.6.2.2. Exposure/Susceptibility

Coping capacity is composed of all the indicators which help the arable land to tolerate the negative effects of flooding. There are five indicators of coping capacity for the arable sector. Figure 4-25 shows the final coping capacity index of the arable lands susceptible to flooding. The area of the City of Kingston upon Hull and its surroundings is noticeably high in terms of coping capacity index. In addition, the urbanised areas have a higher index because of access to the physical help and rescue services. The extent of the Yorkshire Wolds shows a higher coping capacity index owing to the high permeability of the land.

4.6.3. Flood vulnerability index (FVI)

The main outcome of this chapter is the calculation of the vulnerability of the arable sector to flooding (FVI). Table 4-8 shows the summary statistics of the FVI and Figure 4-26 demonstrates the histogram of the resultant index for the grids. The first map of the FVI of arable land is an unclassified version of the scores (Figure 4-27). The graduated colour allows the FVI to be understood as a moving index which varies across the area. To improve the structure of the variability of the vulnerability index across 1 km grids, five classes have been built. The histogram of the composite indicator shows a Gaussian distribution. Classes were derived by means of the quantile classification method. The blue lines in Figure 4-26 represent the boundaries of the five classes (the dashed line stands for the standard deviation). Low values (darker green) symbolize low vulnerability while high values (darker red) represent high vulnerability in a grid cell (Figure 4-28).

The visualisation of the vulnerability index results in a quite heterogeneous picture for the East Riding of Yorkshire. In the western, north-eastern and central Wolds, and in the City of Kingston upon Hull and the areas to the west and the north-east, low and intermediate vulnerability classes are dominant. By contrast, in Humberhead Levels, the eastern Wolds, western and central Holderness, and the northern part of the Humber Estuary, numerous cells exhibit a high or very high vulnerability index. In addition, the cells around cities and urbanised areas show a considerably lower index, especially the cities of Bridlington, Driffield, Hornsea, Beverley and Pocklington.

Table 4-8: Summary statistics of the arable FVI

Descriptive Statistics for Flood Vulnerability Index						
	Number of cases	Range	Minimum	Maximum	Mean	Standard deviation
FVI	2780	1.7547	-3.1864	1.6081	0.0196	0.6126

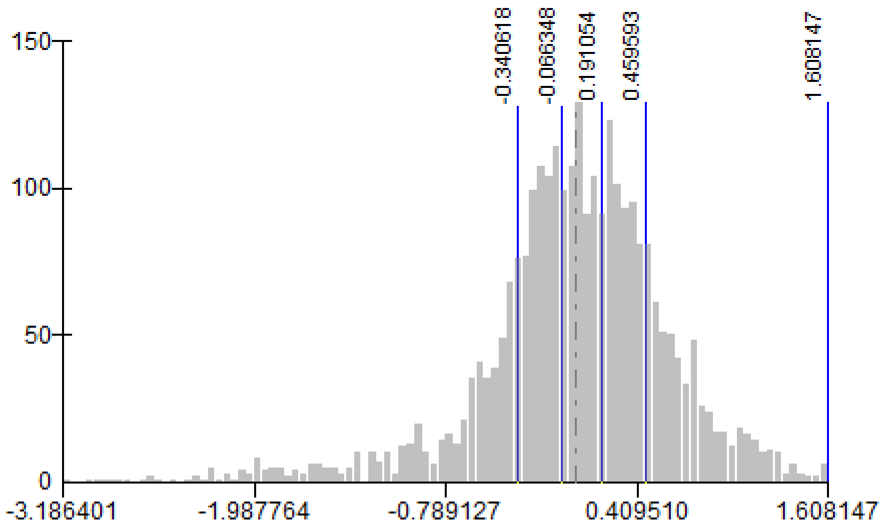


Figure 4-26: Histogram of the flood vulnerability index for the arable sector (FVI)

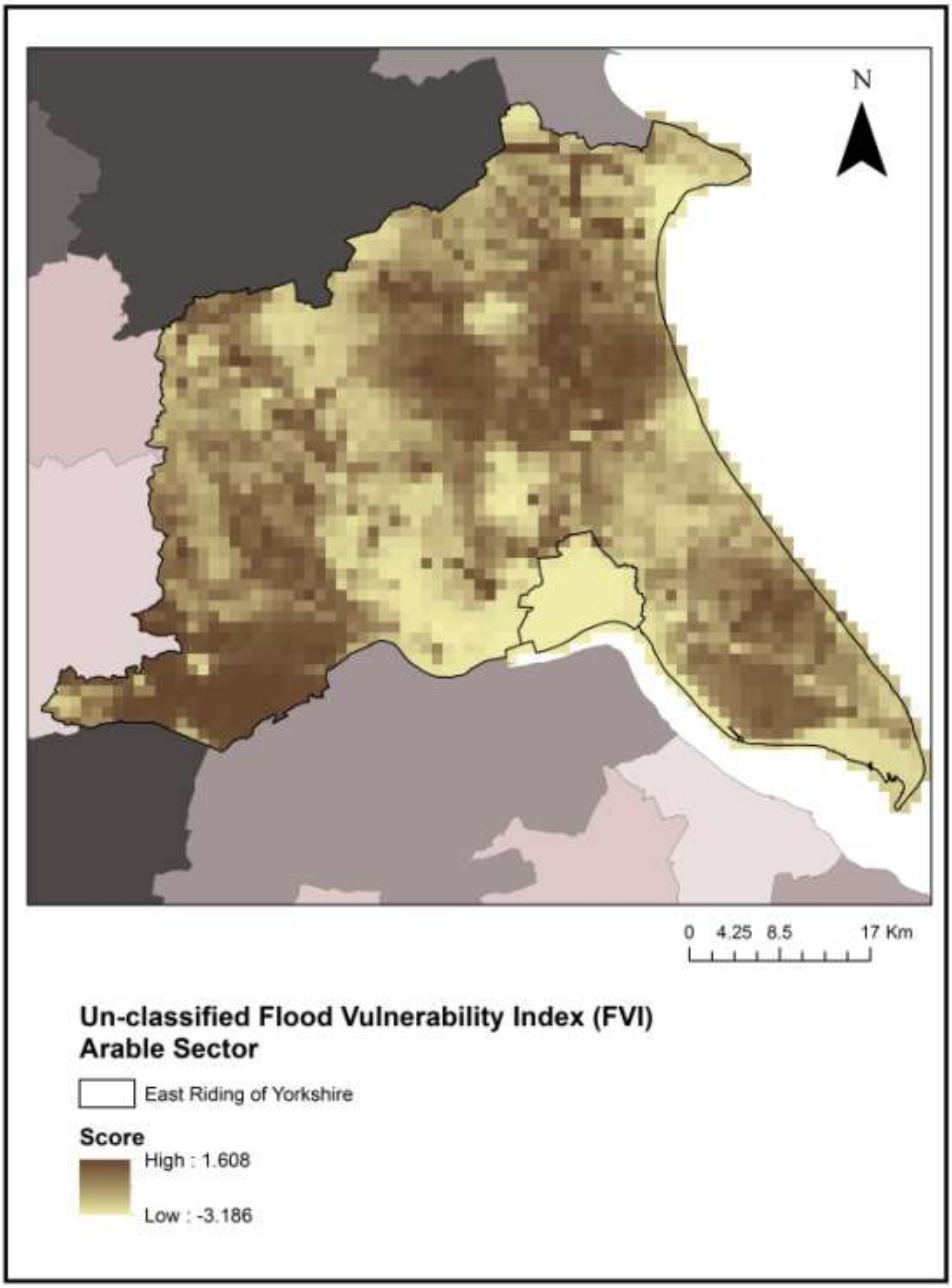


Figure 4-27: Un-classified FVI of the arable sector

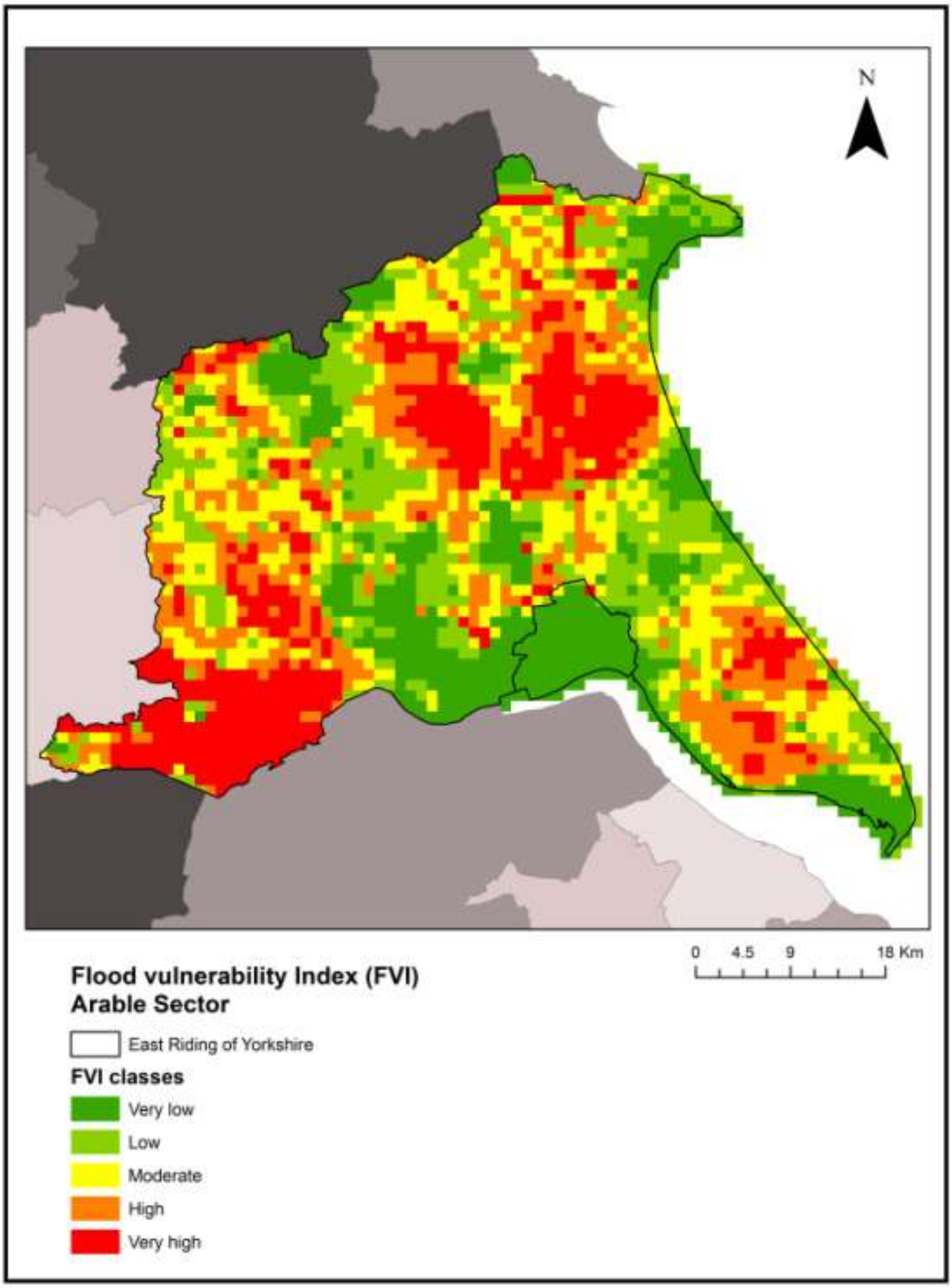


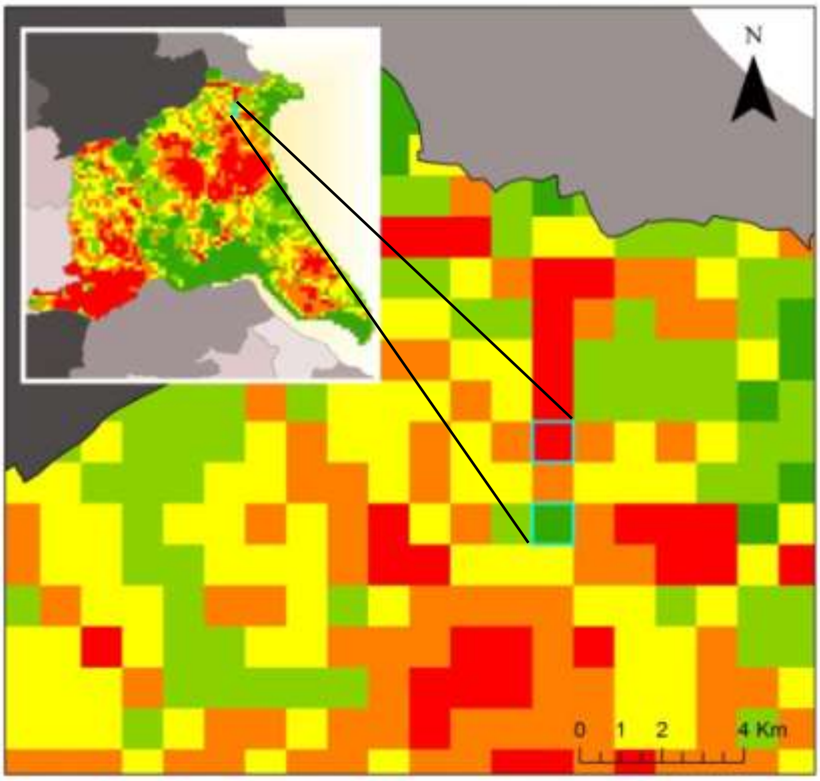
Figure 4-28: FVI classes of the arable sector

4.7.Conclusion

Agricultural activities form most of the economic activities of the area. Therefore the purpose of this chapter is the identification and mapping of arable land which is highly vulnerable to flooding. The vulnerability of the region is evaluated through components and sub-components of vulnerability. From the components of vulnerability the following results are derived:

- The environmental vulnerability index (EnVI) is high, mostly in the Hull river valley, the Humberhead Levels, and the Humber Estuary. However, the Yorkshire Wolds (south to north) accommodate cells with remarkably low EnVI.
- The physical vulnerability index (PhVI) is considerably high in the north-east of the Wolds where there is not sufficient access to coping capacity and access to sources of help (lighter green colour). In contrast, the City of Kingston upon Hull and its surroundings, the northern and eastern part of the Humber Estuary, and the remainder of the Wolds show very low PhVIs. The low PhVIs of the urbanised areas are also noticeable.
- The economic vulnerability index (EcVI) is marked as high in cells in the Humberhead Levels, northern and eastern parts of the Estuary, and the Yorkshire Wolds. This index is low in the urbanised areas where the land productivity and livestock reported are negligible.

The overall FVI of the arable land demonstrates a heterogeneous pattern for the study area (Figure 4-28). There are three main clusters of highly vulnerable cells: the central part of the East Riding, Humberhead Levels, and north of the Humber Estuary. The classification of indicators into components makes it possible to reveal the underlying reasons for the high or low vulnerability of cells. Figure 4-29 shows an example of how this goal could be achieved. Two neighbouring cells with different classes (very low and very high) are unwrapped. It can be seen from the report that the main reason behind the difference is the higher EnVI of the top cell. In addition, other properties of the cells are nicely comparable.



Properties

FID: 1852 (green)
EnVI: -0.87
PhVI: 0.59
EcVI: 1.11
Exposure score: 1.24
Coping capacity score: 1.59
FVI: -0.35

Properties

FID: 1854 (red)
EnVI: 0.61
PhVI: 0.71
EcVI: 1.18
Exposure score: 2.18
Coping capacity score: 1.11
FVI: 1.07

Figure 4-29: Comparison of two cells with different vulnerability classes

5. Vulnerability of the wildlife sector to flooding

5.1. Introduction

The importance of wildlife and the natural habitat in the British landscape has been discussed by the researchers. Although, at the time of a flood event, humans are the first priority, the effect of flooding on the landscape needs to be considered as well. A brief review of the literature on the rationale and importance of a vulnerability assessment for wildlife and the natural habitat is presented. The wildlife indicators are identified, evaluated, transformed, and integrated on the basis of the flowchart and the procedure discussed in the methodology chapter. A flood vulnerability index (FVI) is discussed in the final part of the chapter.

5.2. Flood effects on the wildlife sector

5.2.1. The impact of flooding on trees and woody species

Extreme rainfall followed by flooding not only causes substantial damage to buildings and human property, but is also a significant threat to woods and trees. Flooding has advantages and disadvantages for woods. In this part, the vulnerability of wildlife to the negative effects of flooding is examined. Woods and vegetation affect floods by reducing the peak and the extent of the flood downstream, and recently woodland has been included in flood management strategies (The Parliamentary Office of Science and Technology 2011, Hardie 2011).

The degree to which flooding would affect plant species varies greatly and depends on flood, plant and soil characteristics. Flood damage is largely a function of average inundation depth, frequency, duration, and velocity, weather conditions, and time of year (Kramer, Nijhof et al. 2006, Jull 2008, Jull 2010, Baughman 2010, Iles, Gleason 2008).

Flood water can harm plants of the same species differently according to various soil, flood, plant, and environmental conditions. Plant age, health, height, crown class, vigour, and species are the chief factors in determining the extent of damage (Jull 2008, Jull 2010, Baughman 2010, Iles, Gleason 2008, Coder 1994). There is a directory of the tree species present in the East Riding of Yorkshire on The Woodland Trust's webpage (The Woodland Trust 2013). Various fieldwork and case studies have reported the tolerance/intolerance of tree species to flooding (Jull 2008, Jull 2010, Baughman 2010, Iles, Gleason 2008).

Soil type and landscape characteristics are of great importance in determining vulnerability. For example, sandy soils drain much faster than clay-based soils, and proximity to river and slope is crucial in judging the risk of soil saturation. Changes in organic matter decomposition and therefore in oxygen level can harm plant roots. In addition, increased amounts of carbon dioxide, methane, hydrogen, and nitrogen are caused by soil saturation related to flooding and incidence wet soil-born root and crown rot organisms causing tree and plants damage (Jull 2008, Jull 2010, Iles, Gleason 2008, Ballesteros, Stoffel et al. 2010, Kozlowski 1997).

Flood water affects plants and woods in various ways. Direct damage includes: changing soil conditions, physically knocking over plants, interrupting normal gas exchange and seed germination, oxygen deprivation, and sedimentation. Furthermore, there are important indirect impacts of flooding on trees, such as susceptibility to insects and diseases, tree anatomy, vegetative and reproductive growth, mortality, plant distribution, fruit quality, poor aeration, soil structure, anaerobic organisms, reduced chemical activity (Baughman 2010, Iles, Gleason 2008, Coder 1994, Ballesteros, Stoffel et al. 2010, Kozlowski 1997, Nunes da Cunha, Junk 2002). Flood-stressed trees exhibit symptoms including stomatal closure, reduction in growth of shoots and roots, stem splitting, yellowing, leaves curling, leaves wilting and dropping, reduced size of leaves, crown die-back, and defoliation (Jull 2008, Jull 2010, Baughman 2010, Iles, Gleason 2008, Gomes 1979).

The immediate and long-term flood management practices listed below can significantly improve the site situation and prevent or reduce the secondary injuries (Kramer, Nijhof et al. 2006, Jull 2008, Jull 2010, Baughman 2010, Coder 1994):

- removing debris and covering exposed roots
- harvesting damaged, dead, or diseased branches and trees/plants
- soil testing and providing appropriate fertilizer for at least three years

- improving the drainage system in the area
- assigning some lands as retention basins
- replanting frequently flooded areas with flood-tolerant plants
- aerating the soil
- keeping an eye on the insect and fungal situation.

5.2.2. The impact of flooding on wildlife

Floodplains are among the most important sources of biodiversity. Floodplain species (animals and plants) are well adapted to seasonal/normal inundation, but show a dramatic decrease in abundance after extreme flood events (Junk 1997, Marx, Guhmann et al. 2012). As discussed in the background chapter, rainfall pattern, timing, and precipitation are important factors in determining flood severity for wildlife. In addition to the effects of flooding, human activities make the situation worse for wildlife. Firstly, human economic activities such as fishing, raising livestock, agriculture, mining, deforestation and tourism create huge environmental and ecological disruptions for wildlife (Alho, Silva 2012). Secondly, intense flood recovery and preparedness activities such as river channelisation, streambed excavation, and natural wood removal lessen the quality and diversity of natural habitats (Kirn 2011, Sommer, Harrell et al. 2001). Although the exact impact of flooding on wildlife is yet to be examined, there have been some case studies of wildlife species (Marx, Guhmann et al. 2012, Kirn 2011, Walls, Barichivich et al. 2013, Rodrigo 2011, Guillot 2011).

Floods affect both humans and wildlife; however, people have been the foremost concern. This is due to the evaluation of damage in terms of receivers, where the emphasis is on individual people and pets, whereas where wildlife is concerned the focus is turned to the effects on a population and whether it will survive (Gibbons 2011). In the short term, the impacts of flooding can be catastrophic, but in the long term there are many beneficial and productive impacts for the ecology and for wildlife (Alho, Silva 2012, Guillot 2011, Gibbons 2011). The flood damage to wildlife varies among species and needs to be tested with regards to the flood site, ecology, environmental characteristics, event timing, and the species' taxonomy. Flooding generally affects wildlife by changing their habitat, community structure, population size, and ecology; destroying their homes; washing away young and vulnerable individuals and populations, and wet and cold weather associated with flooding event; washing away trees, foods, and grass; disruption to breeding, reproduction, and clutches of eggs; lack of access to safe water; physical trauma; movement of debris; displacement and stranding of animals; and habitat modification (Alho, Silva 2012, Kirn 2011, Walls, Barichivich et al. 2013, Rodrigo 2011, Guillot 2011, Gibbons 2011, WIRES 2011, Rabbani, Rahman et al. 2013). A source of secondary damage to wild animals is increased encounters with people which frequently result in animal mortality.

Despite all the negative impacts of flooding on wildlife which have been mentioned, wildlife species are generally very resilient to flooding and have evolved various adaption strategies. For instance, Marx et al. (2012) put forward a table of flood adaption schemes used by arthropods (Marx, Guhmann et al. 2012). Different phenological and morphological predispositions are valuable to wildlife in surviving the extreme flooding. In addition, the recovery process depends on the species and the environmental conditions and may take from a year to a decade.

5.3.Inconsistency map of the wildlife sector

There are many organisations supplying maps and data on wildlife, natural habitats, and woodlands. In addition, there are some national maps drawn from various perspectives which show woodlands and protected areas as categories (i.e. Land Cover Map, MasterMap and Strategi).

Eight datasets have been used to map the woodlands and wildlife areas (Table 5-1). Traces of uncertainties have been recognised among the parcels of woods and wildlife habitats due to various organisational objectives, perspectives, rules, methods and tools. Actual change (due to the temporal gap) and errors might also be sources of inconsistency. From eight datasets for urbanised parcels, a binary presence of wildlife was identified on a 30 X 30 m^2 grid cell network. Figure 5-1 shows the inconsistency map of the wildlife sector. The darkest green shows the most consistent grid cells (agreed by seven datasets), and the lightest green show the parcels which have been cited by just one dataset. Great numbers of cells are in light green, which demonstrates the high level of inconsistency among the data sources. This map will be used in the analysis section to show the parcels with importance for biodiversity and wildlife habitat.

Table 5-1: List of data sources for the wildlife sector

Title	Organisation	Scale/ Resolution	Data Format	Availability	Temporal resolution
Land Cover Map (2007)	Centre for Ecology and Hydrology(CEH)	25 m	Raster	License agreement	2007
Strategi	Ordnance Survey	1:250000	Vector	License Agreement	2011
Vector Map District	Ordnance Survey	1: 25000	Vector	License Agreement	2010
MasterMap Topography Layer	Ordnance Survey	1:1250-1:10000	Vector	License Agreement	2012
Ancient woodland	Natural England	1: 63360	Vector	Public domain	2006
England sub-compartments	Forestry commission	1: 10000	Vector	Public domain	2011
National Forest Inventory (NFI)	Forestry commission	1: 10000	Vector	Public domain	2011
Protected areas	Natural England	1:10000	Vector	Public domain	2011

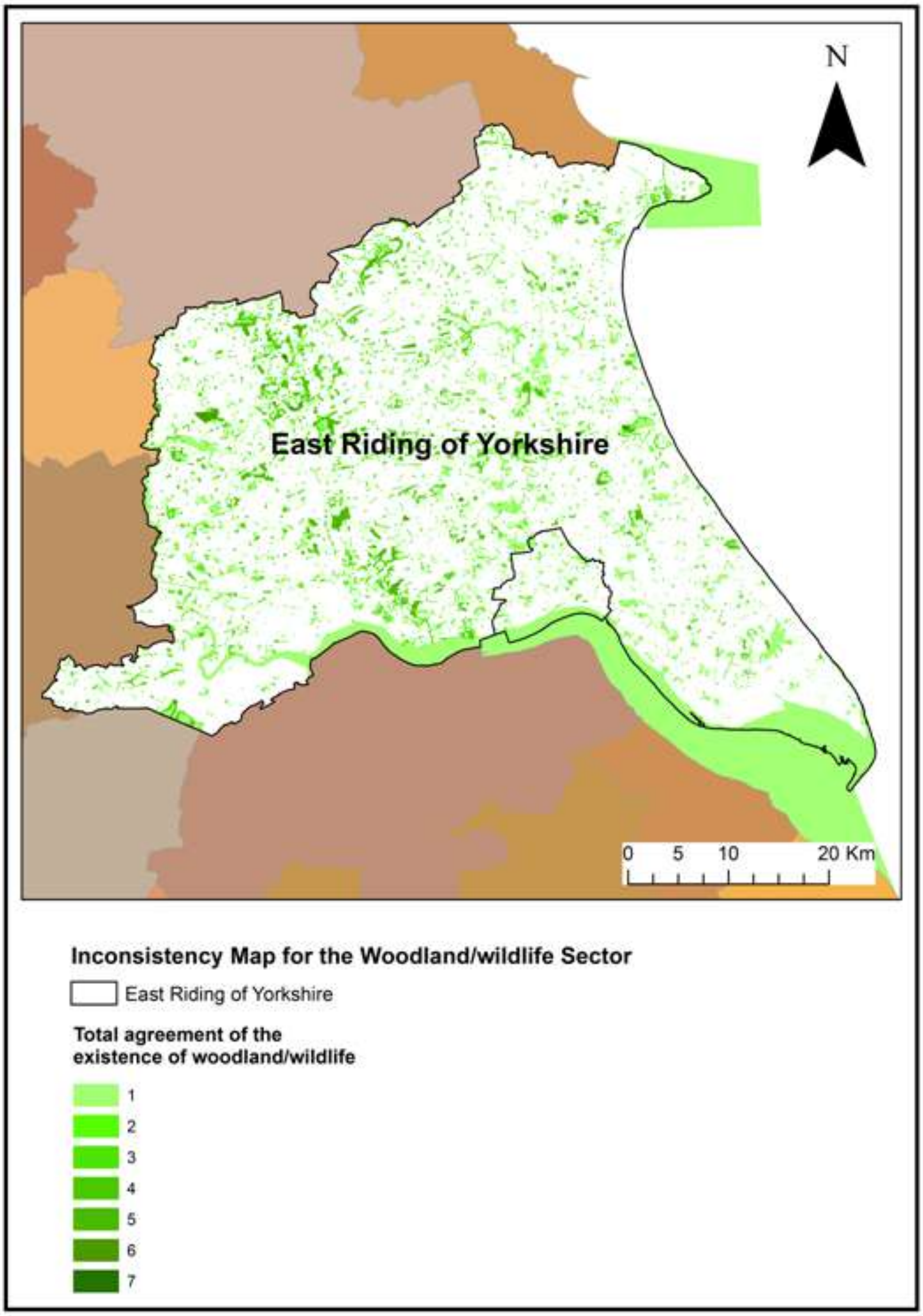


Figure 5-1: Inconsistency map of the wildlife sector

5.4.Indicator selection

In the previous sections the importance of woodland/wildlife flood vulnerability assessment has been identified and some literature has been put forward to support the idea. In addition, an inconsistency map of woodland/wildlife habitat has been sketched from eight different data sources. In this part the appropriate indicators are discussed and selected.

Table 5-2: Potential list of vulnerability indicators for the wildlife sector

Indicator	literature
Land area	(Damm 2010) (Kaly, Pratt et al. 2004)
Employed people in the forestry sector	(Damm 2010) (Cutter, Boruff et al. 2003) (Roy, Blaschke 2011)
Soil erosion	(Damm 2010) (Scheuer, Haase et al. 2011)
Contaminated sites	(Damm 2010) (Scheuer, Haase et al. 2011)
Dominating land use	(Damm 2010) (Kaly, Pratt et al. 2004) (Yahaya, Ahmad et al. 2010) (Myeong, Hong 2009) (Roy, Blaschke 2011) (Scheuer, Haase et al. 2011) (Chen, Chen 2008)
Soil type (Water retaining capacity, texture, type, filter, soil permeability)	(Damm 2010) (Yahaya, Ahmad et al. 2010) (Myeong, Hong 2009)
fragmentation	(Damm 2010)
Buildings, infrastructure, commercial establishments	(Cutter, Boruff et al. 2003) (Kaly, Pratt et al. 2004) (Scheuer, Haase et al. 2011) (Chen, Chen 2008)
Hot/cold periods	(Kaly, Pratt et al. 2004)
Wet/dry periods	(Kaly, Pratt et al. 2004)

Sea Temperatures	(Kaly, Pratt et al. 2004)
Dispersion	(Kaly, Pratt et al. 2004)
Isolation (distance to nearest town or...)	(Kaly, Pratt et al. 2004) (Roy, Blaschke 2011)
slides	(Kaly, Pratt et al. 2004)
borders	(Kaly, Pratt et al. 2004)
Relief	(Kaly, Pratt et al. 2004) (Myeong, Hong 2009) (Chen, Chen 2008)
Loss of cover, degradation	(Kaly, Pratt et al. 2004) (Myeong, Hong 2009) (UN/IEHS and NNGASU 2006) (Damm 2010)
Endangered species	(Kaly, Pratt et al. 2004)
Environmental agreement	(Kaly, Pratt et al. 2004)
Frequency of heavy rainfall	(Connor n.d.) (Myeong, Hong 2009)
Average slope of basin	(Connor n.d.) (Yahaya, Ahmad et al. 2010) (Myeong, Hong 2009) (Chen, Chen 2008)
Investment amount	(Connor n.d.) (UN/IEHS and NNGASU 2006)
Annual rainfall	(Yahaya, Ahmad et al. 2010) (Myeong, Hong 2009) (Connor n.d.)
Drainage network	(Yahaya, Ahmad et al. 2010) (Chen, Chen 2008)
Spills/mining	(Kaly, Pratt et al. 2004)
Distance to river	(Adelekan 2011)
%Protected area	(Damm 2010)
Reforestation rate	(Damm 2010)

On the basis of the modified BBC framework (discussed in the methodology chapter), only three components of vulnerability (environmental, physical, and economic) and two sub-components (exposure/susceptibility and coping capacity) have been used in the development of indicators. The social component has been omitted because of the wildlife and natural habitat focus of this chapter. Categorising the indicators on the one hand gives an insight into the orientation of the indicator and on the other hand provides targets for reducing vulnerability. The potential list of indicators for the wildlife sector has been developed with reference to the great literature on flood vulnerability (Table 5-2). This list was taken for further evaluation and the final list has been extracted by reference to expert opinion and the criteria proposed by Birkmann (Birkmann 2006a) which are mentioned in Chapter 3.

Table 5-3: List of vulnerability indicators for the wildlife sector

Component	Sub-component	Indicator
environmental	Exposure/ susceptibility	Geological indicators of flooding (GIF)
	Exposure/ susceptibility	Flood zones (FZ)
	Coping Capacity	Permeability (PRB)
	Exposure/ susceptibility	Pollution Incidents (PI)
	Exposure/ susceptibility	Groundwater areas (SPZ)
	Exposure/ susceptibility	Landfill sites (LFS)
	Exposure/ susceptibility	Contaminated land (CL)
	Exposure/ susceptibility	Surface water (SWF)
Physical	Coping Capacity	Construction and Repair services (CONS)
	Coping Capacity	Central and local government (RESC)
	Coping Capacity	Train stations (TRN)
	Coping Capacity	Roads (ROAD)
Economic	Exposure/ susceptibility	Forestry workers (FRWR)
	Exposure/ susceptibility	Biodiversity action areas (PA)
	Exposure/ susceptibility	Natural habitat (FRST)
	Exposure/ susceptibility	Felling license areas (FLA)

A comprehensive background to indicator development has been provided in the methodology chapter. The steps and flowchart followed to obtain the final list of indicators are presented in the methodology chapter and are not repeated here. Only the results are presented. Table 5-2 shows the final list of appropriate indicators, grouped into components and sub-components. Appendix 2 provides comprehensive information on each indicator, including driven variables, temporal resolution, spatial resolution/scale, data source, data format, description, and the original mapping. There has not been an inclusive metadata and description for every dataset; however, attempts have been made to present the best outcomes.

5.5.Development and evaluation of a composite indicator

Development of a composite vulnerability index requires sequential steps as described in the methodology chapter. The steps follow the general flowchart presented in the methodology chapter and all the repetitive descriptions have been avoided. Firstly, components and sub-components of vulnerability have been recognised and appropriate indicators have been assigned to them (Table 5-3). Secondly, variables have been transformed into a 1 km grid and normalised. Thirdly, a descriptive approach has been taken to evaluate the statistical characteristics of the indicators. Fourthly, a correlation analysis has been carried out to evaluate the relationship between the indicators. Fifthly, the composite index has been calculated. Sixthly, the final FVI of the wildlife sector is visualised by means of flood vulnerability index (FVI) maps.

5.5.1. Data transformation and normalisation

There are, overall, sixteen indicators of vulnerability in the wildlife sector. The original maps of indicators, their metadata and their descriptions are provided in Appendix 2. Table 5-4 shows a summary of the metadata presented in Appendix 2. For the sake of simplicity, abbreviations have been assigned to variables. Environmentally related indicators are mostly provided by the Environment Agency, while Ordnance Survey, Natural England, Forestry Commission, and CASWEB are the other sources of data sets.

It is essential to have a good understanding of the indicators before making use of them.

Data preparation is a crucial step. Spatial resolutions of indicators vary as demonstrated in Table 5-4. This work has been carried out in a raster theme and at medium administrative level. A grid with 1 km cells has been sketched and all indicators have been remapped into this theme. The transformation method varies among the indicators according to their characteristics. The normalisation method, however, is min/max, as described in detail in Chapter 3.

Table 5-4: Summary metadata of the wildlife indicators

Indicator	Variable	Organisation	Resolution/ scale	Data format	Availability	Date
Geology of land	Geological indicators of flooding (GIF)	British Geological Survey (BGS)	1:50 000	Vector polygon	License agreement	2011
Permeability	Permeability Index (PRB)	BGS	1: 50 000	Vector point data	License agreement	2010
Flood zone	Flood zones 2 and 3 (FZ)	Environment Agency	1: 10 000	Vector polygon	License agreement	2012
Pollution	Pollution incident (PI)	Environment Agency	1: 10 000	Vector point data	License agreement	2001-2012
Groundwater areas	Source protection zones (SPZ)	Environment Agency		Vector point data	License agreement	
Polluted lands	Landfill sites (LFS)	Environment Agency		Vector Polygon	License agreement	1975-2011
Contaminated lands	Contaminated lands (CL)	Environment Agency		Vector Polygon	Vector Polygon	
Surface water	Flood Map from Surface Water (SWF)	Environment Agency		Vector Polygon	License agreement	2010
Construction services	Points of Interest-Construction (CONS)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Rescue services	Points of Interest-rescue services (RESC)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Train stations	Points of Interest-Train stations (TRN)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Roads	Roads from Vector Map District (ROAD)	Ordnance Survey	1:25 000	Vector polyline	License agreement	2011
Forestry workers	Industry of employment (FRWR)	CASWEB	N/A	Vector polygon	License agreement	2001
Biodiversity action areas	Local biodiversity priority &Biodiversity opportunity target areas (PA)	Natural England	1:10 000	Vector polygon	License agreement	2009-2010
Natural habitat	Inconsistency map (FRST)	See part 5-3	50 m	Vector polygon	N/A	N/A
Felling license areas	Felling license application areas(FLA)	Forestry commission	1:2500	Vector polygon	License agreement	2012

The list of environmental and physical indicators is the same as for the arable sector. Therefore, their transformation and normalisation results are not repeated and readers are referred to Chapter 4, part 4-5-1. However, the economic indicators are directly related to the characteristics of the sector and are described as follows.

Four indicators of exposure/susceptibility have been detected for the economic component of the wildlife sector. In this part the transformation and normalisation processes will be described and the resultant maps are presented.

- Forestry workers (FRWR):

This is a census-drived variable holding the density of forestry workers in each output area (OA) (number of workers/hectare). The number of forestry workers is an indicator of people who are economically susceptible to the impacts of flooding. Firstly, a "raster to polygon" operation was applied in order to project the data into 1 km grid cells, and a normalisation formula was then applied at the extent of the East Riding of Yorkshire. Figure 5-2 shows the final normalised scores at 1 km grid cells.

- Biodiversity action areas (PA):

These are polygon data which show the extent of "local biodiversity priority areas" and "biodiversity opportunity target areas". The areas are nationally and locally important in terms of biodiversity. The total area of merged layers (local biodiversity priority areas and biodiversity opportunity target areas) in each 1 km grid cell was calculated using a "polygon in polygon" operation. The maximum value that a grid could obtain is 1,000,000, which is the area of a grid cell. Normalised values were the final scores to be assigned to cells (Figure 5-3).

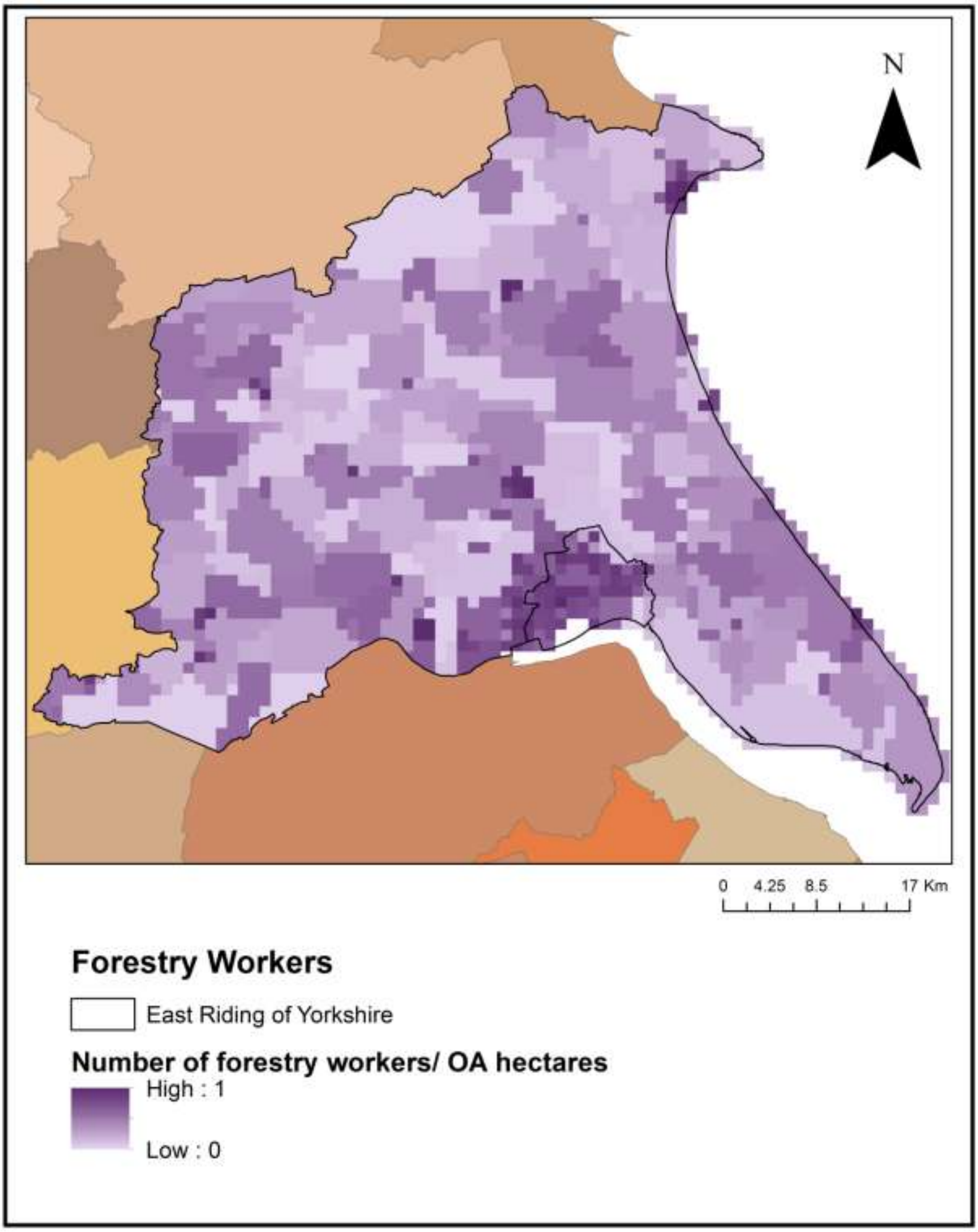


Figure 5-2: Transformed and normalised forestry workers

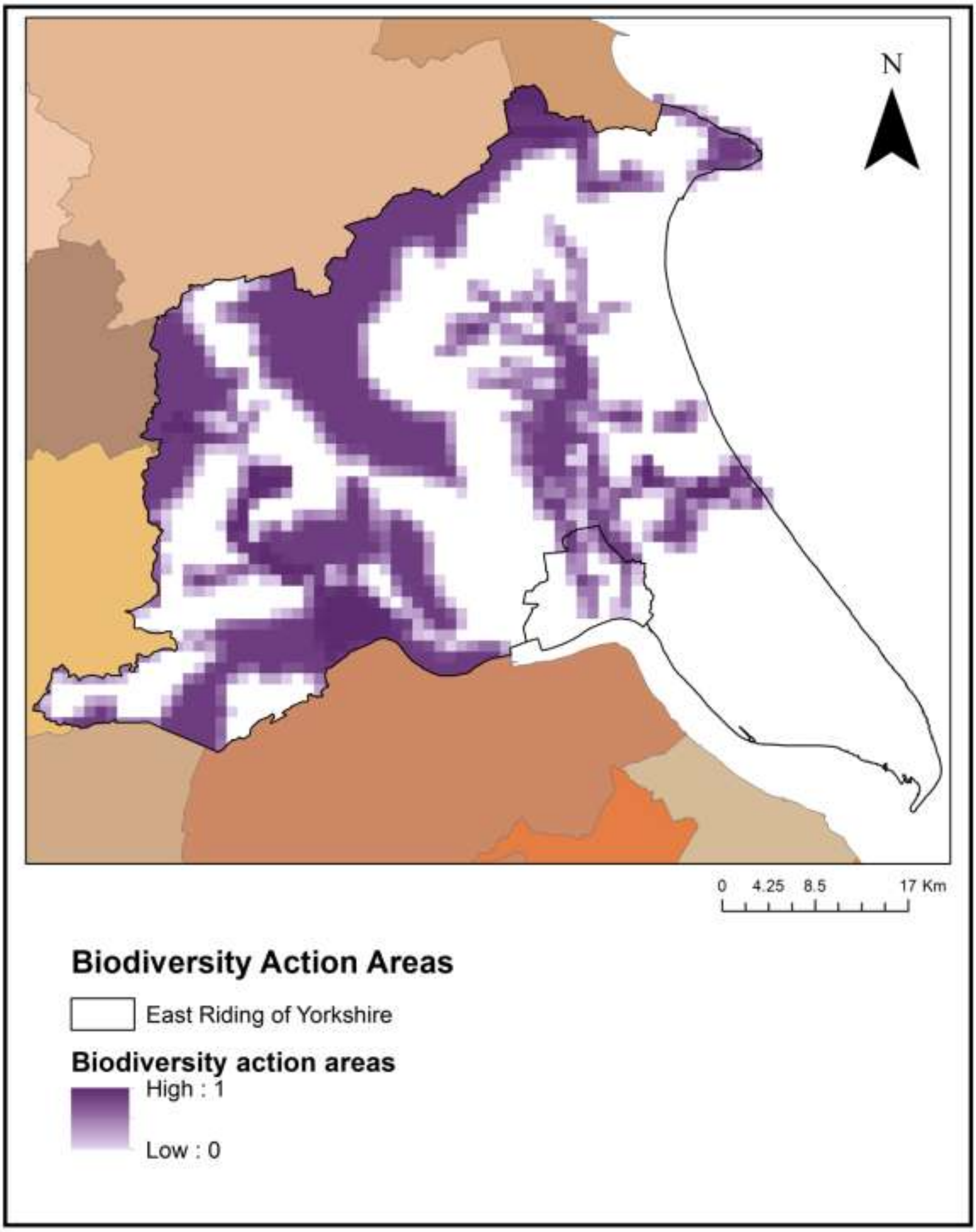


Figure 5-3: Transformed and normalised biodiversity action areas

- Natural habitat (FRST):

The result of the inconsistency analysis of the wildlife sector has been taken to show all the possible parcels of natural habitats. The total area of natural habitat polygons in each 1 km grid cell was calculated using the "polygon in polygon" tool in ArcGIS. Resultant values were normalised at the extent of the East Riding of Yorkshire (Figure 5-4).

- Felling licence application (FLA):

This is a dataset produced by Forestry Commission England which shows the extent of forest parcels with a felling licence. The lands where trees are being felled are more susceptible to the impacts of flooding. In addition, since a business is being carried on in these forest parcels, they are economically important as well. A "polygon in polygon" operation was applied in order to calculate the total area of the FLA layer within each 1 km grid cell. The values then were normalised according to the min/max normalisation method. Figure 5-5 shows the resultant normalised scores for every grid cell.

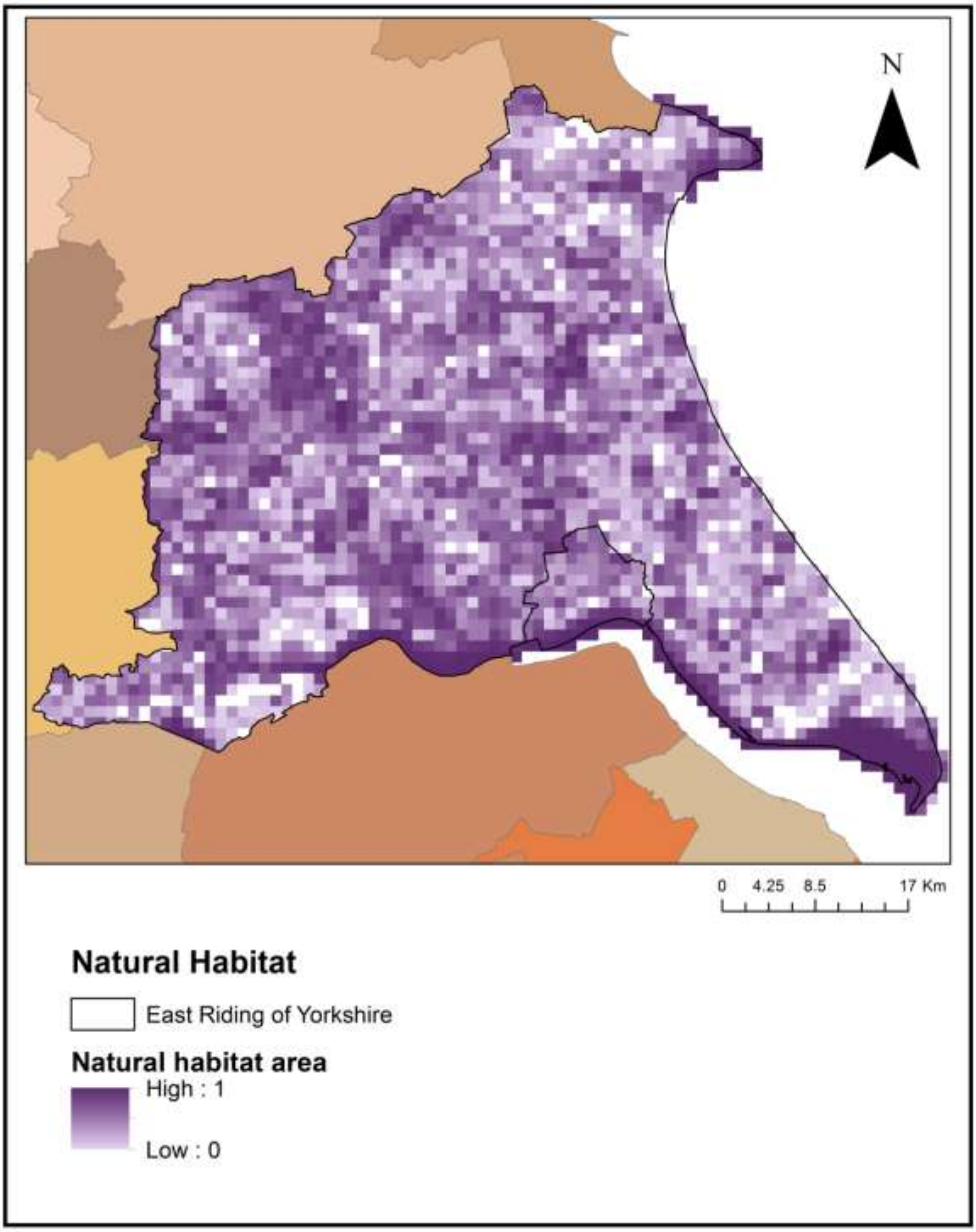


Figure 5-4: Transformed and normalised natural habitat areas

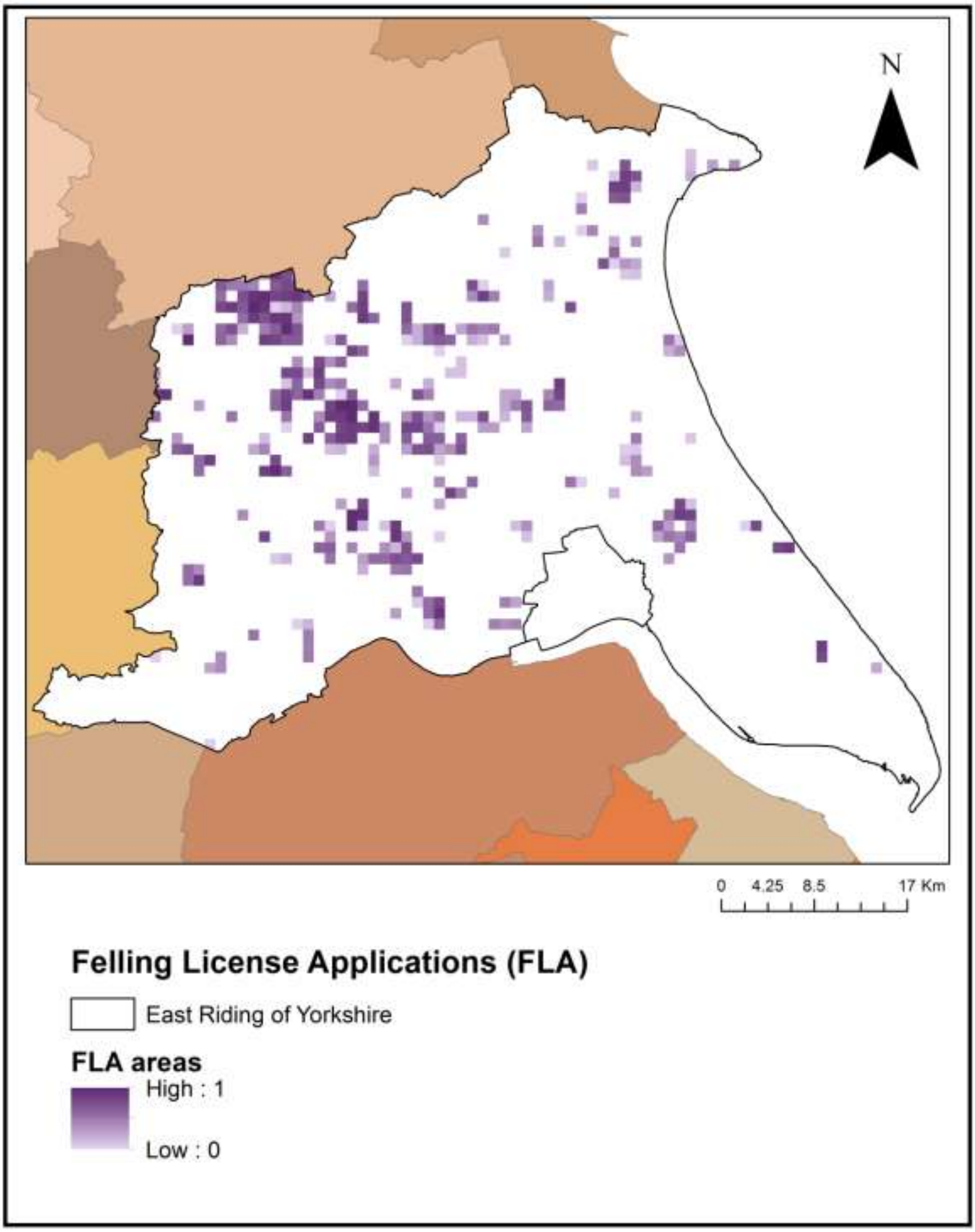


Figure 5-5: Transformed and normalised felling licence areas

5.5.2. Data analysis

To evaluate the vulnerability indicators of the wildlife sector, a descriptive and explorative approach has been carried out. This means that all the statistical characteristics of indicators within and between them have been examined. This part has been structured around three vulnerability components: environmental, physical, and economic. For each component, firstly, tables showing the indicators' information have been set out (Table 5-4); secondly, statistical characteristics have been explored; and, thirdly, a correlation analysis has been carried out using EViews statistical software. The correlation coefficient measures the linear relationships among the variables and is a good gauge of variables dependency. All coefficients above the threshold of r = 0.50 indicate a high correlation and are therefore assessed.

The correlation resultant matrix is provided in Chapter 7 and therefore only relevant points are presented in this chapter. Table 7-2 shows the correlation coefficients of the wildlife vulnerability indicators. The correlation analysis of the indicator set for the wildlife sector delivers the following results:

- The forestry worker indicator (FRST) is noticeably correlated with roads (+0.52). However, the two indicators are derived from different components and sub-components, so neither of them is omitted from the list of indicators.
- Flood zones, permeability (-0.48) and GIF (+0.79) are considerably correlated. The permeability is a variable of coping capacity and hence is kept. However, the GIF is nominated for exclusion.
- Roads and train stations are highly correlated (+0.64), but both are kept as the two indicate different coping capacity sources.
- Construction services are very much associated with train stations (+0.86) and roads (+0.65). However, as mentioned in the previous point, they refer to different helping options and therefore none of them is deleted.

5.5.3. Weighting and aggregation

Central to the construction of a composite indicator is the need to combine the indicators in a meaningful way, which in turn implies a decision on a specific weighting and aggregation model. The weighting and aggregation methods described in Chapter 3 have been applied on the final fifteen indicators of the wildlife sector. Equal weighting and summation of weighted variables are the first stage in the weighting and aggregation processes.

5.6.Results

In this section, the results of the vulnerability analysis conducted through its components and sub-components are put forward. By means of maps, summary statistics and graphs an investigation has been made into the indices. The final section presents the main outcome of the chapter, which is the wildlife FVI.

5.6.1. Components of vulnerability

5.6.1.1. Environmental vulnerability index (EnVI)

The environmental vulnerability index (EnVI) shows the vulnerability of a cell in environmental terms. Table 5-5 illustrates summary statistics of the EnVI. There are some cells with negative values due to the presence of the permeability indicator as a coping capacity factor with negative values. Figure 5-6 shows the histogram of the EnVI for wildlife. By means of GIS, the results of the environmental vulnerability index are illustrated in a map (Figure 5-7). The real scores are illustrated, ranked from the least (light green) to the most (dark green) environmentally vulnerable grids. Quantile classification methods have been used to visualise the index (please see the discussion in the methodology chapter).

Most of the cells fall within the very low to moderate category of vulnerability. However, there are two main hot spots of cells with high levels of vulnerability: around Humberhead Levels, and the area of the City of Kingston upon Hull to the north and south-east. These are the hot spots in terms of environmental vulnerability.

Table 5-5: Descriptive statistics for the EnVI of the wildlife sector

Descriptive Statistics for the environmental vulnerability index						
	Number of cases	Range	Minimum	Maximum	Mean	Standard deviation
EVI	2780	3.075	-1	2.075	-0.1671	0.4593

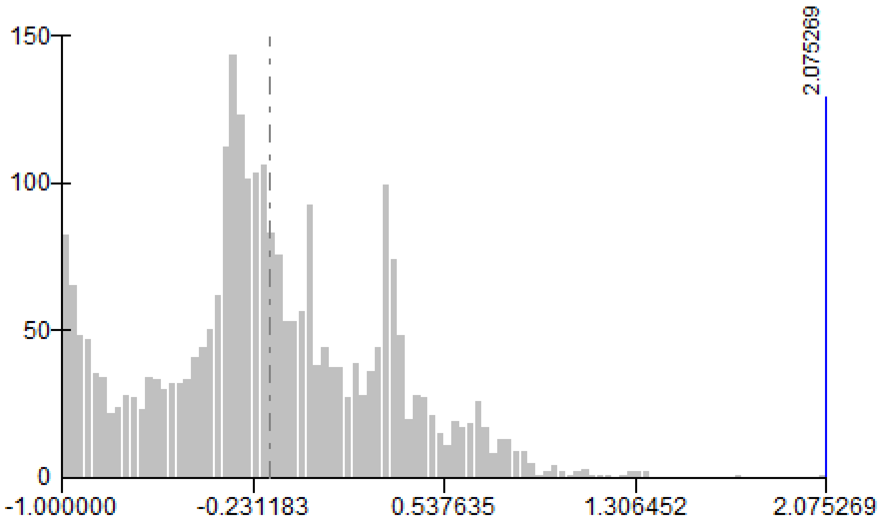


Figure 5-6: Histogram of the EVI of the wildlife sector

5.6.1.2. *Physical vulnerability index (PhVI)*

Physical factors which affect the vulnerability of an area in a wildlife context have been considered in the PhVI. Table 5-6 shows the summary statistics for the PhVI. Since all detected factors are measures of coping capacity, PhVIs hold negative values, with a maximum of -0.1921. The extent of the range is close to the number of factors.

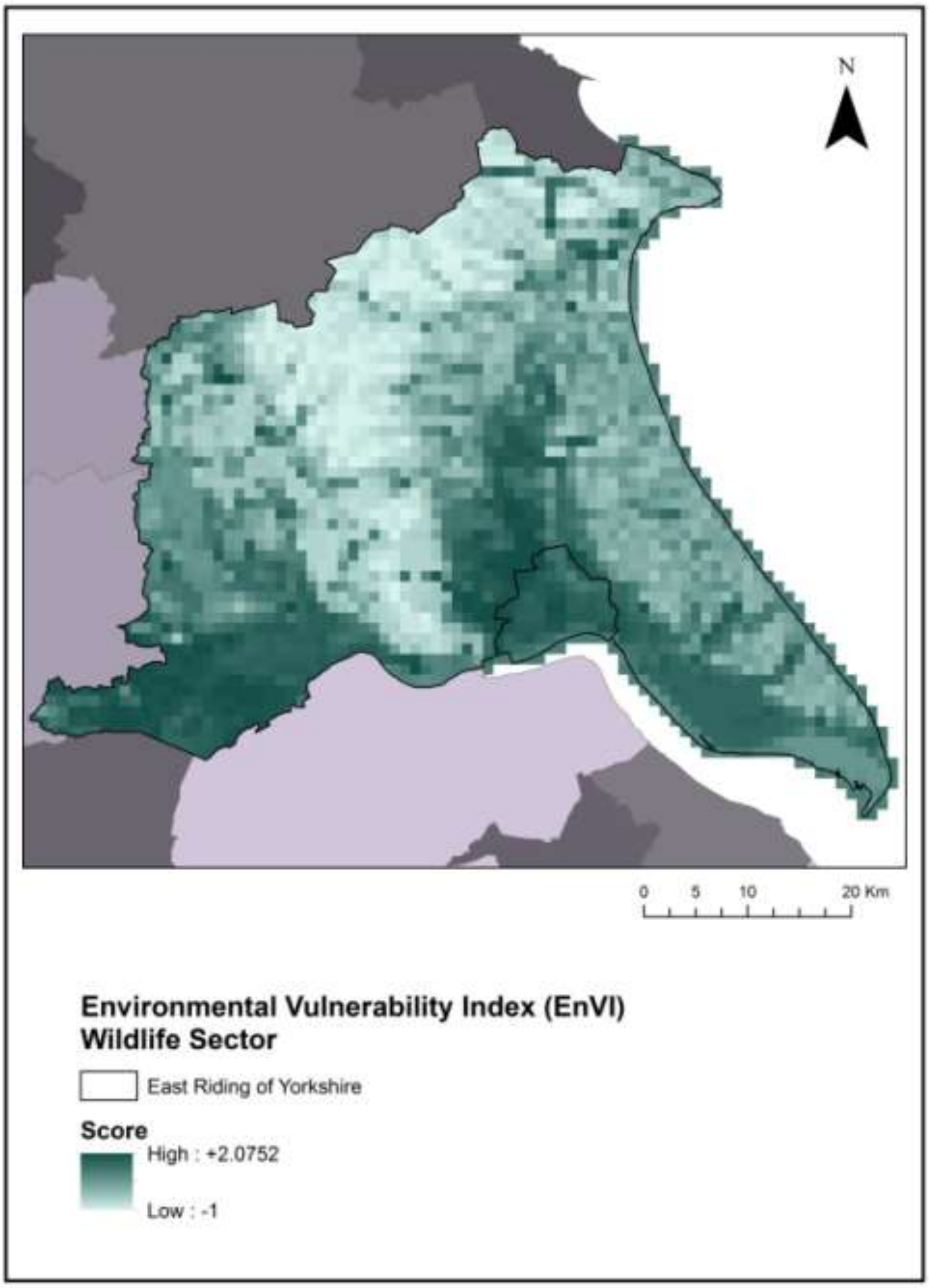


Figure 5-7: Environmental vulnerability index (EVI) for the wildlife sector

Figure 5-8 shows the histogram of the PhVIs. As predicted by the table of statistics, values are negative and close to zero (mean= -0.7335). Vulnerable cells in terms of physical factors have been highlighted in dark orange in Figure 5-9. Areas around highly populated centres hold the lowest PhVI scores. This is due to the fact that physical resources are located with reference to the population distribution. The resultant map highlights some highly vulnerable areas around the east and north of the East Riding of Yorkshire.

Table 5-6: Descriptive statistics for the PhVI of the wildlife sector

Descriptive Statistics for the PhVI						
	Number of cases	Range	Minimum	Maximum	Mean	Standard deviation
PhVI	2780	3.7926	-3.9847	-0.1921	-0.7335	0.4649

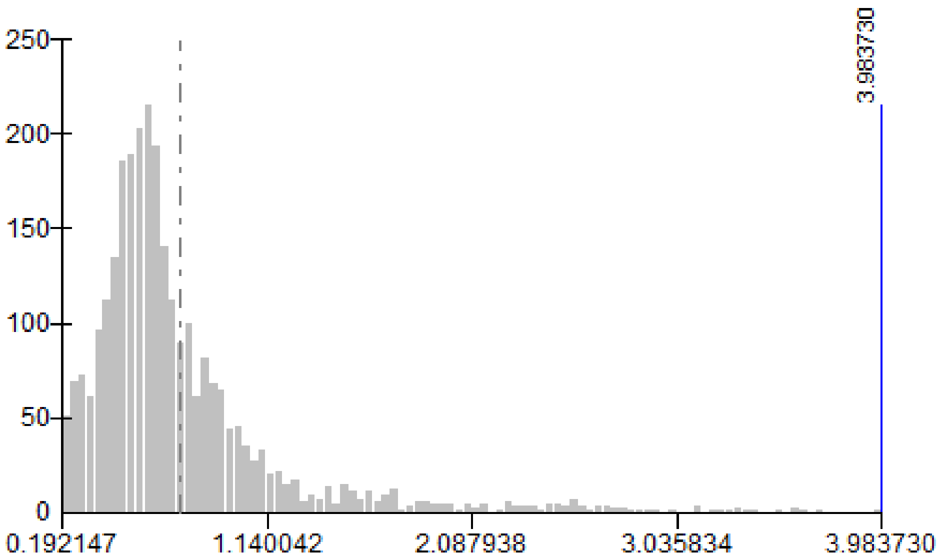


Figure 5-8: Histogram of the PhVI of the wildlife sector

5.6.1.3. *Economic vulnerability index (EcVI)*

The EcVI has been extracted for the wildlife sector on the basis of the steps discussed in the previous sections. Four factors play a role in shaping the EcVI (Table 5-4). Table 5-7 shows summary statistics of the EcVI. Since all factors measure exposure/susceptibility, EcVI hold positive values and have a range close to the number of factors (n=4). Figure 5.10 demonstrates the histogram of the EcVI values ranging from 0 to 2.78. Figure 5-11 shows the EcVI of the cells within the East Riding of Yorkshire. There are patches of hot spots and cold spots. Hot spots are mostly distributed in the west of the region and cold spots in the east. In fact, the hot spots follow the footprints of biodiversity action areas.

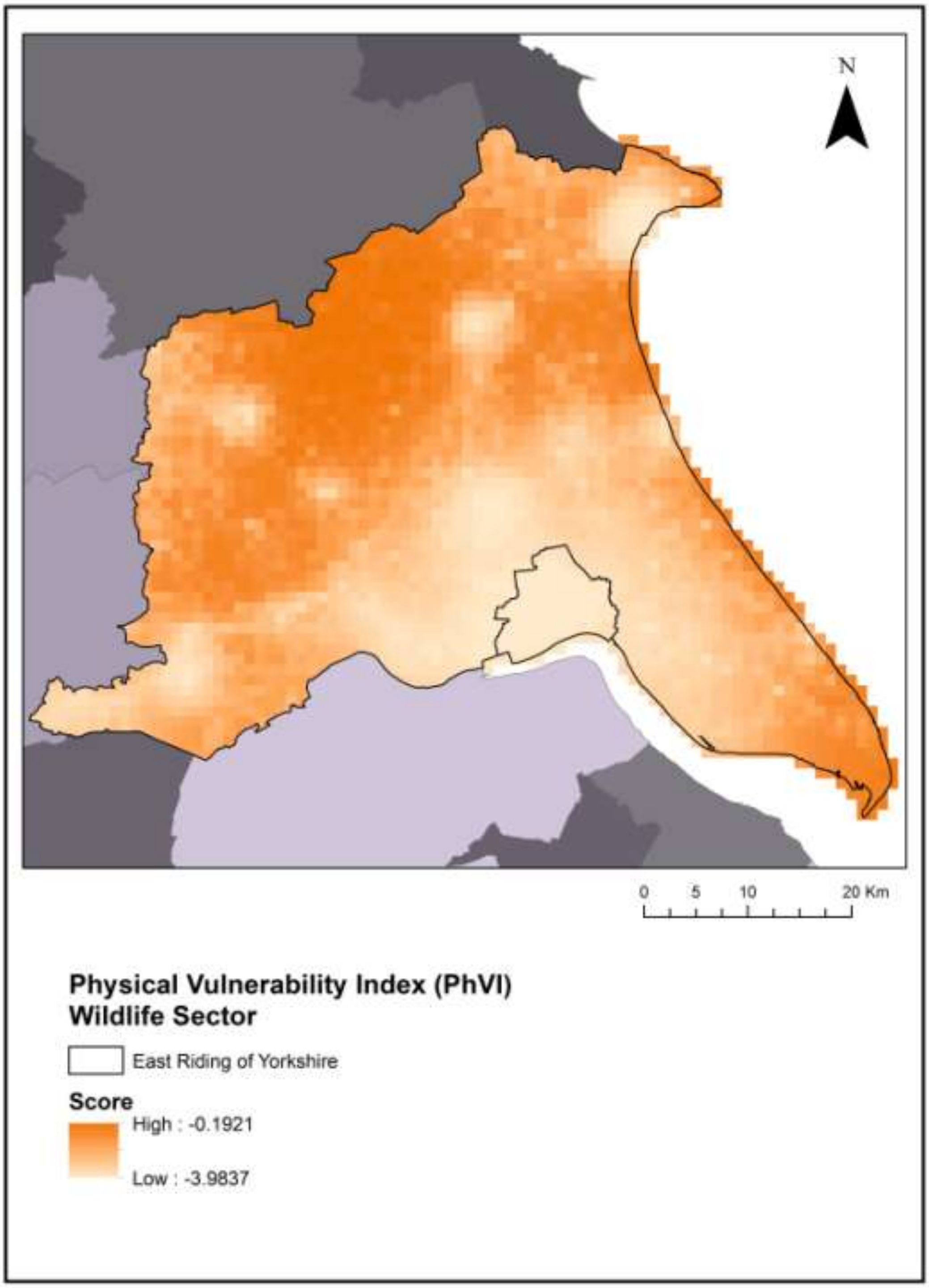


Figure 5-9: Physical vulnerability index (PhVI) for the wildlife sector

Table 5-7: Descriptive statistics for the EcVI of the wildlife sector

Descriptive Statistics for the EcVI						
	Number of cases	Range	Minimum	Maximum	Mean	Standard deviation
EcVI	2780	2.7893	0	2.7893	0.5585	0.5431

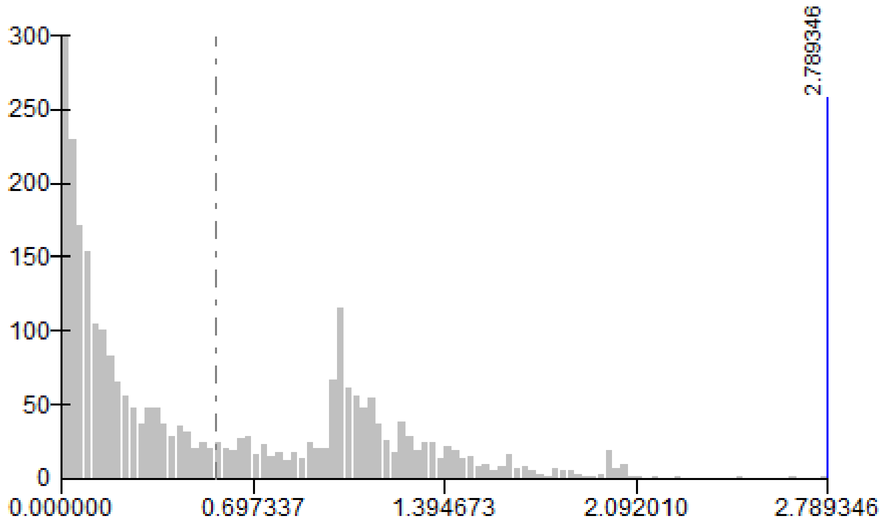


Figure 5-10: Histogram of the EcVI of the wildlife sector

5.6.2. Sub-components of vulnerability

5.6.2.1. Exposure/susceptibility

In this section, the focus is on the sub-components of vulnerability. Ten factors shape the exposure/susceptibility sub-component of wildlife flood vulnerability (Table 5-3). Figure 5-12 shows the pattern of the exposure index throughout the East Riding of Yorkshire. There are clusters of highly exposed cells especially around the Humber Estuary, River Hull, Humberhead Levels, and the northwest of the region.

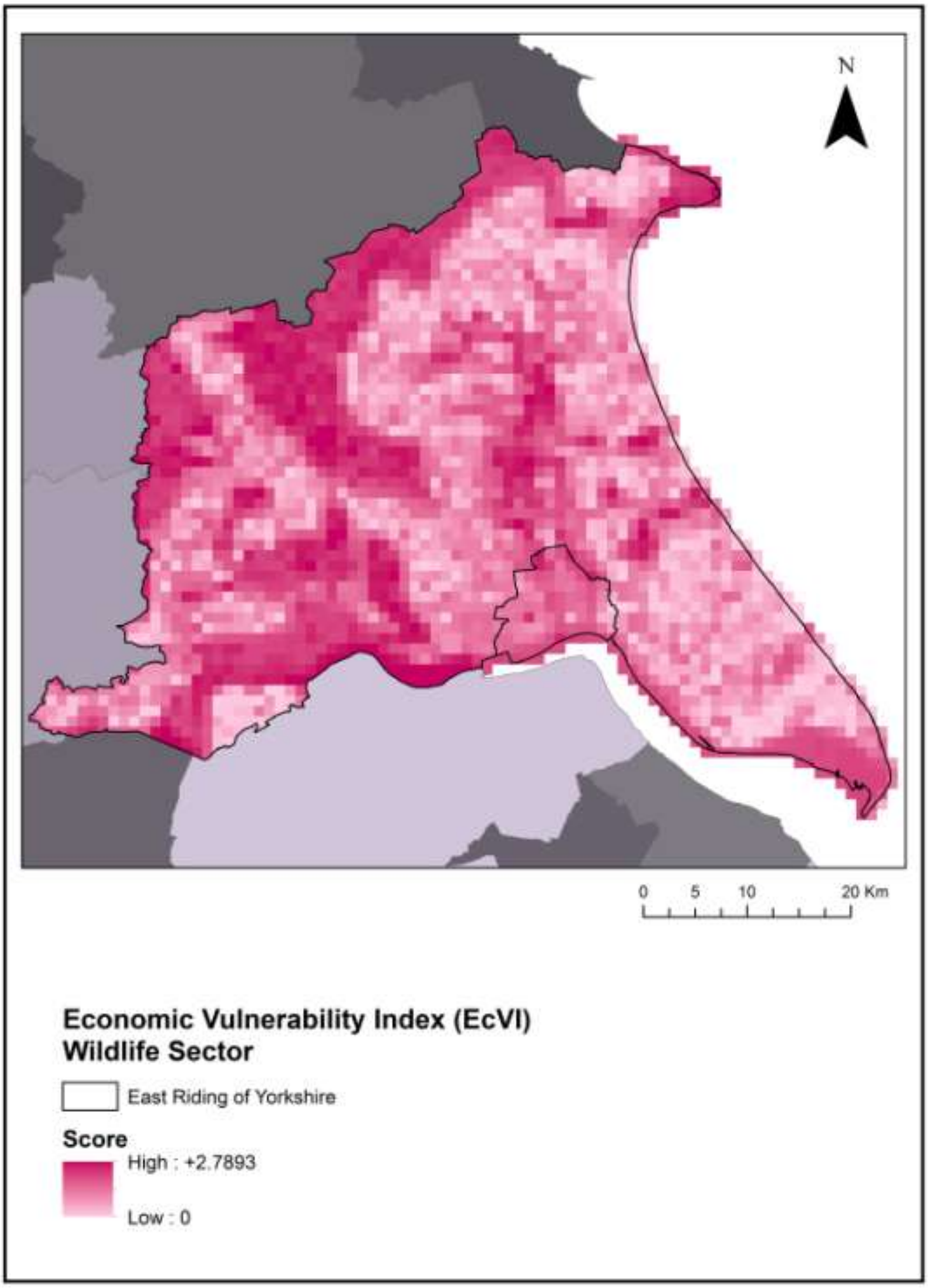


Figure 5-11: Economic vulnerability index (EcVI) for the wildlife sector

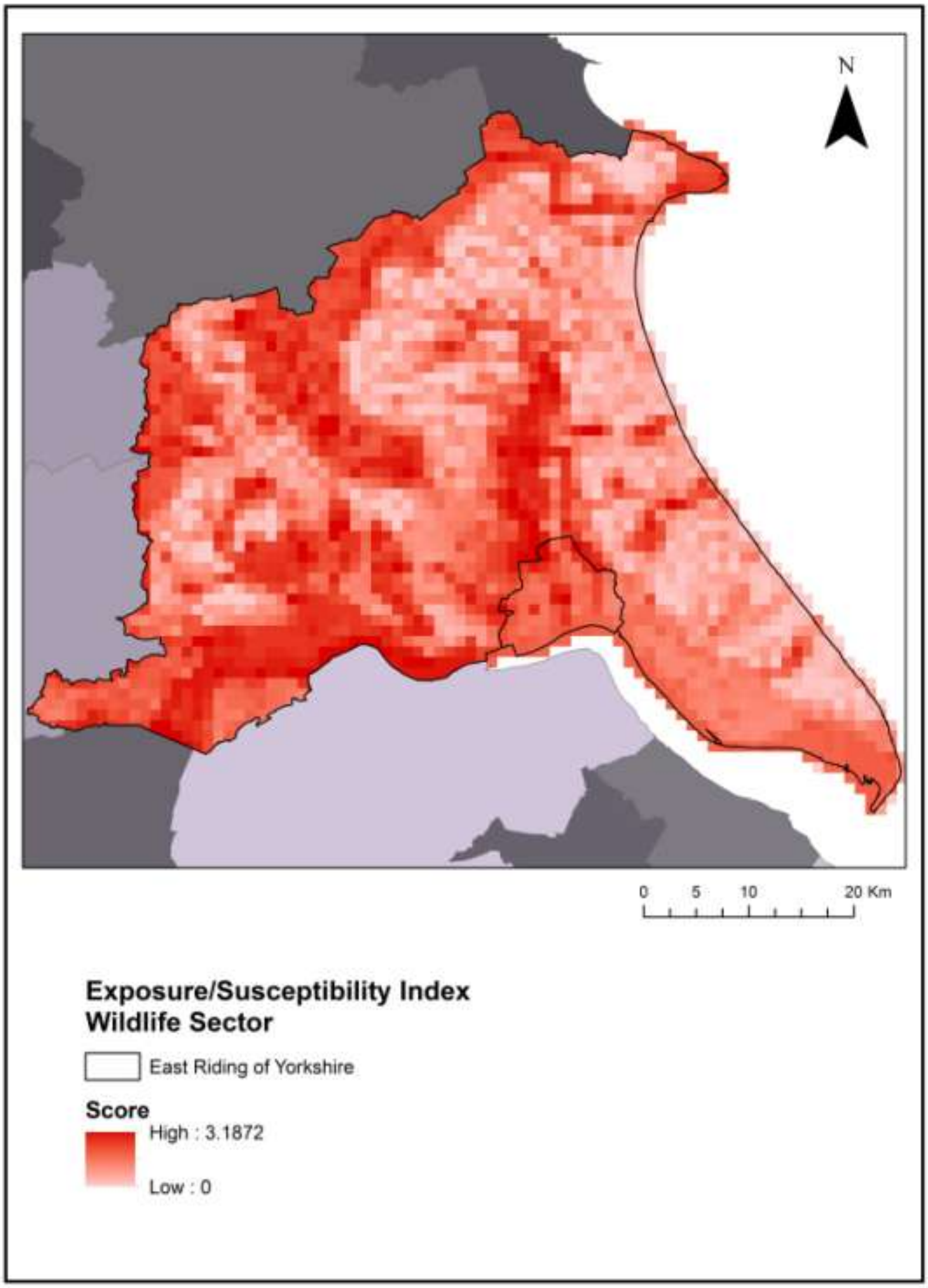


Figure 5-12: Exposure/susceptibility index for the wildlife sector

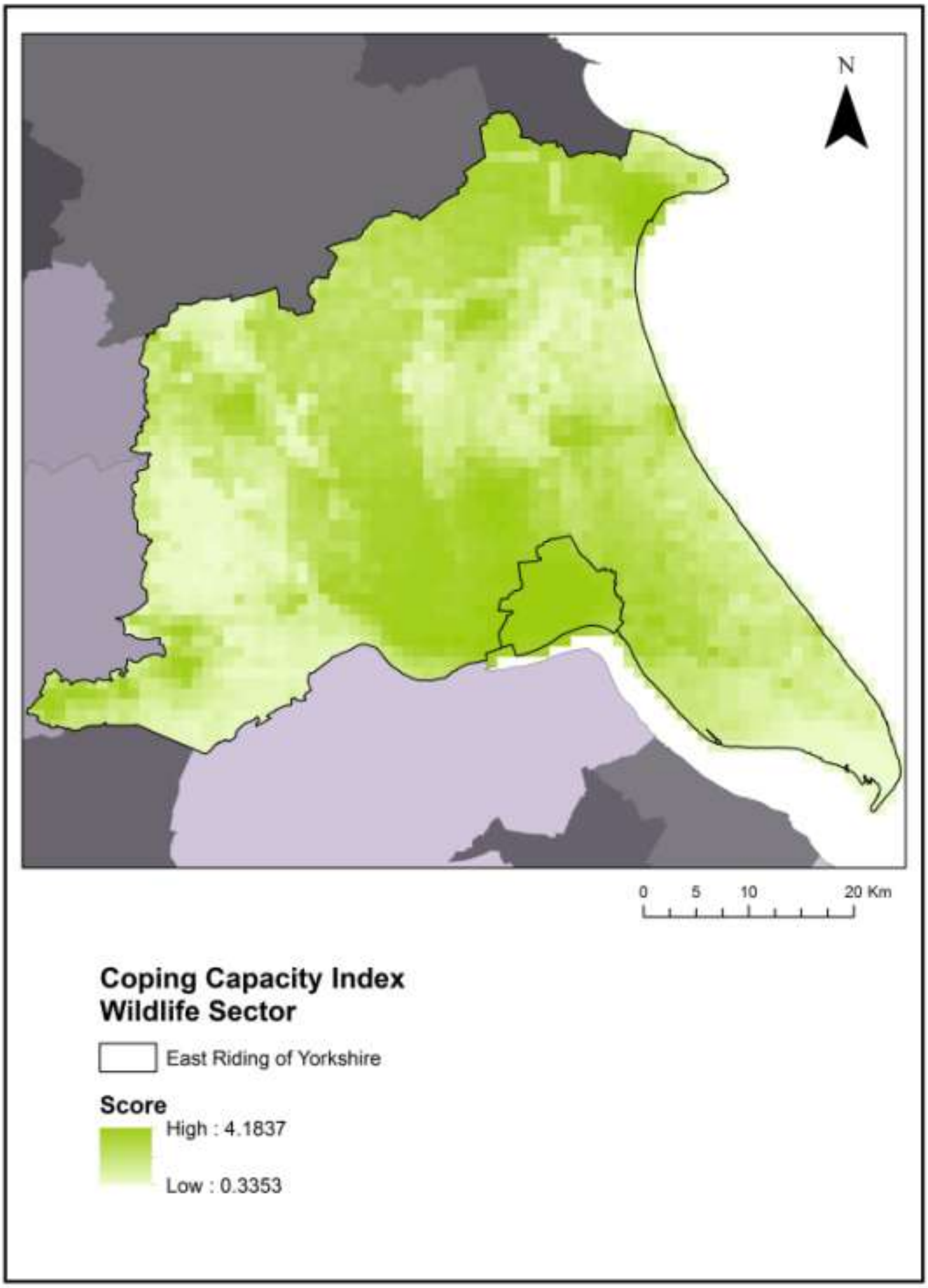


Figure 5-13: Coping capacity index for the wildlife sector

5.6.2.2. *Coping capacity*

In contrast to exposure is coping capacity, which helps to reduce the level of vulnerability. Five indicators of coping capacity have been identified from environmental and physical components (Table 5-3). Figure 5-13 shows the coping capacity index throughout the East Riding of Yorkshire. There are some cold spot clusters in the east and the west of the region. However, highly populated locations show a higher level of coping capacity due to the access to physical resources.

5.6.3. Flood vulnerability index (FVI)

The outcome of all the previous steps described in this chapter is the vulnerability score (FVI). Each 1 km grid cell has been assigned a score which determines its vulnerability level to the impacts of flooding. An integrated index consisting of the environmental, physical and economic components and the exposure/susceptibility and coping capacity sub-components has been developed and is demonstrated in Figure 5-15.

Table 5-8 presents summary statistics of the flood vulnerability index (FVI). The index holds both positive and negative scores. The cells with coping capacity and no exposure/ susceptibility factor reveal negative index scores. The higher index scores represent the higher level of vulnerability. Figure 5-14 shows the histogram of the FVI. Blue lines symbolise the boundaries of FVI classes as presented in Figure 5-16.

Figure 5-15 shows the real FVI index in 1 km grid cells. As discussed in the methodology chapter, an unclassified map could convey a realistic picture of the mapped phenomenon. For a better visualisation, FVI scores have been placed in five classes (Figure 5-16). The quantile classification method has been applied to define FVI classes. The boundaries of classes are always a matter of debate; however, the flexibility of this work allows users to define the threshold on the basis of their own opinion.

Generally speaking, the wildlife in the western part of the East Riding is more vulnerable to flooding. In addition, there are two other spots of highly vulnerable cells:

one around the River Hull north of the City of Kingston upon Hull, and the other at Spurn Point.

Table 5-8: Descriptive statistics for the FVI of the wildlife sector

Descriptive Statistics for the FVI						
	Number of cases	Range	Minimum	Maximum	Mean	Standard deviation
FVI	2780	5.2874	-3.0736	2.2138	-0.3421	0.7339

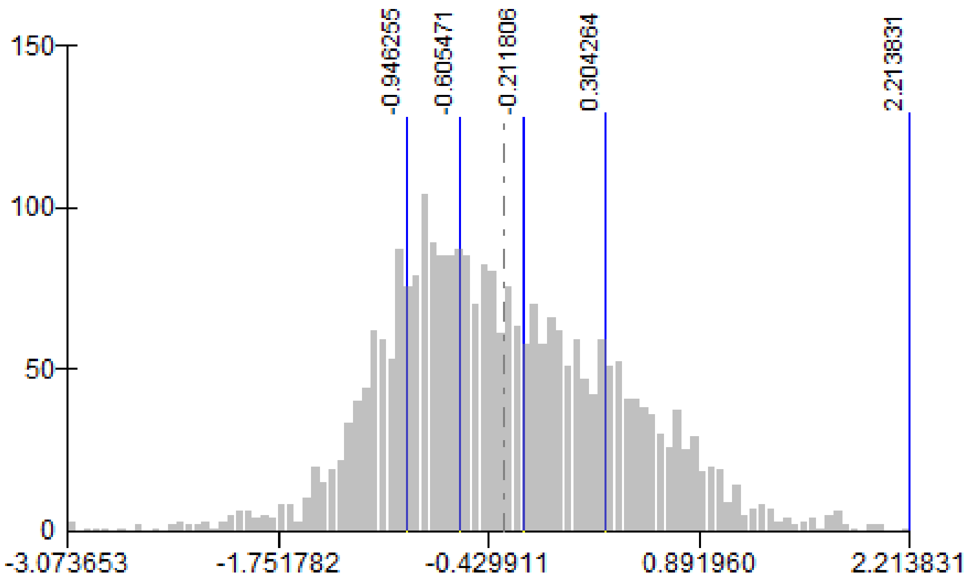


Figure 5-14: Histogram of the flood vulnerability index for the wildlife sector

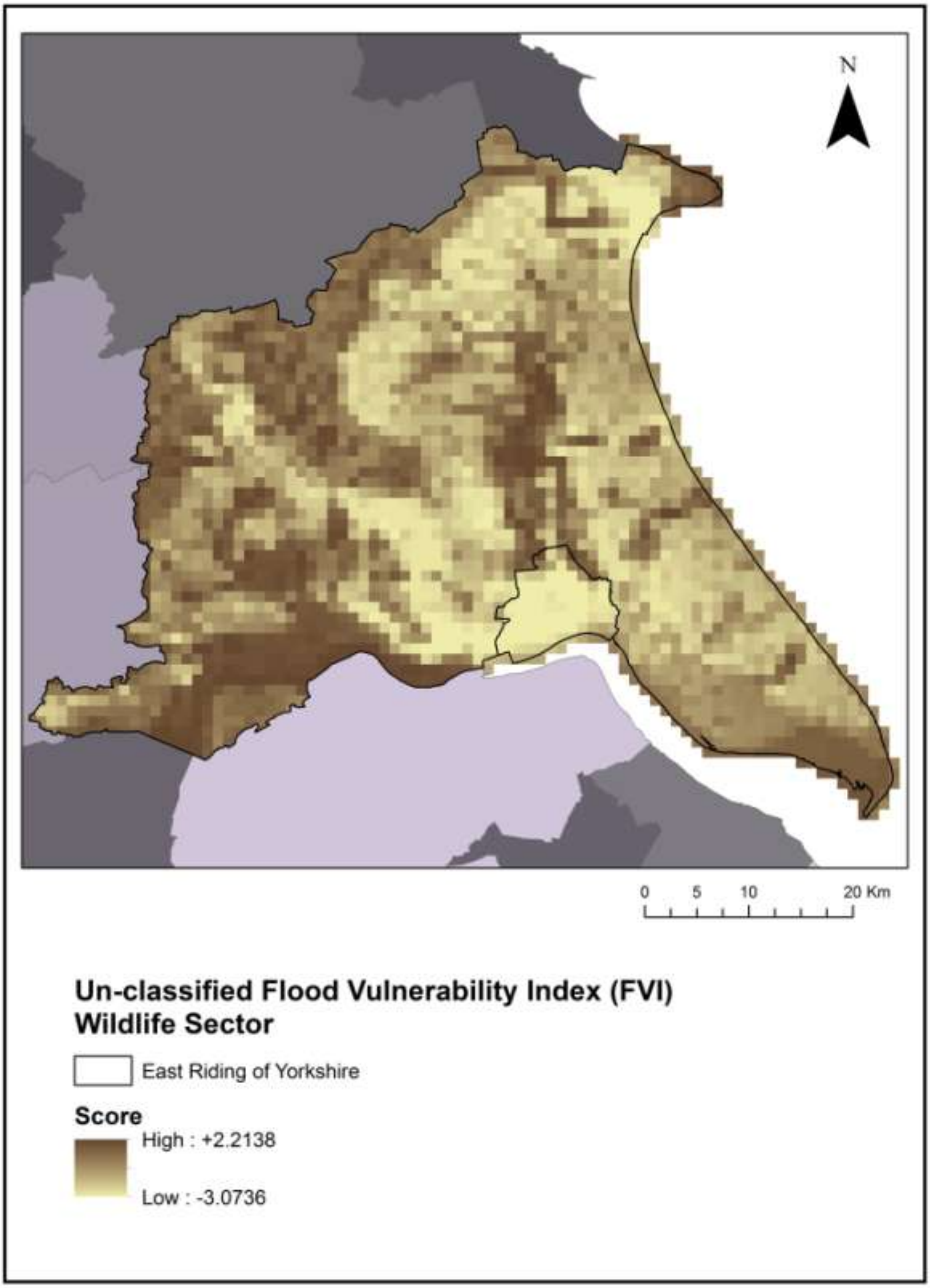


Figure 5-15: Unclassified FVI of the wildlife sector

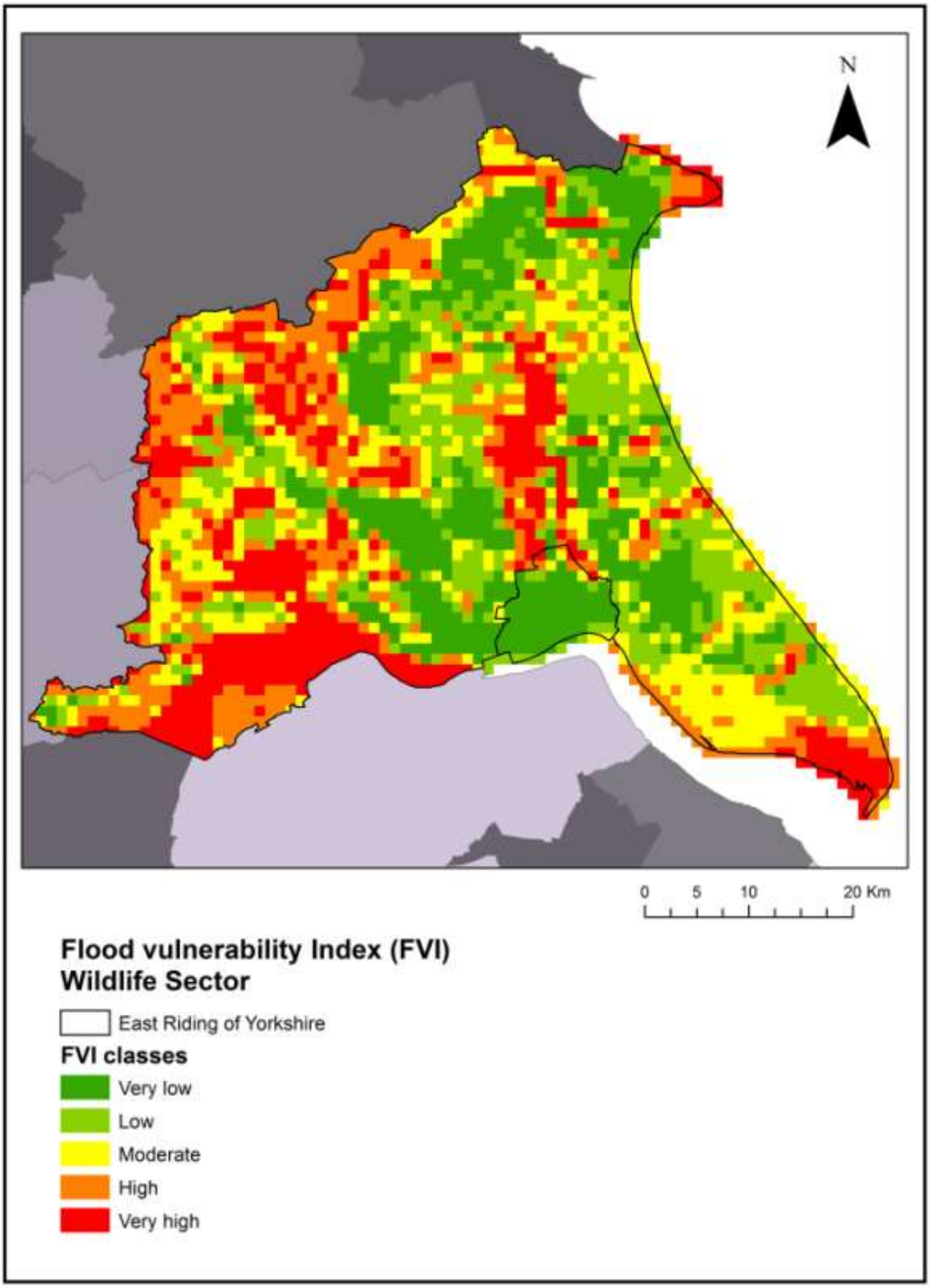


Figure 5-16: FVI classes for the wildlife sector

5.7.Conclusion

Vulnerability assessment is one of the most useful strategies in terms of disaster risk reduction. The importance of vulnerability analysis in the wildlife and natural habitat context was inferred from the literature discussed at the beginning of the chapter. The issue of wildlife vulnerability to flooding is highlighted, especially because of the large areas of biodiversity conservation throughout the region.

Overall, fifteen indicators have been selected to explain the pattern of flood vulnerability of wildlife in the East Riding of Yorkshire. The flood vulnerability index (FVI) is an integrated index consisting of all environmental, physical, and economic indicators. The following conclusions are drawn from the presented maps:

- The EnVI is high at Humberhead Levels, the Humber Estuary, and the surroundings of the River Hull.
- The PhVI is noticeably high in the north, east, and north-east of the region.
- The EcVI is considerably high in the western part of the region which coincides with the areas of protected natural habitat.
- It is noticeable from Figure 5-16 that the protected areas are mostly classed as "very high", which is a cause for concern in terms of natural habitat management.
- The urbanised areas are classed as "very low" because there is less natural habitat present and physical resources are more accessible.

If two adjacent cells hold different FVI classes (very low and very high), the attributes tables could be used to investigate the underlying reasons. Figure 5-17 provides an example, where two cells (top and bottom) hold very different vulnerability classes (top = very high, bottom = very low). Further investigation into the properties of the two cells reveals that the higher rank of the top cell is due to a higher coping capacity score. In addition, physical vulnerability is much lower in the bottom cell, resulting in overall lower vulnerability, while the economic vulnerability of the top cell is noticeably higher that of the bottom cell.

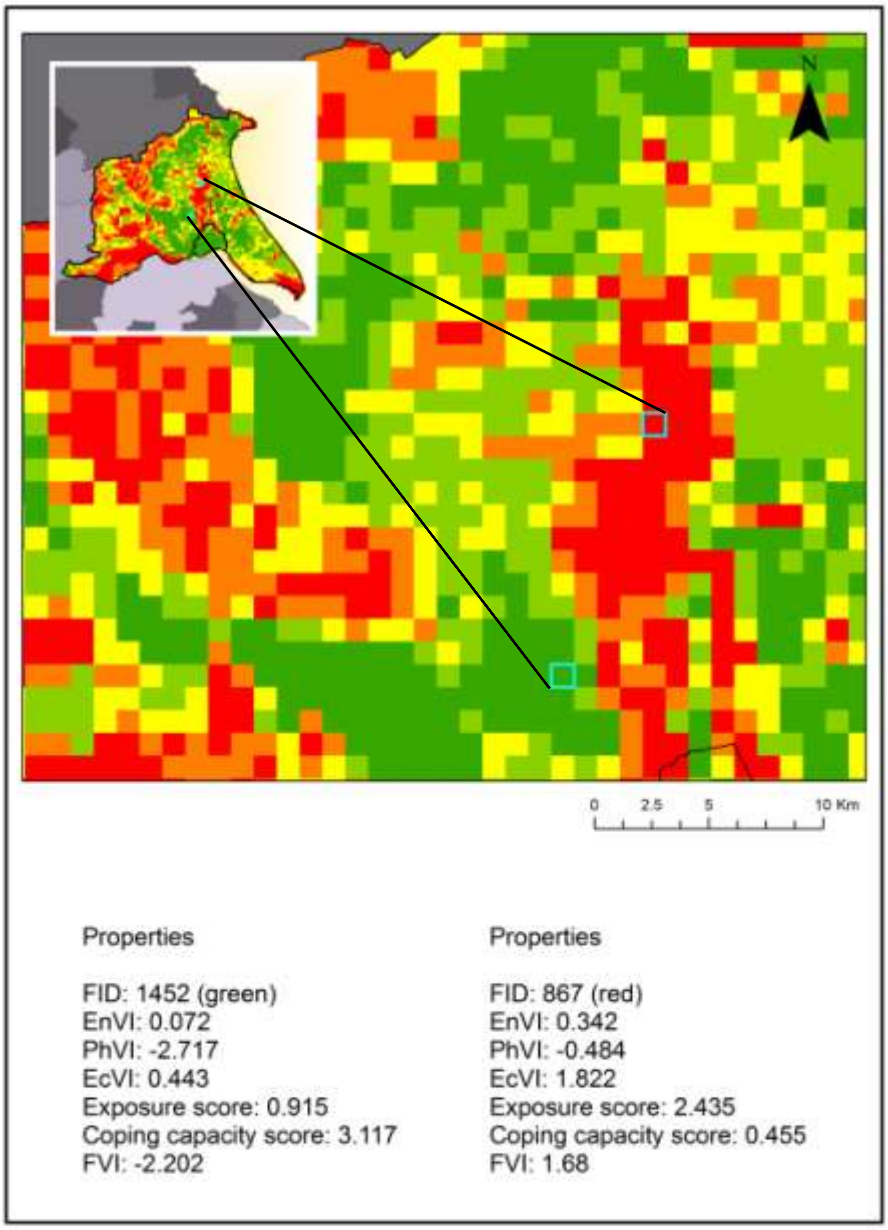


Figure 5-17: Comparing two grid cells holding different vulnerability classes in terms of components and sub-components indices

6. ulnerability of the urban sector to flooding

6.1.Introduction

Natural hazards such as flooding have the potential to threaten human lives and property. Integrated flood risk management is a powerful strategy for reducing flood damage. Vulnerability is one component of risk (Risk = Vulnerability + Hazard) which can greatly assist policymakers and managers to achieve a better insight into the root causes of flood impacts. On the basis of the methodology and perspectives of the research, scholars have considered vulnerability on an individual, household, or municipal scale for the urban sector, using a wide range of indicators which are mostly people-centric and inclusive (Muller, Reiter et al. 2011, Liao, Chang 2011).

The objectives of this chapter are to develop flood vulnerability indicators in the urban sector, map the resultant FVI, and investigate the underlying reasons for the presence of highly vulnerable cells by means of the components and sub-components of vulnerability. Firstly, the importance of flood vulnerability assessment in an urban context is explained through a review of the literature. Secondly, the indicators are selected, evaluated, transformed and integrated. Finally, the flood index is mapped and discussed.

6.2.Flood effects on the urban sector

Urban areas are mostly located in hazardous places, making them an interesting subject for many vulnerability assessment research studies. Urban centres might be residential, commercial, and industrial, and are highly populated, centroid of enterprises, infrastructure, industrial and commercial sectors, and public services (Jha, Bloch et al. 2012, Hawkesbury-Nepean Floodplain Management Steering Committee 2006). UN-HABITAT reported that in 2008, for the first time, half of the world's population lived in urban areas (UN-HABITAT 2008).

For example, Pistrika estimated direct flood damage using depth-damage curves and simulation scenarios in a vulnerability framework. She concluded that, despite traditional views which assume that flood depth is the core factor in flood damage, there are other factors which play a role, including flow velocity, flood duration, and sediment concentration (Pistrika 2010). Liao and Chang made use of a flood routing model (FLO-2D) to simulate flood scenarios in Taiwanese urban areas. They forecast the result of urban flooding for different land use types (Liao, Chang 2011). Barroca and colleagues proposed a wide range of indicators organised into groups as web-based software. This software obtains a user's point of view in order to compare and compose indicators (Barroca, Bernardara et al. 2006).

Most of the researchers have mentioned two chief categories for vulnerability assessment in the urban sector: physical and socio-economic (Adelekan 2011, Muller, Reiter et al. 2011, Adelekan 2010, Đinh Kha, Ngoc Anh et al. 2011, Dutta, Khatun et al. 2005). However, there are studies using more detailed indicator categories: health, political factors, coping capacity, adaptive capacity, housing, prevention, and management (Jha, Bloch et al. 2012, Barroca, Bernardara et al. 2006, De Graaf 2008).

There is evidence indicating regional change in the pattern and intensity of floods caused by global climate change (Intergovernmental Panel on Climate Change (IPCC) 2001, Adelekan 2010, Cooper, Hunt et al. 2009, Coulthard, Frostick et al. 2007). In addition, some other causes for higher flood risk, vulnerability and damage have been mentioned by researchers specialising in this field. Rapid urban growth, uncontrolled expansion of impermeable surfaces, soaring economic growth, land cover alteration, lack of infrastructure, and poor drainage systems under high intensity rainfall are leading factors for higher risk in urbanised regions (Katsuhama, Grigg 2010, Adelekan 2011, Jha, Bloch et al. 2012, Adelekan 2010, Dutta, Khatun et al. 2005, De Graaf 2008). It is worth mentioning that setting flood risk management and policies through intervention policies and sufficient governmental management can greatly improve the situation: for example, by defining rules for the structure of buildings, regulating land use activities, maintaining storm-water drainage and defences, improving urban administration, and supporting the disadvantaged population.

Analysing flood vulnerability in an urban environment requires a good insight into primary and secondary flood impacts and recipients. The recipients can be classified into three categories: people, buildings and contents, and animals and crops. The impacts can be divided into two main classes: direct and indirect (or primary and secondary). Economic loss and damage, death, water-related disease, post-traumatic stress, common mental disorders, and suicide are some of the direct impacts of flooding on people. In recent decades, there has been a trend towards more economic loss and less human death (Centre for Research on the Epidemiology of Disasters (CRED) 2011). Demographic change, psychological disorders, delayed trauma, water-related syndrome, decreased birth rate, family break-up, education postponement, and economic turmoil are examples of indirect influences. Impacts of flooding on buildings and contents could be caused by water pressure, water soaking into building materials and foundations, water contamination and chemical reaction, electrical system failure, erosion, fire, and damage due to the collision of buildings and debris. Economic damage to human settlements from a flood event is mostly due to this category of receptors. Damage and loss to individuals' gardens in a city is another category of flood impacts in urbanised regions. In addition to the impacts mentioned above, the effects of flooding on the natural environment, economy and politics of the community should be identified (Jha, Bloch et al. 2012).

Coping capacity can be improved by enhancing early warning systems, emergency planning, flood-proofing and elevating buildings, and by improving building materials, structure and design. Threshold capacity enhancement could be achieved through adequate drainage systems, flood defences, increasing river capacity, reducing surface run-off, and increasing pumping capacity. Land development policy, flood education and knowledge, proper waste collection, and integrating spatial planning with flood management are the principal methods for achieving a better adaptive capacity. Recovery capacity could be advanced by insurance, emergency funds, and available charity services (Hawkesbury-Nepean Floodplain Management Steering Committee 2006, Pistrika 2010, Adelekan 2010, Dutta, Khatun et al. 2005, De Graaf 2008).

6.3.Inconsistency map of the urban sector

In an effort to map the extent of built-up and residential lands, a number of relevant datasets have been collected. Table 6-1 shows four datasets from various organisations. They vary in spatial/temporal resolution and data format. In addition, they have been created for specific targets and according to the organisation's perspectives. The issues mentioned result in different maps of urbanised parcels.

Table 6-1: List of data sources for urban lands

Title	Organisation	Scale/ Resolution	Data Format	Availability	Temporal resolution
Land Cover Map (2007)	Centre for Ecology and Hydrology (CEH)	25 m	Raster	License agreement	2007
Urban areas from Strategi	Ordnance Survey	1:250000	Vector	License Agreement	2011
Built-up areas from Vector Map District	Ordnance Survey	1: 25000	Vector	License Agreement	2010
Buildings from Master Map Topography Layer	Ordnance Survey	1:1250-1:10000	Vector	License Agreement	2012

From the four datasets for urbanised parcels (i.e. LCM2007, Strategi, Vector Map District, and MasterMap), a binary presence of each data source was recognised on a 30 X 30 m^2 grid cell (Figure 6-1). The darkest grey stands for cells which have been agreed by all four datasets as urban/built-up parcels. It can be seen in Figure 6-1 that large urbanised areas are coloured in dark grey and are almost fully consistent among all four datasets. However, sparse parcels of built-up areas are cited by one or two datasets only, showing up as light grey.

The reasons behind the inconsistency of data sets could be errors, actual change, ontology differences, organisational objectives, rules, methods, tools, political variations, and perspective (Robinson, Fisher et al. 2005, Comber, Fisher et al. 2004b, Comber, Fisher et al. 2004a). It is possible to integrate dissimilar data bases to map a phenomenon, depending on the purpose of the study; therefore the footprints of all four datasets were used to make the final map of the urban sector (Comber, Fisher et al. 2004b).

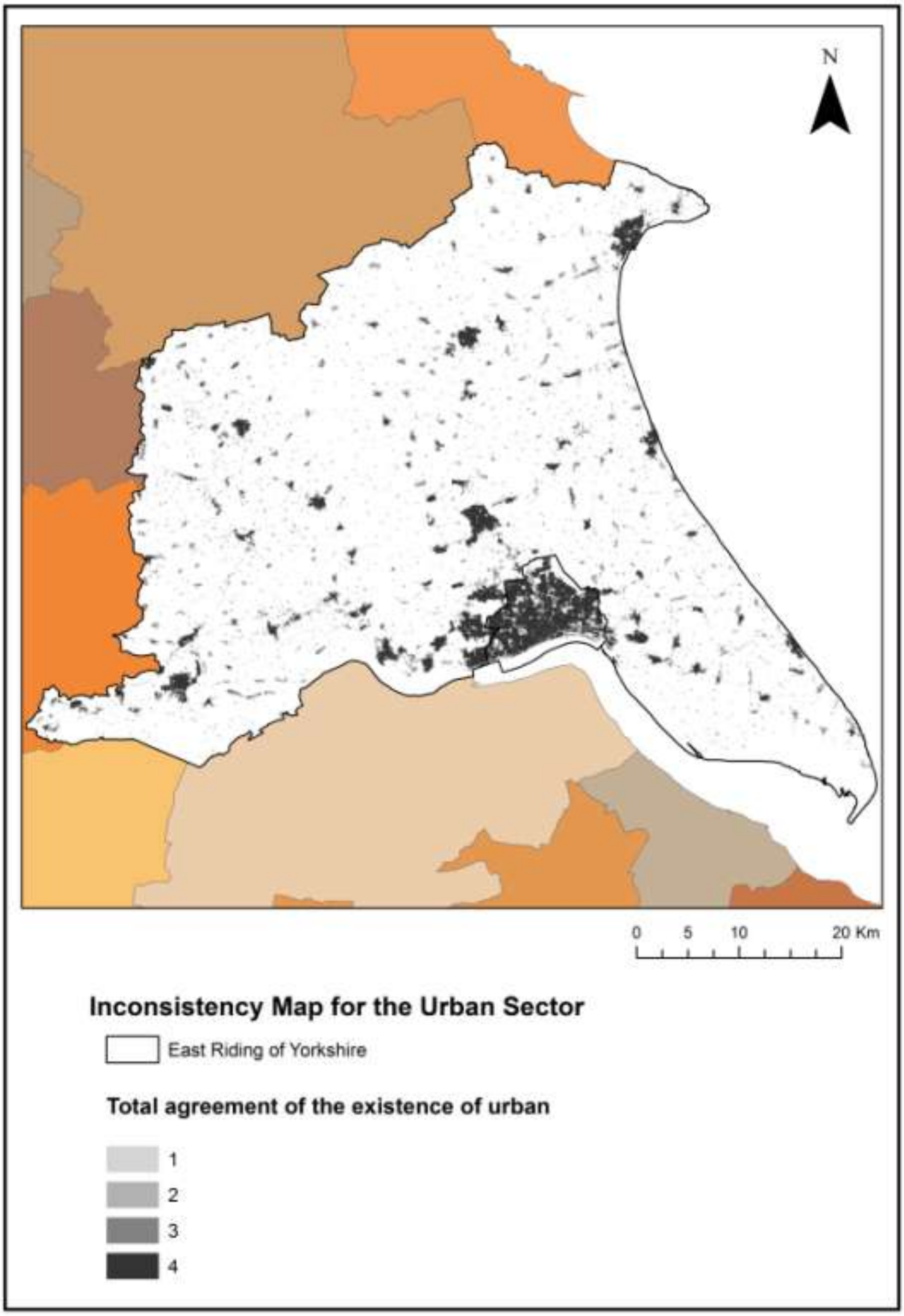


Figure 6-1: Inconsistency map for the urbanised land

6.4. Indicator selection

Flood vulnerability in an urban context has been widely examined and a wide range of indicators have been suggested by researchers from various perspectives. Different aspects of vulnerability from social to physical have been considered. Table 6-2 provides an inclusive list of indicators for flood vulnerability assessment in an urban environment.

With regards to the modified BBC framework, four components of vulnerability are identified for the urban sector: physical, environmental, social, and economic. In addition, for each component, indicators refer to either exposure/susceptibility or coping capacity. The final list of indicators is selected from Table 6-2 on the basis of the criteria proposed by Birkmann (see Chapter 3).

Table 6-2: Potential list of vulnerability indicators for the urban sector

Indicator	Literature
Land area	(Damm 2010) (Kaly, Pratt et al. 2004)
Unemployment rate	(Damm 2010) (Birkmann 2006a) (Roy, Blaschke 2011) (Scheuer, Haase et al. 2011)
Dominating land use	(Damm 2010) (Kaly, Pratt et al. 2004)EVI (Yahaya, Ahmad et al. 2010) (Myeong, Hong 2009) (Roy, Blaschke 2011) (Scheuer, Haase et al. 2011) (Chen, Chen 2008)
GDP	(Damm 2010) (Chen, Chen 2008)
Income	(Cutter 2003) (Damm 2010) (Adelekan 2011) (Chen, Chen 2008)
Density of the built environment	(Cutter, Boruff et al. 2003)
% of housing units that are mobile homes	(Cutter, Boruff et al. 2003)
Race/ethnic	(Cutter, Boruff et al. 2003)
Hot/cold periods	(Kaly, Pratt et al. 2004)
Wet/dry periods	(Kaly, Pratt et al. 2004)
Sea Temperatures	(Kaly, Pratt et al. 2004)
Dispersion	(Kaly, Pratt et al. 2004)

Isolation distance to major/minor road/town	(Kaly, Pratt et al. 2004) (Roy, Blaschke 2011)
Relief Elevation	(Kaly, Pratt et al. 2004) (Myeong, Hong 2009) (Chen, Chen 2008)
Loss of cover Degradation	(Kaly, Pratt et al. 2004) (Myeong, Hong 2009) (UN/IEHS and NNGASU 2006) (Damm 2010) (Myeong, Hong 2009)
Migration	(Kaly, Pratt et al. 2004)
Renewable water	(Kaly, Pratt et al. 2004)
Sulphur dioxide emission	(Kaly, Pratt et al. 2004)
Fishing	(Kaly, Pratt et al. 2004)
Waste production/treatment	(Kaly, Pratt et al. 2004)
Habitat fragmentation	(Kaly, Pratt et al. 2004)
Industry	(Kaly, Pratt et al. 2004)
Spills	(Kaly, Pratt et al. 2004)
Sanitation	(Kaly, Pratt et al. 2004)
Mining	(Kaly, Pratt et al. 2004)
Vehicle	(Kaly, Pratt et al. 2004) (Birkmann 2006a)
Population	(Kaly, Pratt et al. 2004) (Connor n.d.) (Myeong, Hong 2009) (UN/IEHS and NNGASU 2006) (Scheuer, Haase et al. 2011) (Chen, Chen 2008)
Tourists	(Kaly, Pratt et al. 2004)
HH with access to radio/TV/phone	(Birkmann 2006a) (Roy, Blaschke 2011)
Literacy rate	(Birkmann 2006a) (Birkmann, Fernando et al. 2006) (Connor n.d.) (Roy, Blaschke 2011) (Chen, Chen 2008) (UN/IEHS and NNGASU 2006) (Adelekan 2011)
Preparedness for possible flood occurrence	(Birkmann 2006a) (Adelekan 2011)
Dependency ratio	(Birkmann 2006a) (Roy, Blaschke 2011)
Sex	(Birkmann 2006a) (Roy, Blaschke 2011) (Adelekan 2011)

% of female headed Household	(Birkmann 2006a)
% of household that live in 1-storey building	(Birkmann 2006a)
Morbidity rate	(Birkmann 2006a)
Average slope of basin	(Connor n.d.) (Yahaya, Ahmad et al. 2010) (Myeong, Hong 2009) (Chen, Chen 2008)
Poverty	(Connor n.d.) (Roy, Blaschke 2011) (UN/IEHS and NNGASU 2006)
Years sustaining healthy life	(Connor n.d.)
Infant mortality rate	(Connor n.d.)
Frequency of heavy rainfall	(Yahaya, Ahmad et al. 2010) (Myeong, Hong 2009) (Connor n.d.)
Drainage network	(Yahaya, Ahmad et al. 2010) (Chen, Chen 2008)
Distance to nearest hospital	(Roy, Blaschke 2011) (Scheuer, Haase et al. 2011) (Chen, Chen 2008) (Birkmann 2006a)
Age	(Roy, Blaschke 2011) (Adelekan 2011) (Scheuer, Haase et al. 2011) (Cutter, Boruff et al. 2003)
female workers	(Roy, Blaschke 2011)
Number of houses	(UN/IEHS and NNGASU 2006)
% of businesses with fewer than 20 employees	(UN/IEHS and NNGASU 2006)
Distance of dwelling to river	(Adelekan 2011)
Depth of flood water	(Adelekan 2011)
Social network	(Scheuer, Haase et al. 2011)
Transport	(Scheuer, Haase et al. 2011)
Supermarkets	(Scheuer, Haase et al. 2011)
Buildings, infrastructure, commercial establishments, available budget	(Cutter, Boruff et al. 2003) (Kaly, Pratt et al. 2004) (Scheuer, Haase et al. 2011) (Chen, Chen 2008)
Land value	(Scheuer, Haase et al. 2011)
Social hot spots(Social infrastructure such as schools, kindergartens, and hospitals)	(Scheuer, Haase et al. 2011)
Infrastructure investment	(Chen, Chen 2008)
Height of the buildings from ground, type of the building	(Adelekan 2011)

Table 6-3 reveals the final list of indicators selected for vulnerability assessment of the urban sector. Indicators are grouped into components and sub-components. In addition, the abbreviations of indicators throughout the work are introduced. Comprehensive information on the indicators in Table 6-3 is provided in Appendix 2, including indicators, corresponding variables, temporal resolution, spatial resolution/scale, data source, data format, description, and the original map.

The preliminary focus in the urban sector is humans and their property. Therefore, the environmental indicators of vulnerability are the same as in the two previous chapters. However, the quantity of physical and economic indicators is higher. Furthermore, the social components have been added to the table to cover all the human-related aspects.

6.5.Development and evaluation of a composite indicator

The development of the flood vulnerability index (FVI) of the urban sector requires a set of steps. The relevant flowchart is provided in Chapter 3 along with a comprehensive description of the following steps:

1. identification of components and sub-components of vulnerability
2. assigning the appropriate indicators to components
3. data transformation into 1 km cells
4. data normalisation
5. correlation analysis
6. aggregation of indicators.

Table 6-3: Final list of urban flood vulnerability indicators

Component	Sub-component	Indicator
environmental	Exposure/ susceptibility	Geological indicators of flooding (GIF)
	Exposure/ susceptibility	Flood zones (FZ)
	Exposure/ susceptibility	Pollution Incidents (PI)
	Exposure/ susceptibility	Groundwater areas (SPZ)
	Exposure/ susceptibility	Landfill sites (LFS)
	Exposure/ susceptibility	Contaminated land (CL)
	Exposure/ susceptibility	Surface water (SWF)
Physical	Coping Capacity	Construction and Repair services (CONS)
	Coping Capacity	Central and local government (RESC)
	Coping Capacity	Train stations (TRN)
	Exposure/ susceptibility	Household type (MOHS)
	Coping Capacity	Vehicle (CAR)
	Exposure/ susceptibility	House level (LWL)
	Exposure/ susceptibility	Buildings and assets (BLD)
	Coping Capacity	Roads (ROAD)
Economic	Exposure/ susceptibility	Unemployment (UNEP)
	Exposure/ susceptibility	Communal establishment residents (CER)
	Coping Capacity	Tenure (TNUR)
	Exposure/ susceptibility	Household size (HHSZ)
	Exposure/ susceptibility	Commercial services (CMRC)
	Exposure/ susceptibility	Manufacturing and production (MNU)
	Coping Capacity	Income (INCM)
Social	Exposure/ susceptibility	Population (POP)
	Exposure/ susceptibility	Age (AGE)
	Exposure/ susceptibility	General health (GHLT)
	Exposure/ susceptibility	Students away from home (STWY)
	Exposure/ susceptibility	Lone parents (LNPR)
	Exposure/ susceptibility	Migrant (MGR)
	Exposure/ susceptibility	Limiting long term illness (LLTI)
	Exposure/ susceptibility	Qualification (QUAL)
	Exposure/ susceptibility	Accommodation/eating services(ACDR)
	Exposure/ susceptibility	Attractions (ATT)
	Exposure/ susceptibility	Sport and entertainment services (SPR)
	Coping Capacity	Health services (HLTH)
	Coping Capacity	Infrastructure (INFR)
	Exposure/ susceptibility	Retails (RTL)
	Exposure/ susceptibility	Sex (SEX)
	Coping Capacity	Schools (SCHL)

6.5.1. Transformation and normalisation

Table 6-4 summarises the metadata of the indicators. The characteristics of data must be fully considered before transformation into a 1 km^2 grid. The transformation could potentially create some inconsistency between the original and the new version of the dataset. In addition, there is some temporal inconsistency among datasets. However, the objective of this work is to reveal the pattern of vulnerability in the East Riding of Yorkshire, and minor geographical displacements and temporal inconsistencies should not invalidate comparisons. In this section, the process of transforming datasets into the uniform theme of a 1 km grid will be described. Various GIS tools, operations, and functions were utilised.

There are six indicators of environmental vulnerability in the urban sector. They are the same as for the arable and wildlife sectors and are therefore not repeated here. Only the permeability indicator is omitted because in a built-up context almost everywhere is impermeable and this variable would be misleading.

Table 6-4: Summary metadata of the urban indicators

Indicator	Variable	Organisation	Resolution/ scale	Data format	Availability	Date
Geology of land	Geological indicators of flooding (GIF)	British Geological Survey (BGS)	1:50 000	Vector polygon	License agreement	2011
Flood zone	Flood zones 2 and 3 (FZ)	Environment Agency	1: 10 000	Vector polygon	License agreement	2012
Pollution	Pollution incident (PI)	Environment Agency	1: 10 000	Vector point data	License agreement	2001-2012
Groundwater areas	Source protection zones (SPZ)	Environment Agency	N.A	Vector point data	License agreement	
Polluted lands	Landfill sites (LFS)	Environment Agency	N.A.	Vector Polygon	License agreement	1975-2011
Contaminated lands	Contaminated lands (CL)	Environment Agency	N.A.	Vector Polygon	Vector Polygon	
Surface water	Flood Map from Surface Water (SWF)	Environment Agency	N.A.	Vector Polygon	License agreement	2010
construction services	Points of Interest-Construction (CONS)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Rescue services	Points of Interest-rescue services (RESC)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Train stations	Points of Interest-Train stations (TRN)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Roads	Roads from Vector Map District (ROAD)	Ordnance Survey	1:25 000	Vector polyline	License agreement	2011
House Hold type	Mobile houses (MOHS)	Office for National Statistics (ONS)	N.A.	Vector polygon	License agreement	2001
Vehicle	Number of car and vans (CAR)	(ONS)	N.A.	Vector polygon	License agreement	2001
House level	House lowest level (LWL)	(ONS)	N.A.	Vector polygon	License agreement	2001
Buildings	Uncertainty map of urbanised land use (BLD)	Part 6-3	30 m	30 m grid cell	License agreement	N.A.
Unemployment	Unemployed population (UNEP)	(ONS)	N.A.	Vector polygon	License agreement	2001
Communal establishment residents	CER residents (CER)	(ONS)	N.A.	Vector polygon	License agreement	2001
Tenure	Households who own the house (TNUR)	(ONS)	N.A.	Vector polygon	License agreement	2001

Household size	Household size (HHSZ)	(ONS)	N.A.	Vector polygon	License agreement	2001
Commercial services	Points of Interest (CMRC)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Manufacturing and production services	Points of Interest (MANU)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Income	Income (INCM)	(ONS)	N.A.	Vector polygon	Public domain	2007/08
Population	Population density (POP)	(ONS)	N.A.	Vector polygon	License agreement	2001
Age	Inactive economic population (AGE)	(ONS)	N.A.	Vector polygon	License agreement	2001
Health condition	Population with "no-good" health condition (GHLT)	(ONS)	N.A.	Vector polygon	License agreement	2001
Students away from home	Number of students away from home (STWY)	(ONS)	N.A.	Vector polygon	License agreement	2001
Lone parents with dependent children	Lone parents with dependent children (LNPR)	(ONS)	N.A.	Vector polygon	License agreement	2001
Migration	Migrant population (MGR)	(ONS)	N.A.	Vector polygon	License agreement	2001
Limiting long term illness	Limiting long term illness population (LLTI)	(ONS)	N.A.	Vector polygon	License agreement	2001
Qualification	Population with no qualification (QUAL)	(ONS)	N.A.	Vector polygon	License agreement	2001
Sex	Female population (SEX)	(ONS)	N.A.	Vector polygon	License agreement	2001
Accommodation, eating services	Points of Interest (ACDR)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Attractions	Points of Interest (ATT)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Sports and entertainment	Points of Interest (SPR)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Health services	Points of Interest (HLTH)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
schools	Points of Interest(SCHL)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Public infrastructure	Points of Interest (INFR)	Ordnance Survey	± 1m	Vector point data	License agreement	2012
Retails	Points of Interest (RTL)	Ordnance Survey	± 1m	Vector point data	License agreement	2012

6.5.1.1. Physical indicators

The physical component considers indicators related to the physical characteristics and services in the study area. Both sub-components (i.e. coping capacity and exposure) have indicators which refer to physical vulnerability. Seven indicators have been selected from the potential list of indicators on the basis of the criteria proposed by Birkmann, such as availability, understandability, cost effectiveness, and accuracy. The following section describes how the physical indicators have been transferred and normalised onto a 1 km grid cells.

- Repair and construction:

These are point data from Ordnance Survey which show commercial services related to construction, repair, and servicing. In case of emergencies such as extreme floods, local repair and construction services are potential resources for help. The "kernel density" operation in ArcGIS has been utilised in order to calculate the score of each cell in terms of proximity to repair and construction services; a 5 km radius was applied. Figure 6-2 shows the resultant normalised scores. There are hot spots around large urban areas which are highly populated. In addition, there are areas not covered by any station. These areas are places that should be considered in future planning of distribution of services.

- Central and Local Government:

Ordnance Survey Points of Interest show locations of government-related services including police stations, armed services, coastal safety, fire brigade stations, social service activities, and local government. These are government posts in charge of public help and rescue in the case of extreme events. A radius of 30 km was applied to the “kernel density” calculation to project point data onto a 1 km grid representing the distribution of rescue services. Figure 6-3 shows the resultant normalised scores in grey ramp. Highly populated regions show higher scores in terms of accessibility to rescue services as well.

- Train stations:

This indicator has been developed using transport points from Ordnance Survey Points of Interest. The transport category includes air, public, road, rail, and water transport locations. A "kernel density" operation with a 5 km radius was applied to the point layer in order to extract a rasterised grid cell distribution of transport locations within the East Riding of Yorkshire. Figure 6-4 shows the normalised scores of the grid cells.

- Roads:

This indicator has been developed using the roads network from the Ordnance Survey "Vector Map District" dataset. Categories of roads in the Vector Map District dataset are much more comprehensive than in MasterMap or Strategi and include A roads, B roads, minor roads, local streets, motorways, primary roads, private roads, and pedestrian roads. Using Hawth's Tool in ArcGIS, “line in polygon” analysis was applied and the sum of the length of roads in each grid cell was calculated. Normalised values were given to cells as their rank (Figure 6-5).

- Household type: mobile houses:

This indicator has been developed using census data. The spatial density of mobile houses in OAs is an indicator of physical exposure to flooding. The "polygon to raster" operation was used to transfer the density into the scores of 1 km grid cells. The resultant scores are presented as colour ramp with the highest scores coloured in dark orange. Normalised scores are illustrated in Figure 6-6. There are some clustered around the City of Kingston upon Hull and the coast of Holderness.

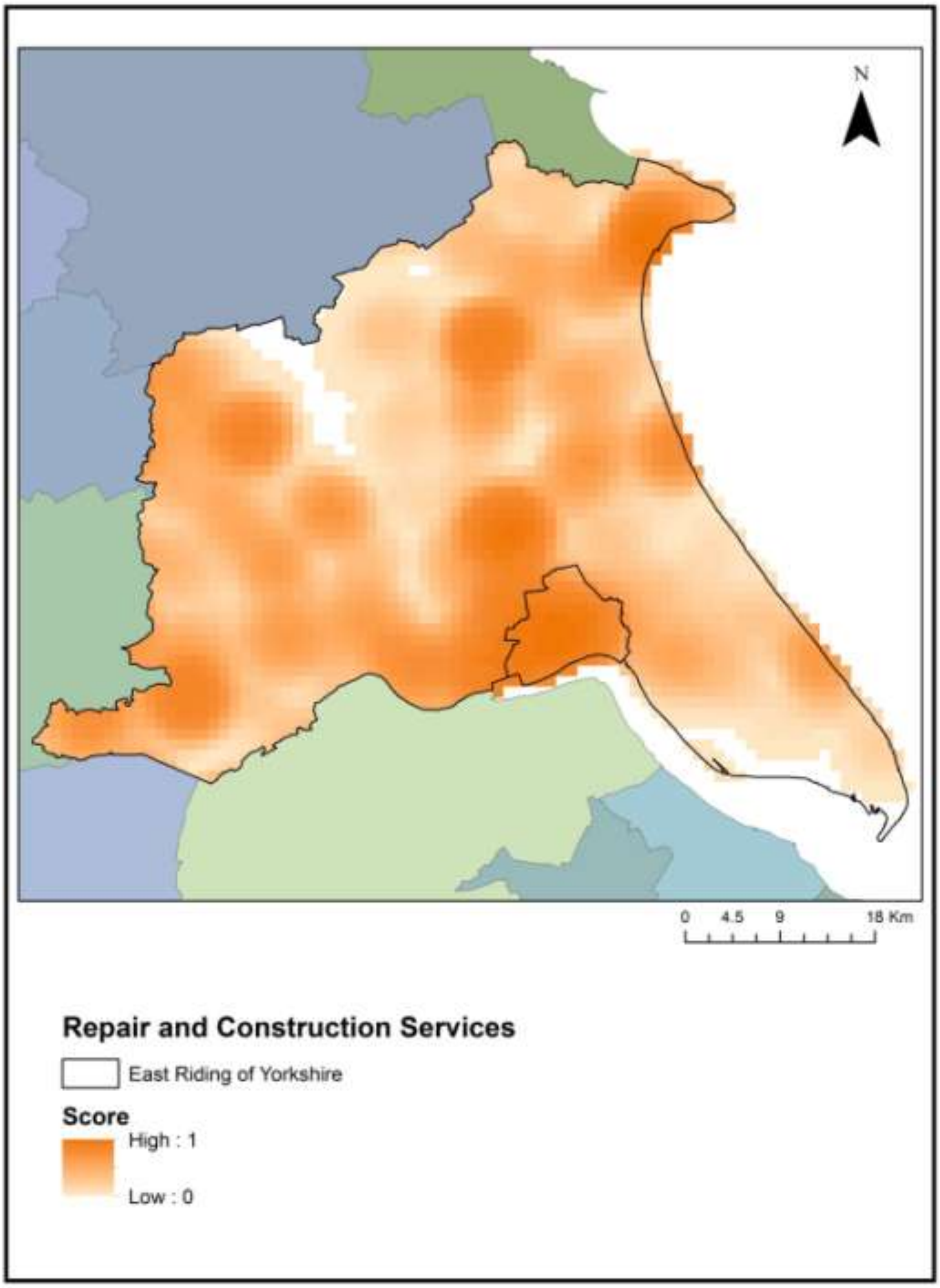


Figure 6-2: Transformed and normalised construction, repair, and servicing

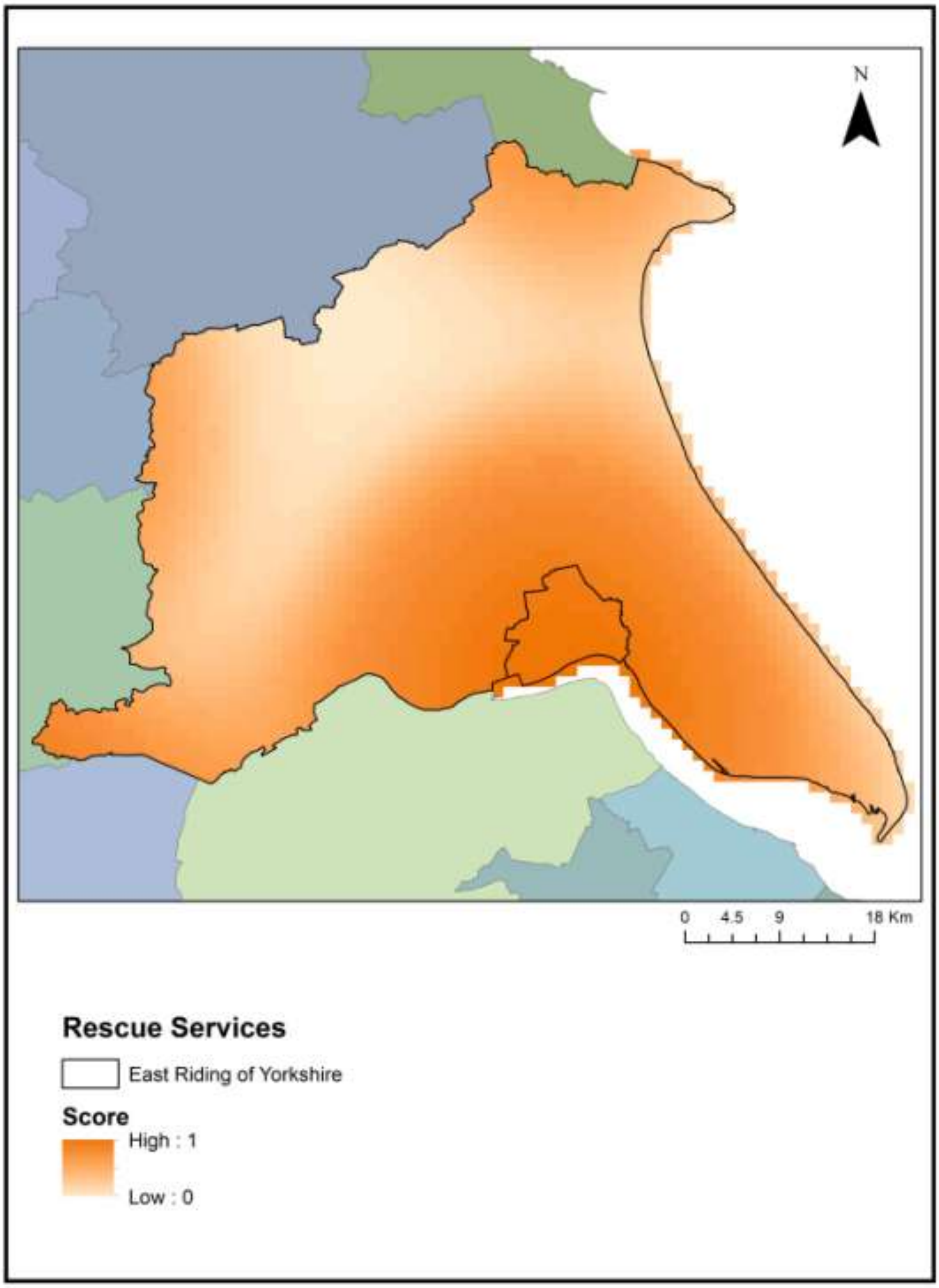


Figure 6-3: Transformed and normalised rescue services

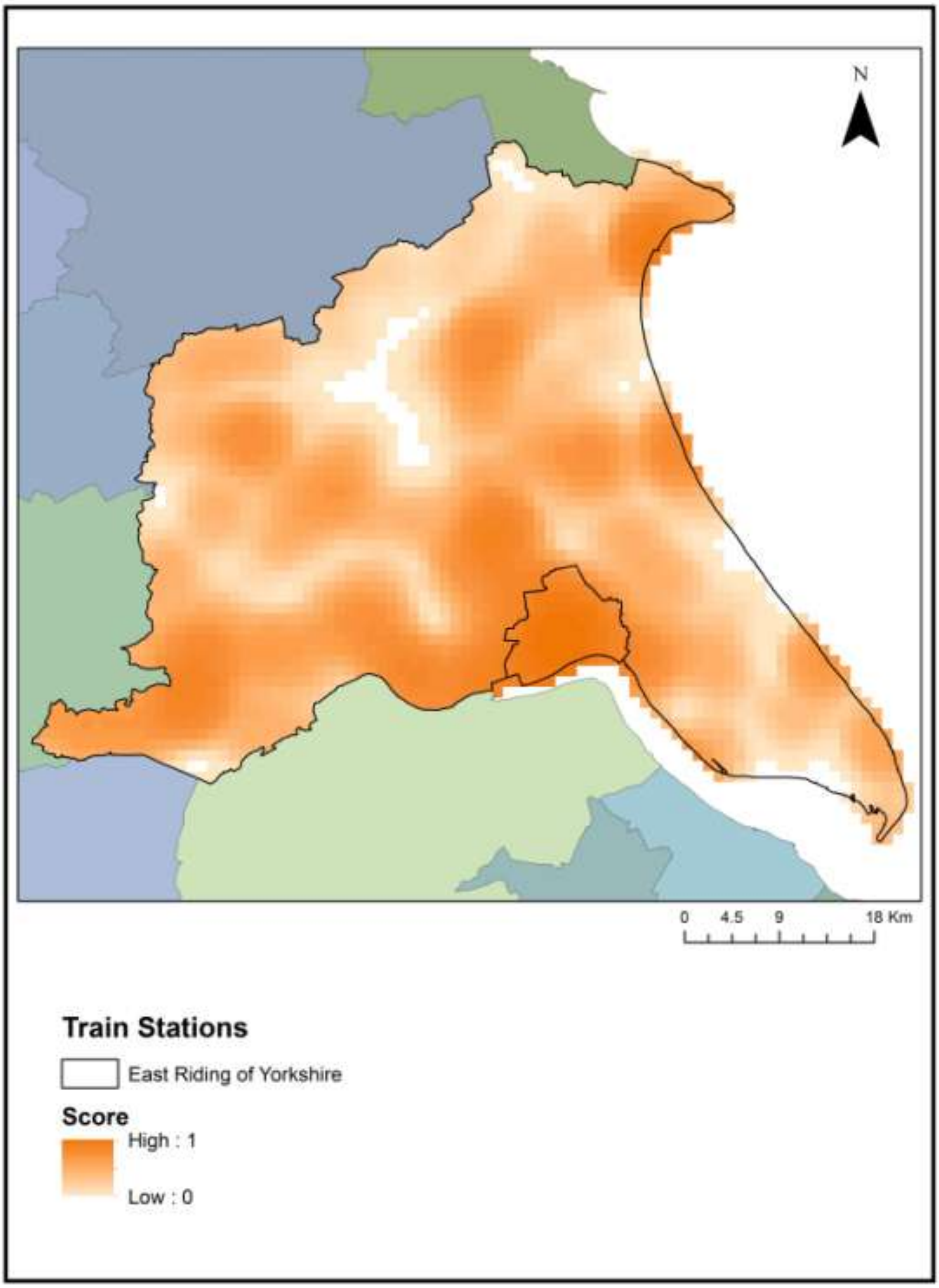


Figure 6-4: Transformed and normalised train stations

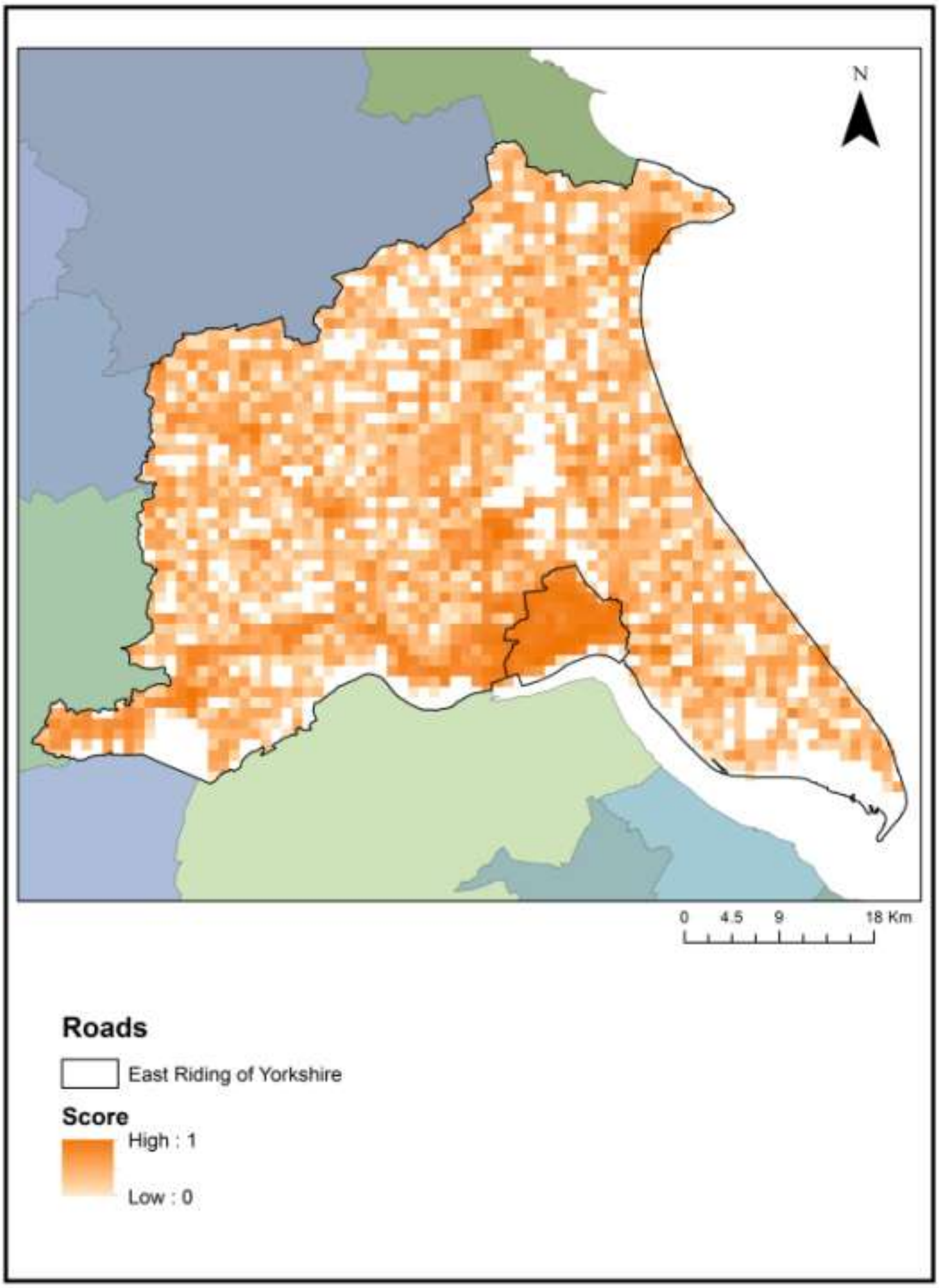


Figure 6-5: Transformed and normalised roads network

- Vehicles:

Census data from CASWEB have been used to derive the vehicle indicator. The spatial density of households with one or more cars and vans for each OA has been calculated. The "polygon to raster" geoprocessing tool was used to transfer the density from OA polygons to 1 km grid cells. The normalised spatial density of vehicles was the final score given to each grid cell. Cells with high scores are distributed within the area especially in larger urban regions (Figure 6-7).

- House level:

Census data at OA level have been used to obtain this indicator. The number of houses at ground or street level per hectare in each OA has been calculated. The "polygon to raster" tool was applied to transfer the data from polygons to 1 km grid cells. Normalised densities were the final scores to be given to each cell. There are clusters of cells with high scores in large urban regions, especially the City of Kingston upon Hull, Beverley, and Bridlington (Figure 6-8).

- Buildings:

This indicator shows the presence of buildings and assets. The location and extent of buildings is a factor of physical exposure, since they hold physical values. The inconsistency map of the urban sector is used to present the existence of buildings. Four layers of urbanised lands from LCM2007, Strategi, Vector Map District, and MasterMap have been added together to get the final map of buildings' locations. The total area of buildings in each 1 km grid cell was calculated and normalised values were the final scores to be given to each cell (Figure 6-9).

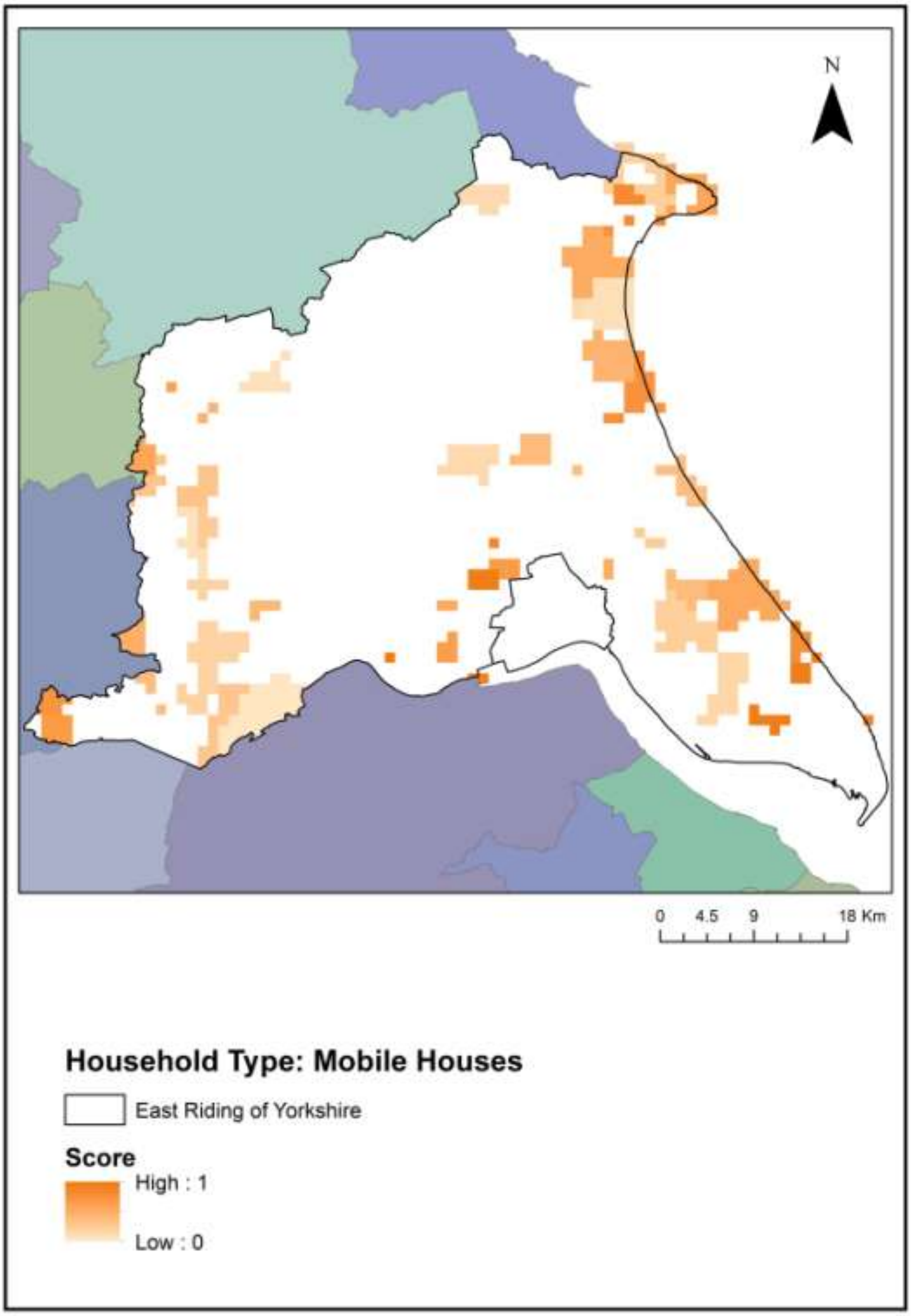


Figure 6-6: Transformed and normalised household type - mobile houses

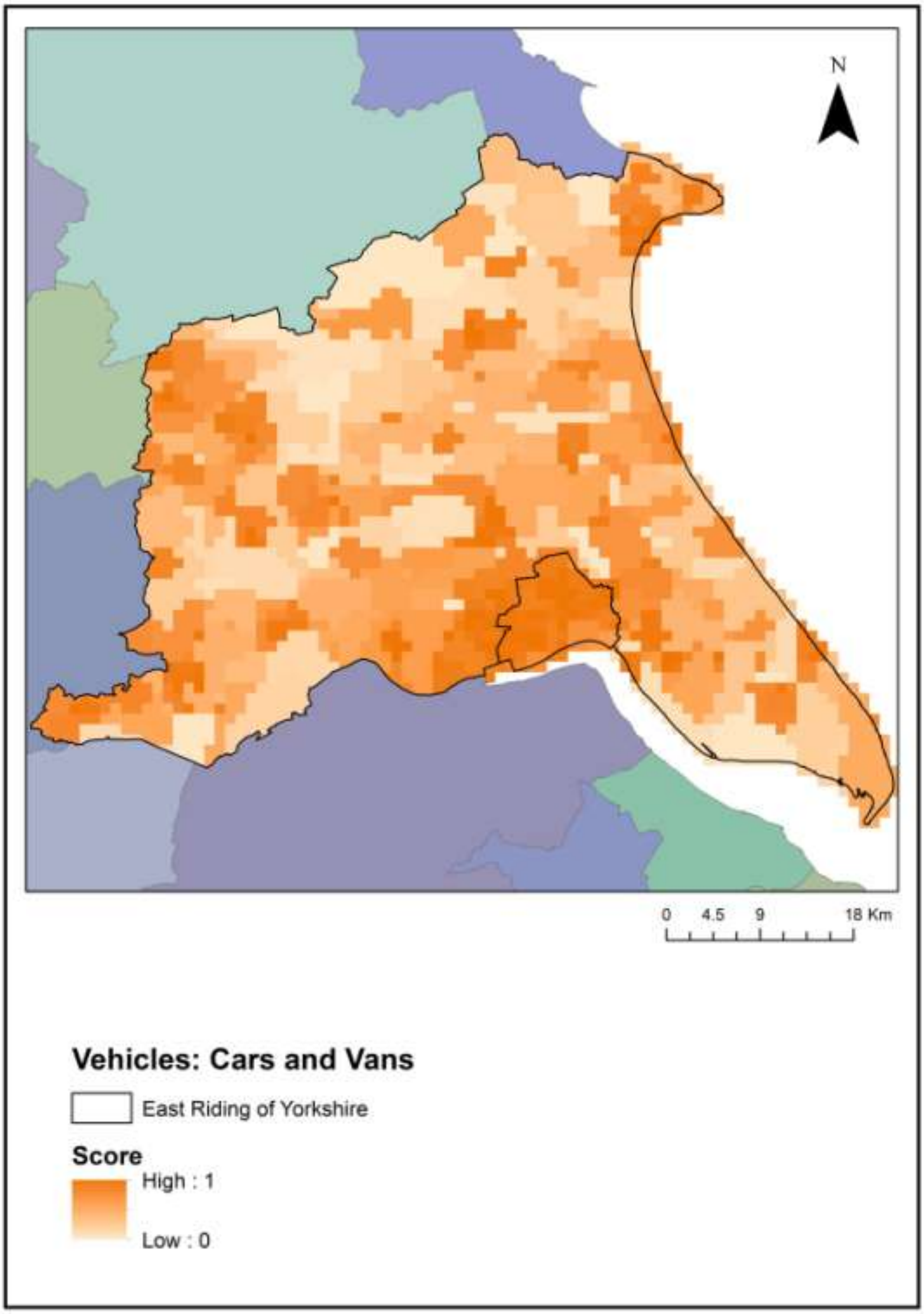


Figure 6-7: Transformed and normalised vehicles

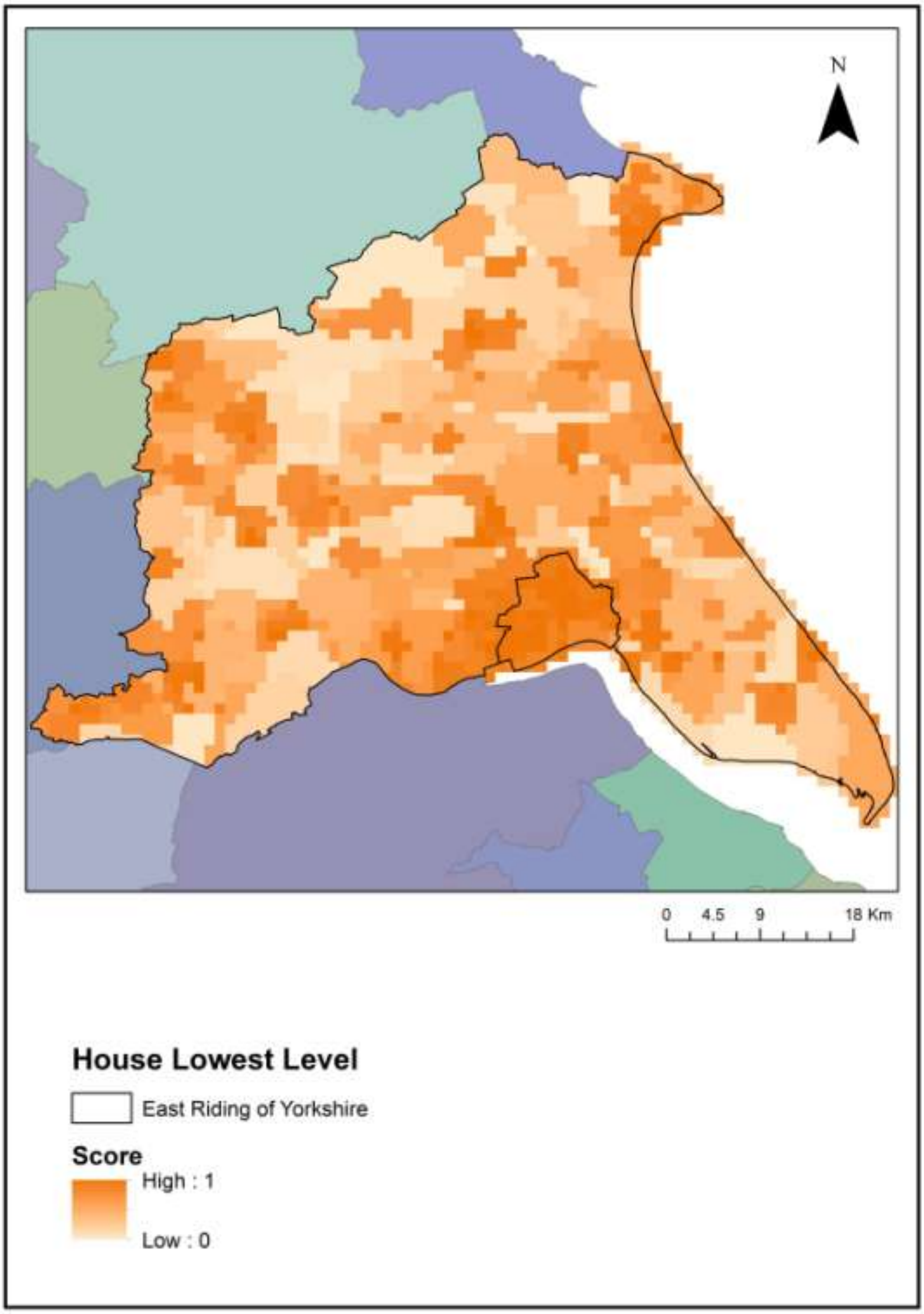


Figure 6-8: Transformed and normalised house lowest level

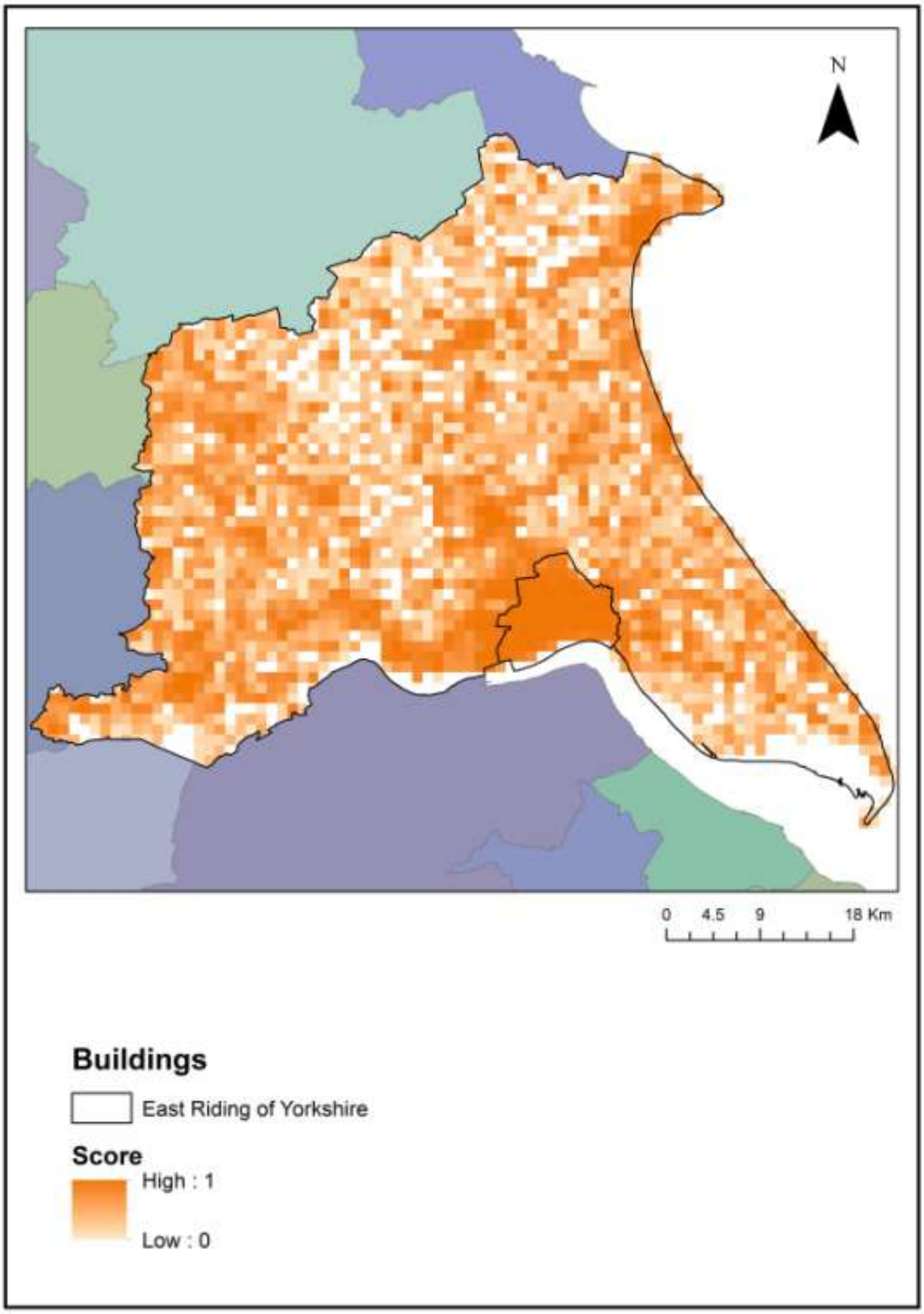


Figure 6-9: Transformed and normalised buildings

6.5.1.2. Economic indicators

The third component of vulnerability is concerned with economically valuable assets and services. Both coping capacity and exposure indicators are present in this component. Coping capacity factors may include financial support through insurance, grants, and incentives. Incentives are not included in the vulnerability analysis because they vary in expiry date, grant duration, spatial resolution, and terms and conditions. In fact, the result of this research will show decision makers the most vulnerable places to assign the grants.

- Unemployment:

The unemployed population are more susceptible to the impact of flooding and have fewer resources to cope with extreme events. Census data have been used to develop this indicator. Unemployment rates are calculated at OA level by dividing the number of unemployed people in the age range 16-74 by the total number of people of working age (16-74). The "polygon to raster" tool was used to transfer the data into 1 km grid cells and the normalised rate was the final score for each cell. Interestingly, the highest scores are in larger urban areas such as the City of Kingston upon Hull, Beverley, Goole, and Bridlington (Figure 6-10).

- Residents in communal establishments:

The number of residents in communal establishments is an indicator of the number of people who are more susceptible to the impacts of flooding. Communal establishments are defined as managed residential accommodation where there is full-time or part-time supervision of the accommodation, such as prisons, hotels, and large hospitals (Office for National Statistics 2011a). The number of residents in the communal establishments was divided by the total population in the OA and the resultant rate was transferred to 1 km grid cells using the "polygon to raster" tool. The normalised rate was the final score to be assigned to each cell. As Figure 6-11 shows, most of the cells with high scores are close to highly populated regions.

- Tenure:

House ownership is an important factor in economic coping capacity. This factor has been cited by many researchers working on vulnerability assessments. If a household owns a house, on the one hand they have the responsibility of fixing and refurnishing the house, but on the other hand the house is a financial back-up for them and gives them an advantage in terms of economic coping capacity. The number of householders who are homeowners divided by the total number of households in an OA gives the indicator rate. The "polygon to raster" tool has been used to transfer the data into 1 km grid cells. The normalised rate was the final score given to each cell (Figure 6-12).

- Household size:

The number of people per household is a measure of economic susceptibility. Average household size at OA level has been transferred into a 1 km grid using the "polygon to raster" tool. Normalised values have been assigned to grid cells. The range of scores is relatively low and the variation of scores within the area is high (Figure 6-13).

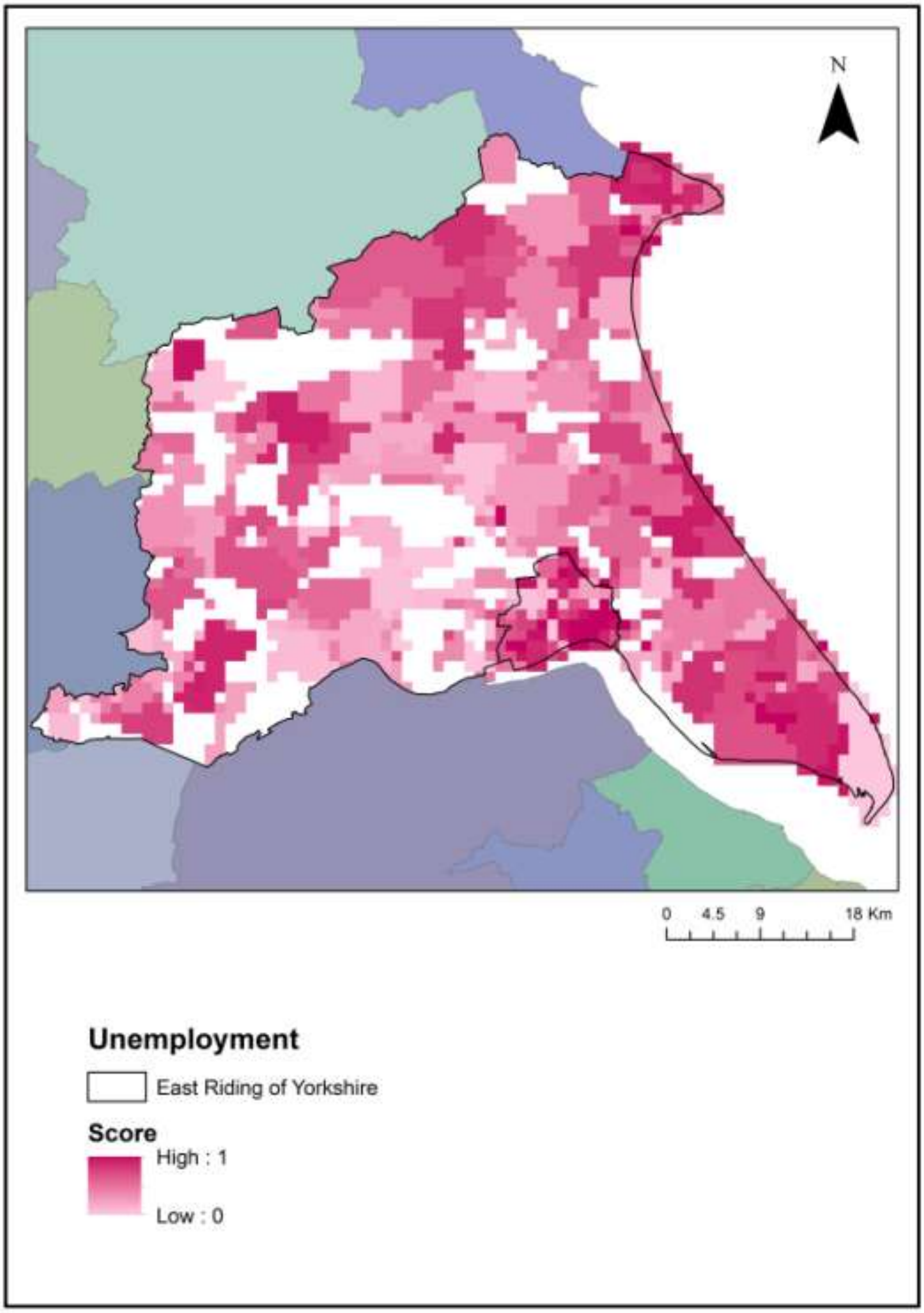


Figure 6-10: Transformed and normalised unemployment

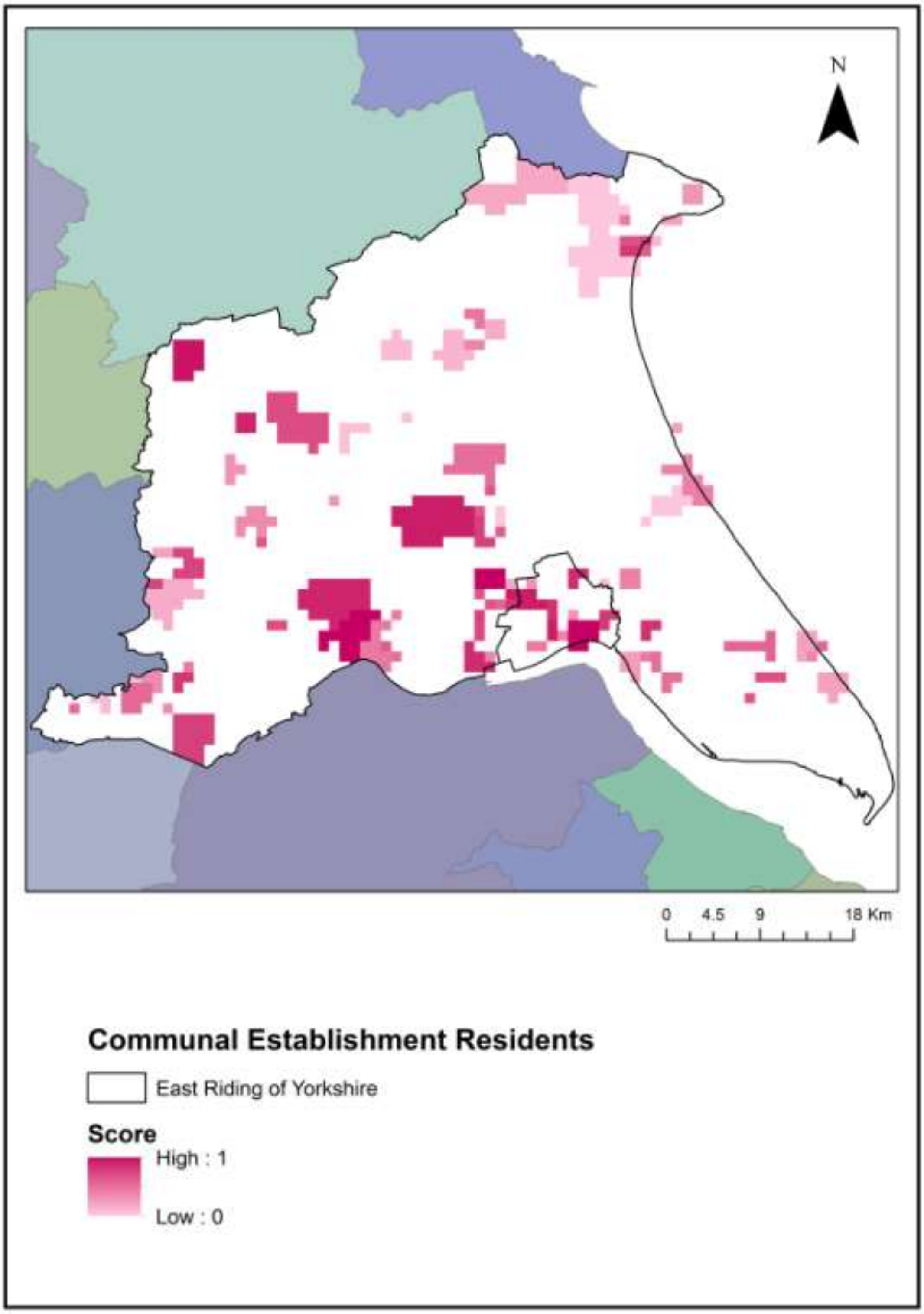


Figure 6-11: Transformed and normalised communal establishment residents

- Commercial services:

Locations of commercial services which are economically valuable have been considered as an indicator for economic exposure to flooding. The commercial services class has been extracted from the Points of Interest dataset. The "point in polygon" operation using Hawth's tool was applied in order to calculate the number of services in each grid cell. Normalised spatial density was the final score to be assigned to each cell (Figure 6-14).

- Manufacturing and production:

"Manufacturing and production" is another class of POI, which shows the locations of important assets in terms of economic value. The "point in polygon" operation using Hawth's tool was applied in order to calculate how many services fall into each cell. Normalised values were assigned to cells as the final scores (Figure 6-15).

- Income:

Households' average weekly income from the Office of National Statistics (ONS) was used as an indicator of the economic coping capacity of people. Average income at MSOA level was transferred into 1 km grid cells. Normalised values were the final scores for grid cells (Figure 6-16).

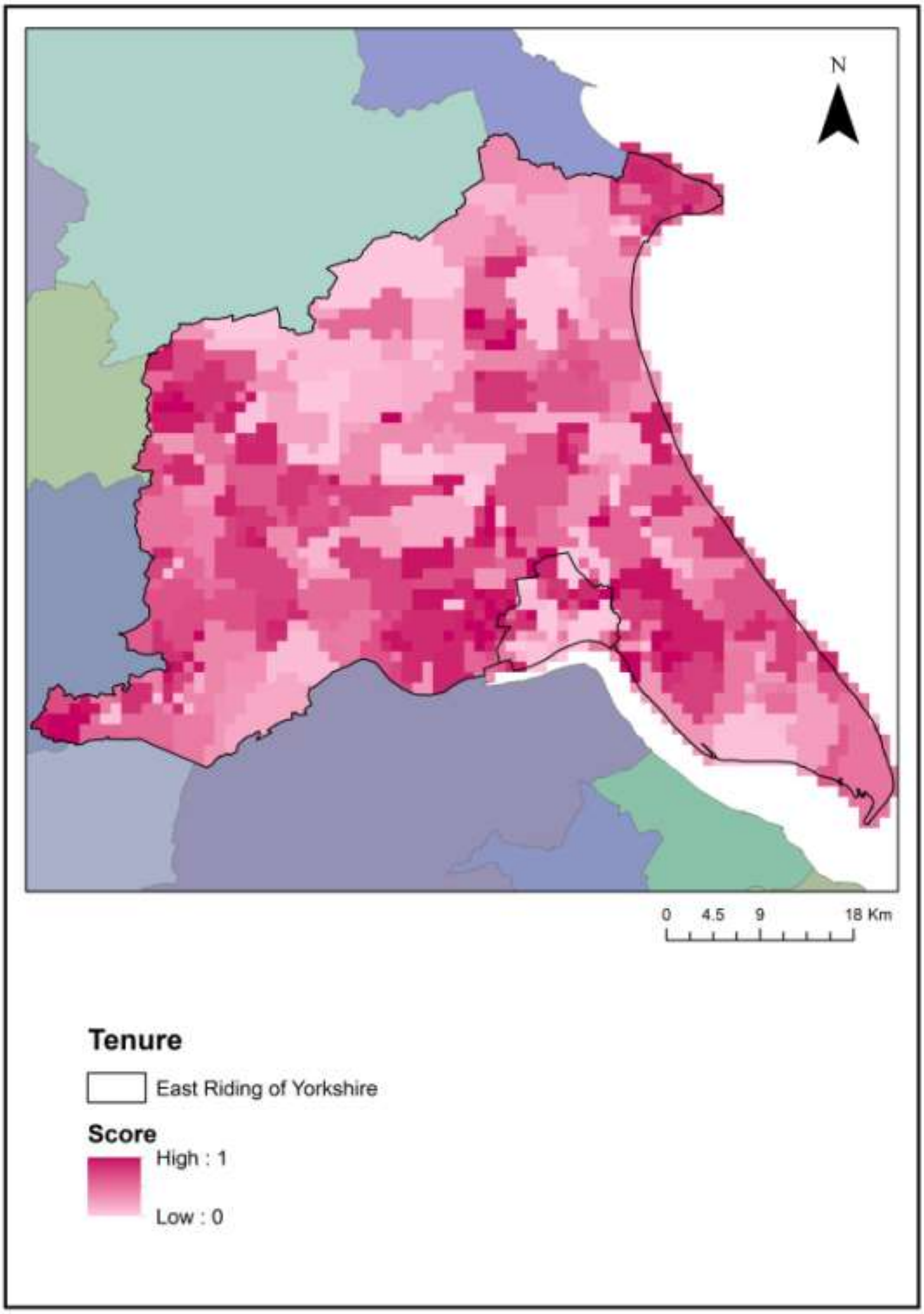


Figure 6-12: Transformed and normalised tenure

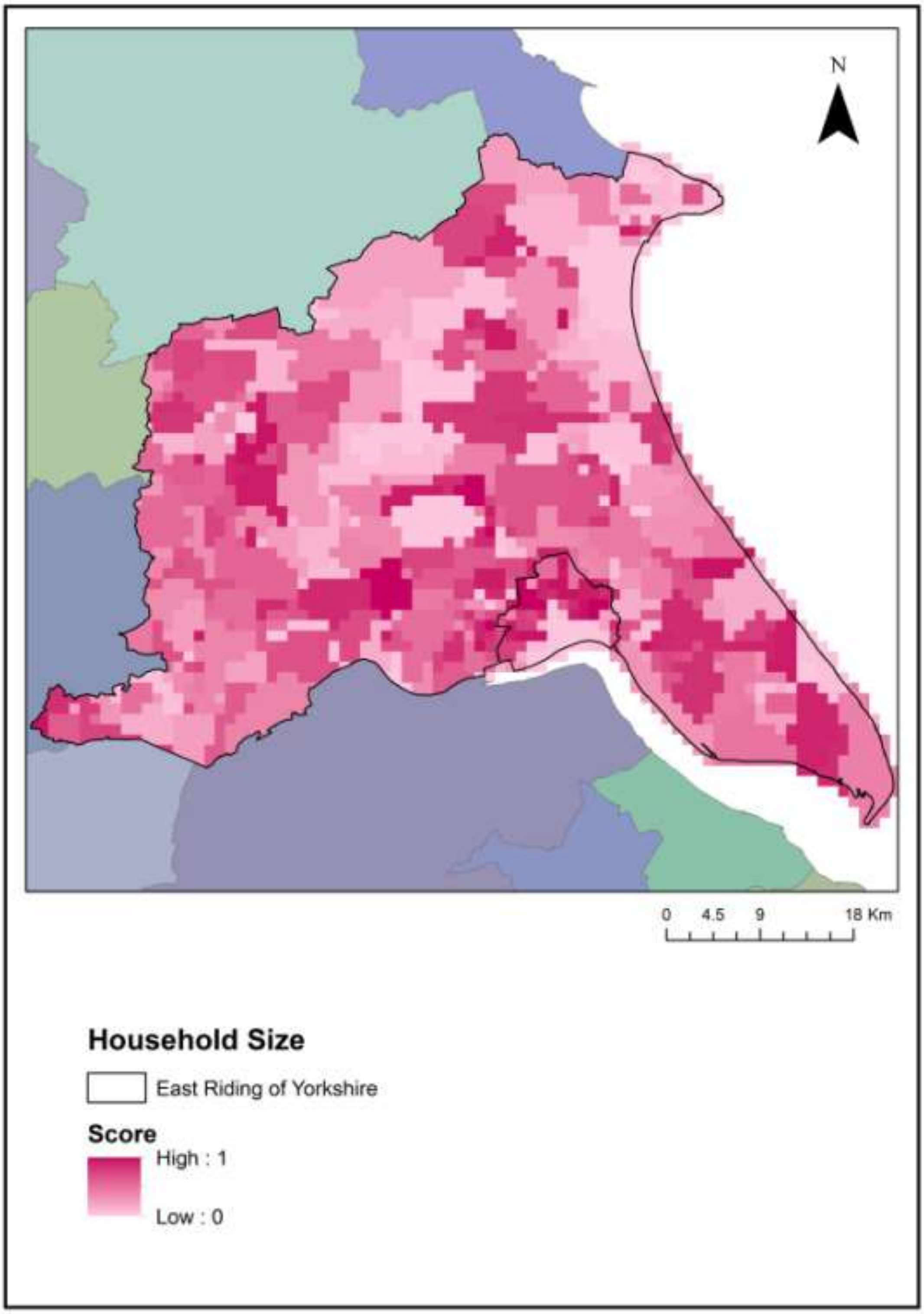


Figure 6-13: Transformed and normalised average household size

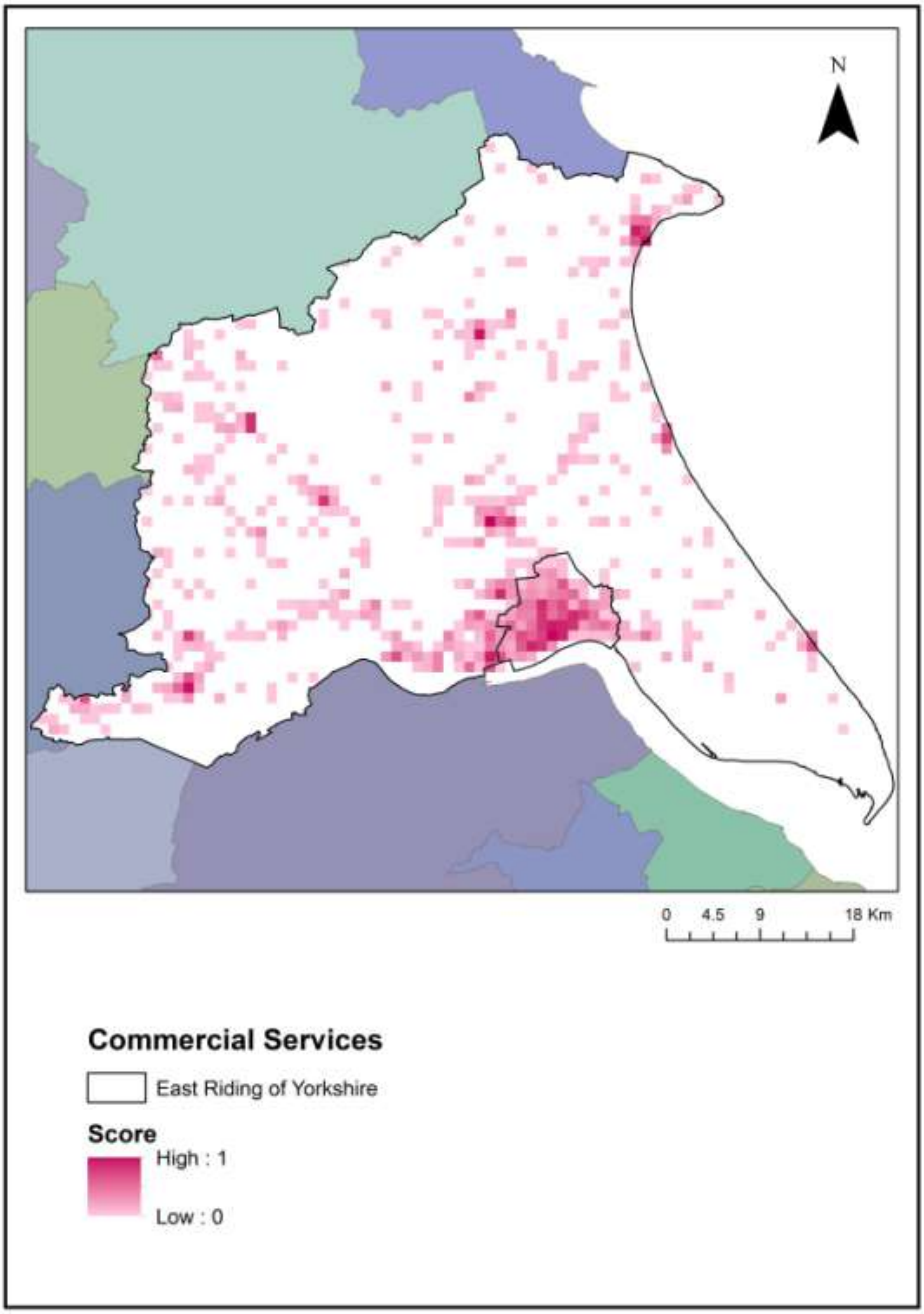


Figure 6-14: Transformed and normalised commercial services

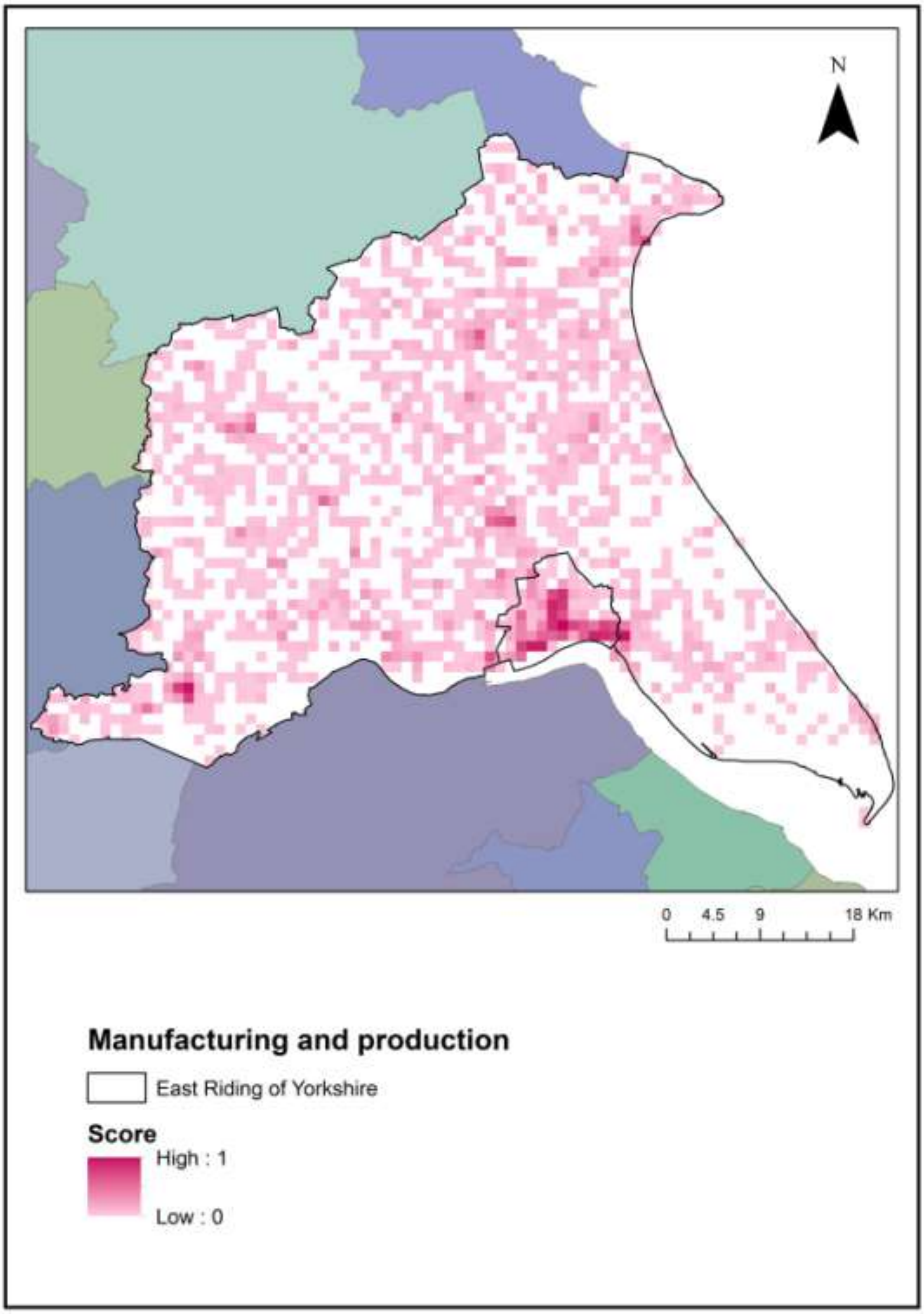


Figure 6-15: Transformed and normalised manufacturing and production

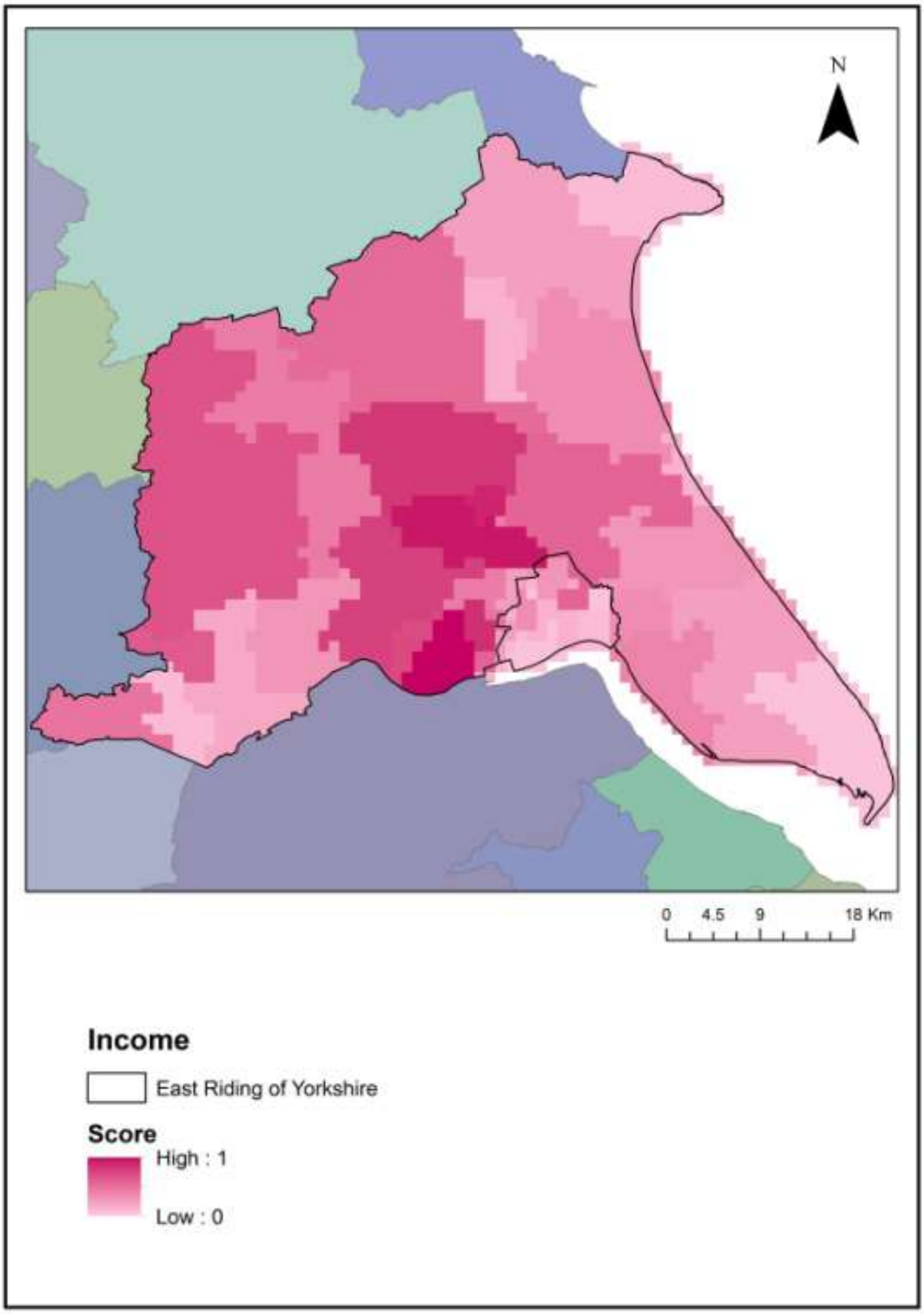


Figure 6-16: Transformed and normalised average weekly income

6.5.1.3. Social vulnerability

The social component of vulnerability considers exposure and coping capacity factors related to people's social lives. Most of the indicators are from census data, and the rest are from Ordnance Survey's Points of Interest (POI). Social indicators are complicated and typically interrelated, so allocating indicators to components and sub-components is not easy and should proceed with extra care. For example, "retail location" is an indicator of the social component of vulnerability; on the one hand it could indicate the exposure of retail premises to flooding, and on the other hand it could give people access to food, clothing, and urgent requirements.

- Population:

The number of people living in an OA is an indicator of social exposure to flooding. Highly populated areas are more susceptible to the impacts of flooding. Population density has been calculated for each OA and transferred into a 1 km grid. Normalised density was the final score to be given to each cell (Figure 6-17).

- Age:

The population under 16 and above 74 years old is more susceptible to the impacts of flooding. This is classified as the non-working-age population. The rate of the non-working-age population (i.e. the number of people aged above 74 or under 16 divided by the total population) in each OA was calculated and transferred into 1 km grid cells. Normalised rates were the final score to be given to each cell (Figure 6-18).

- Health:

A good state of health can greatly help people to cope with the shock of extreme events such as flooding. In this study, the number of people with a "not good" state of health was taken and divided by the total population at OA level to give the rate of this indicator as a measure of social exposure to flooding. The final score was derived from normalised rates at the 1 km grid level (Figure 6-19).

- Students away from home:

Students who live alone and away from home are more exposed and susceptible to the diverse impacts of flooding. The proportion of students away from home in the total population in each OA has been calculated and transferred into 1 km grid cells. Values were normalised and assigned to cells as the final score (Figure 6-20).

- Lone parents with dependent children:

Lone parents who have dependent children need extra help at the time of flooding and are more exposed to the impacts. In addition, they face more difficulties in terms of coping with the impacts in the longer term. The proportion of lone parents with dependent children to the total population in each OA was calculated as the variable for this indicator. Values were normalised and transferred into 1 km grid cells (Figure 6-21).

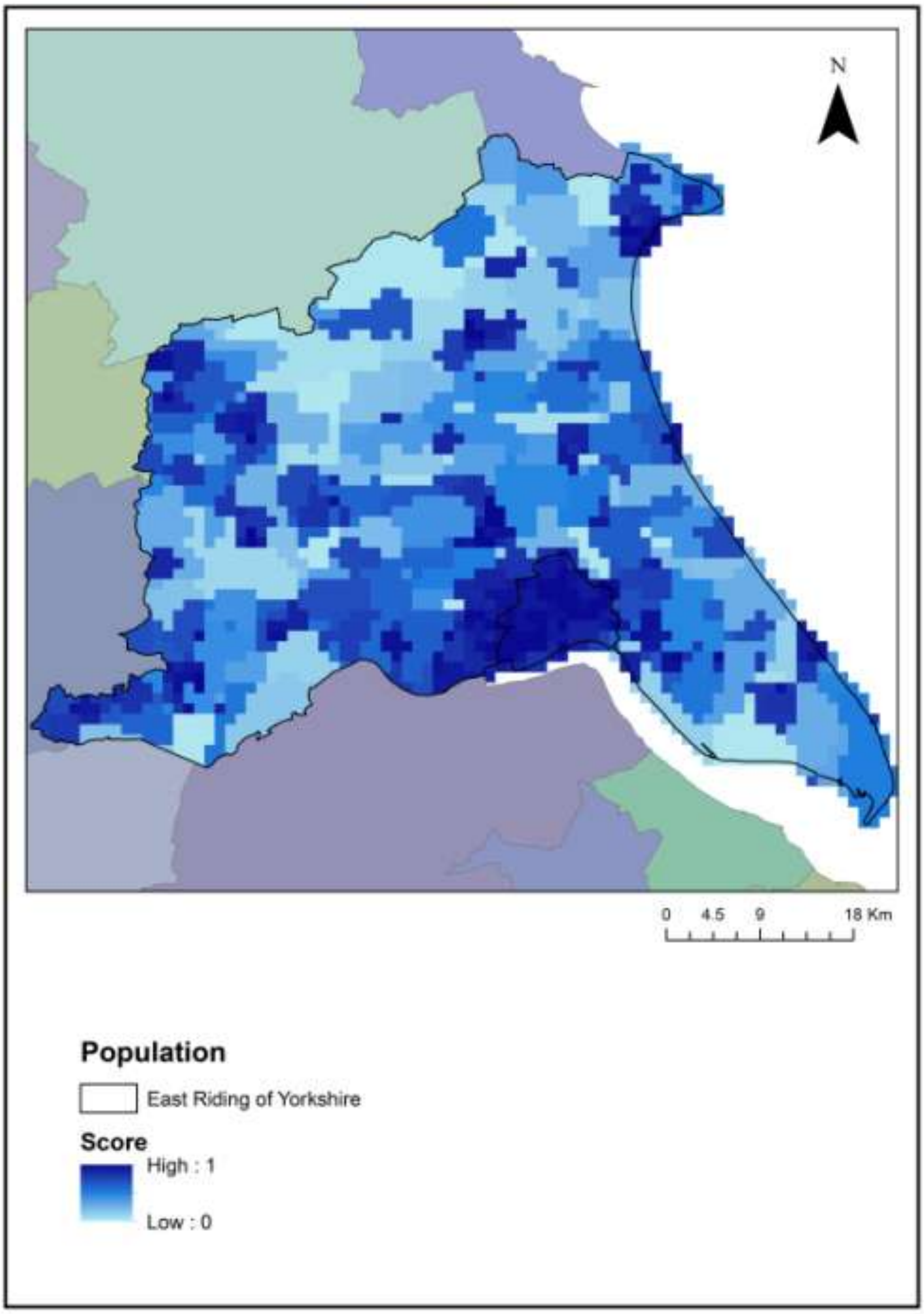


Figure 6-17: Transformed and normalised population

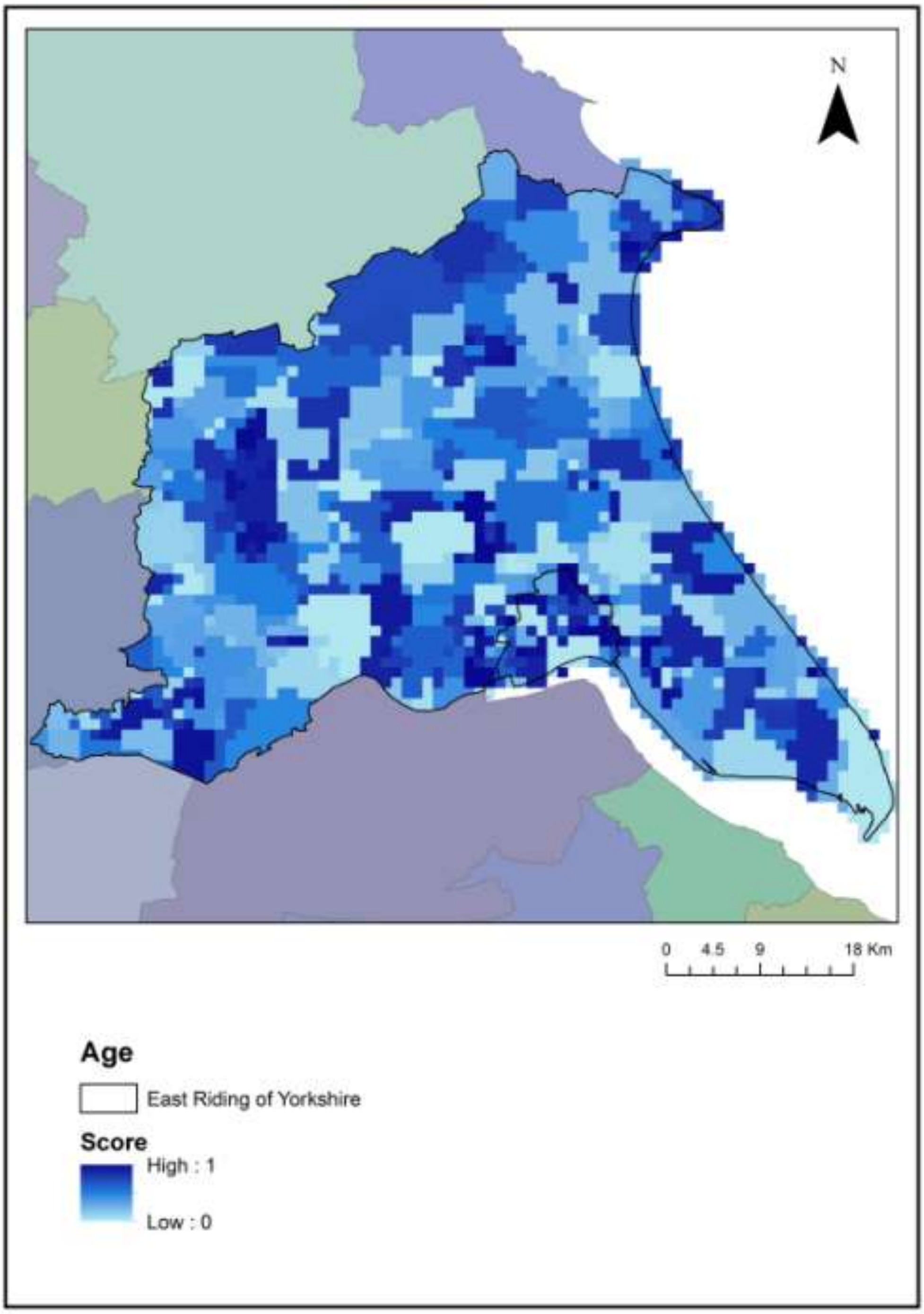


Figure 6-18: Transformed and normalised age

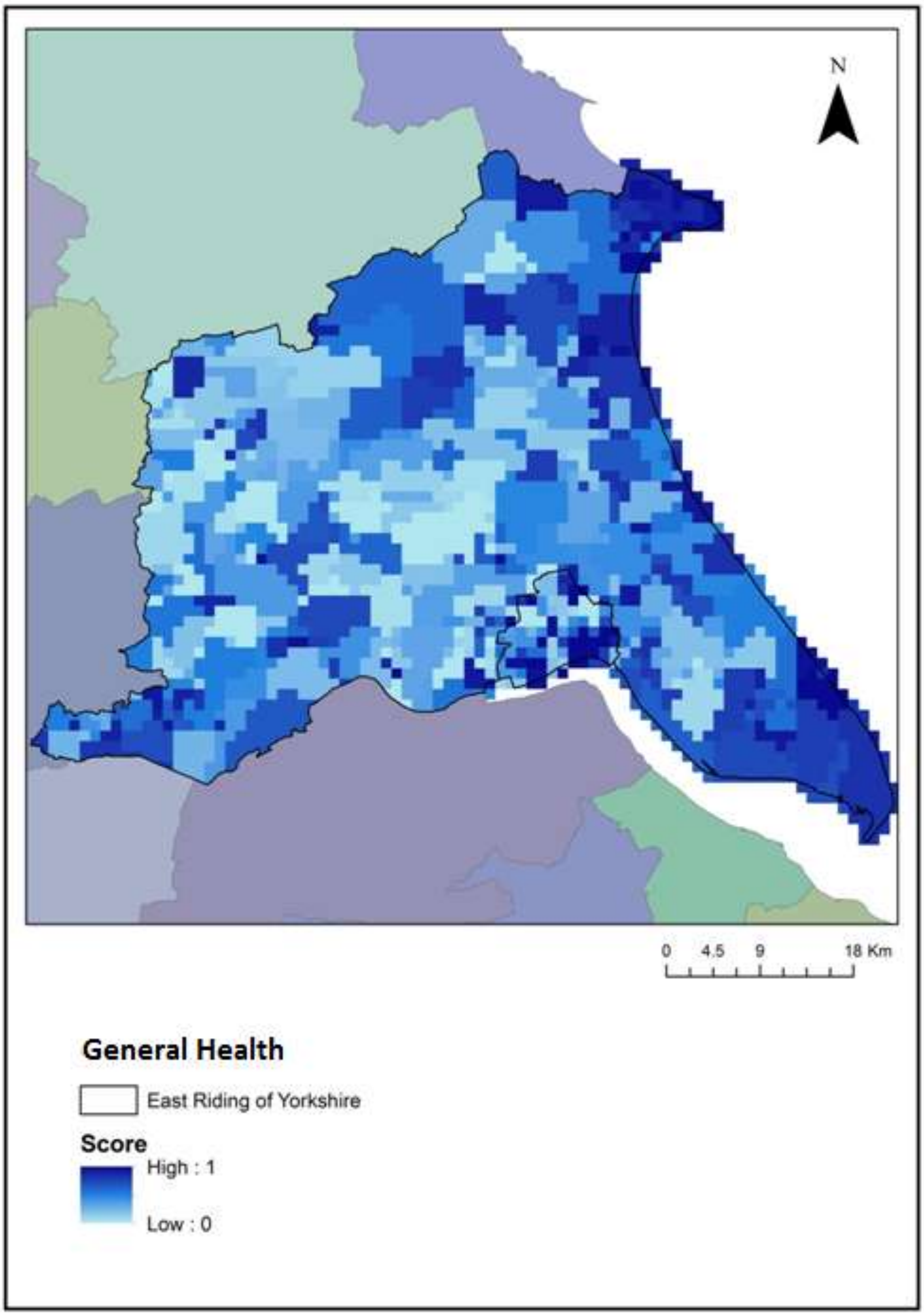


Figure 6-19: Transformed and normalised health condition

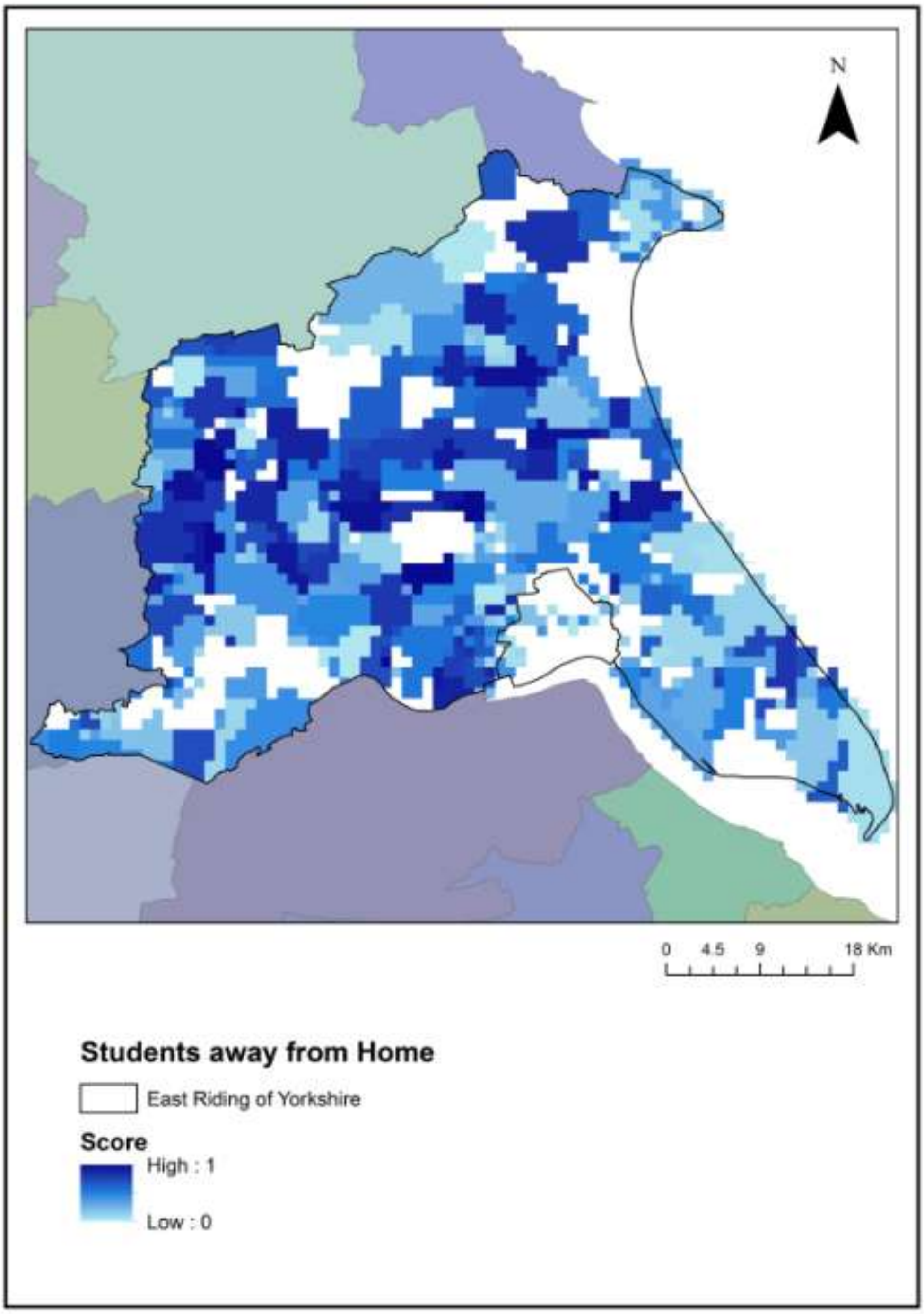


Figure 6-20: Transformed and normalised students away from home

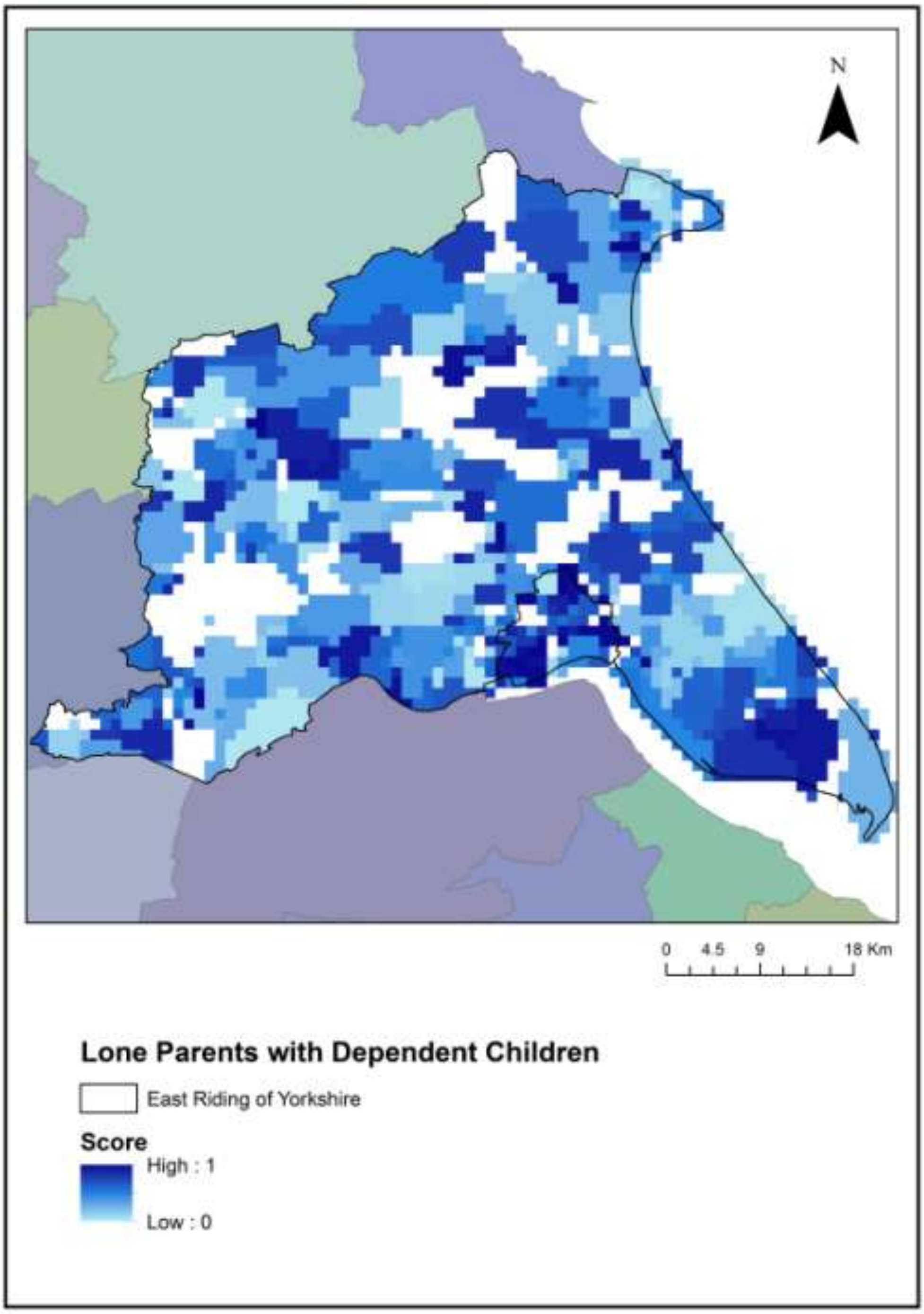


Figure 6-21: Transformed and normalised lone parents with dependent children

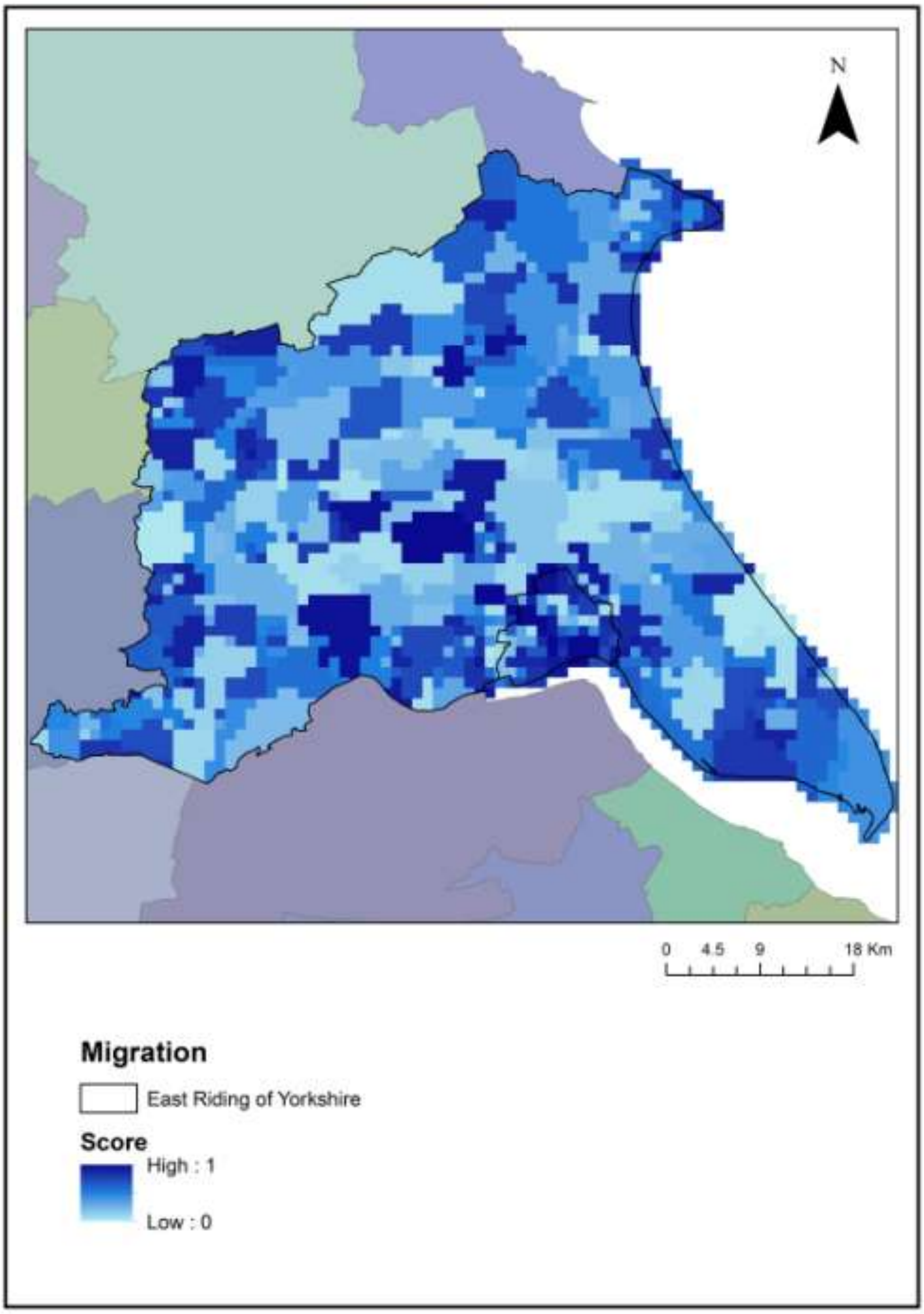


Figure 6-22: Transformed and normalised migration

- Migration:

Urban migration is a well-known indicator in vulnerability studies in the urban sector. Migrants are more susceptible and have fewer resources to cope with the impacts of flooding. The proportion of migrants to the total population in each OA was calculated. Normalised values were given to each 1 km cell as the final score (Figure 6-22).

- Limiting long-term illness:

This group in society is greatly exposed to flooding and needs extra help in extreme events. The proportion of people with limiting long-term illness in the total population was calculated and normalised. The scores of this indicator are shown in Figure 6-23.

- Qualifications:

The proportion of people at OA level who do not have any qualifications has been identified as an indicator of exposure/susceptibility. This indicator shows the people who have fewer resources and qualifications and less knowledge to face the impacts of flooding. Figure 6-24 illustrates the proportion of people with no qualifications.

- Sex:

In addition to the elderly (i.e. those aged above 74) and children (i.e. those aged below 16), the female population has been identified as a susceptible population in cases of extreme events. The proportion of females to the total population was calculated at OA level and transferred onto a 1 km grid. Normalised values were the final score to be assigned to each cell (Figure 6-25).

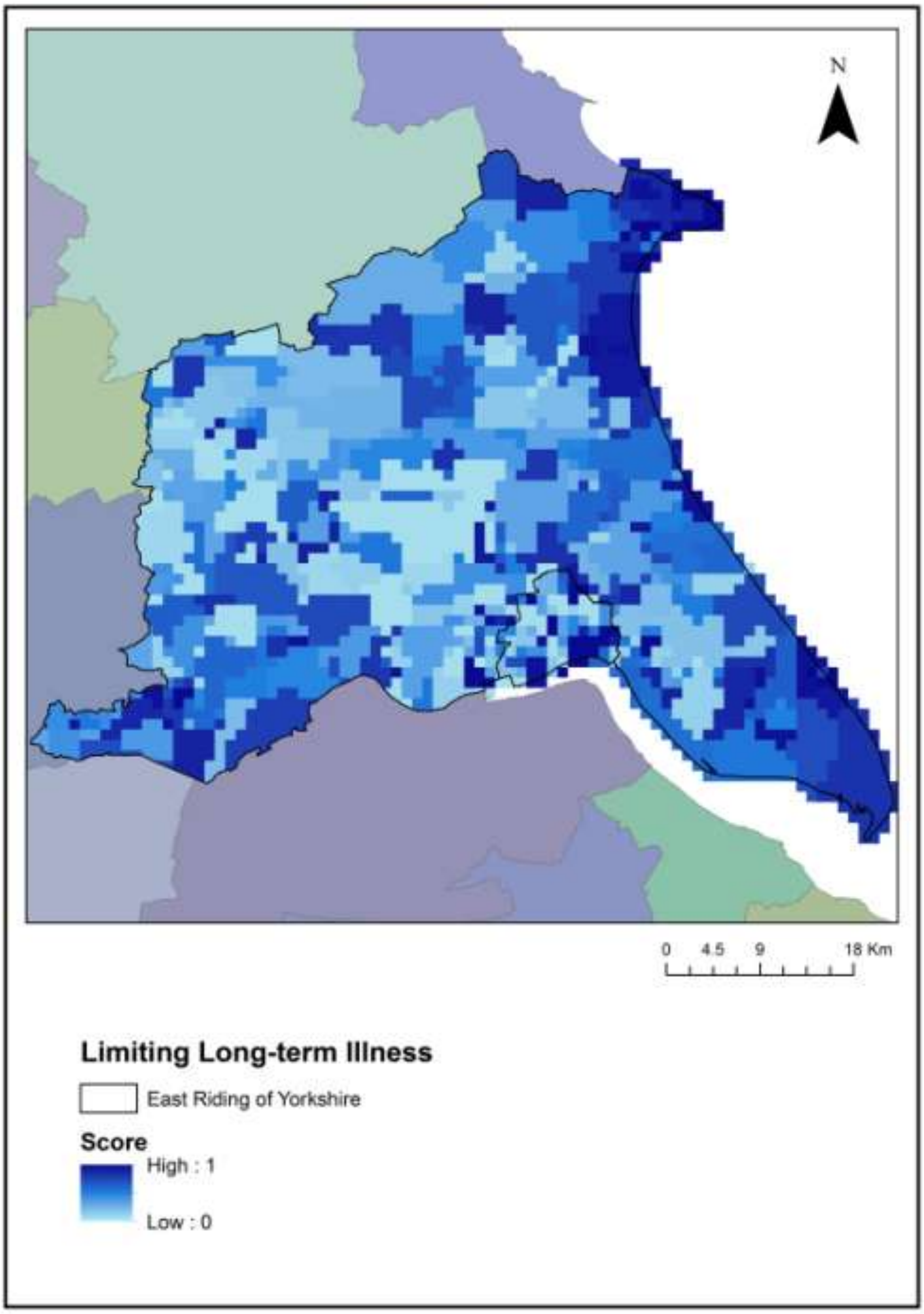


Figure 6-23: Transformed and normalised limiting long-term illness

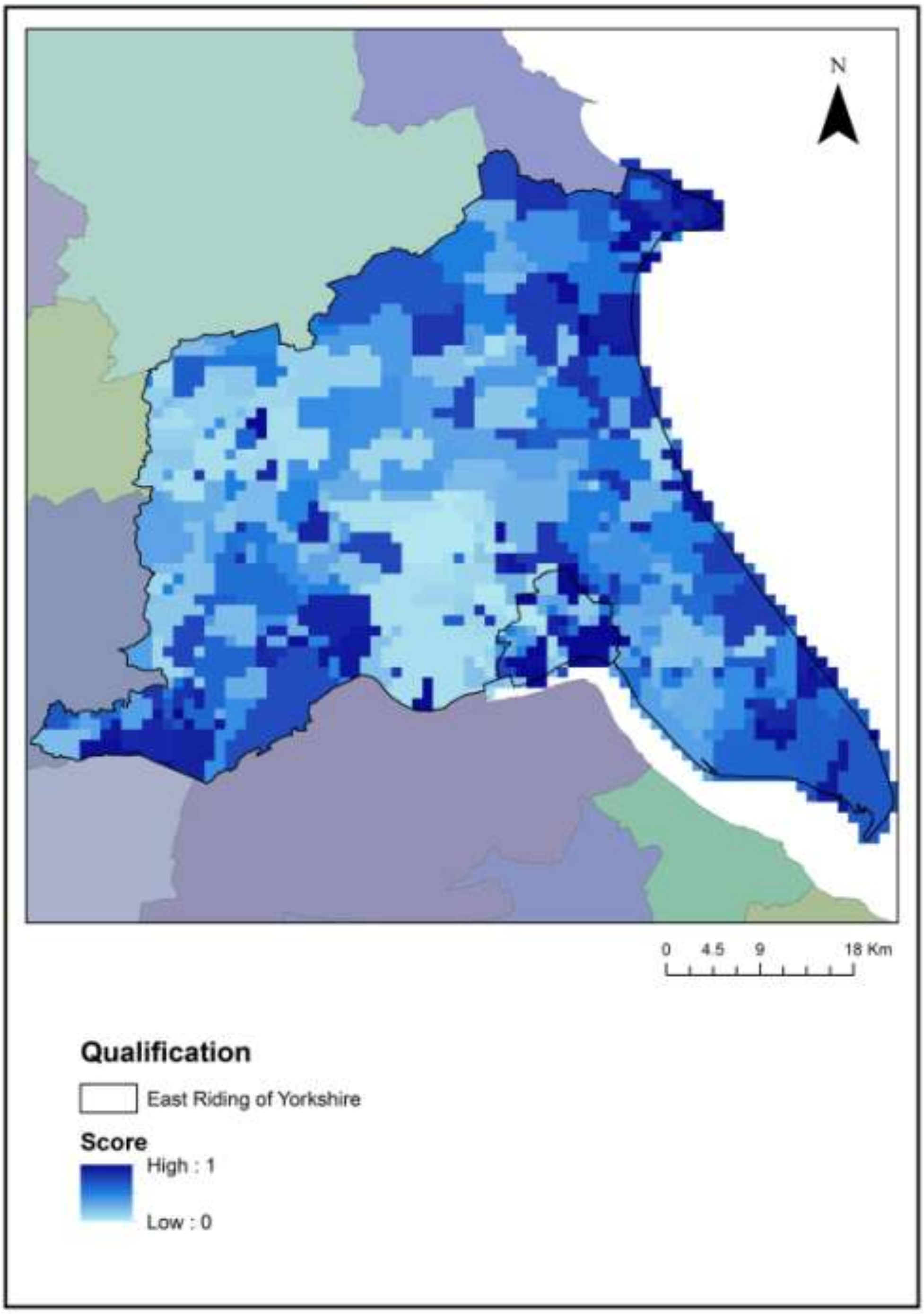


Figure 6-24: Transformed and normalised qualifications

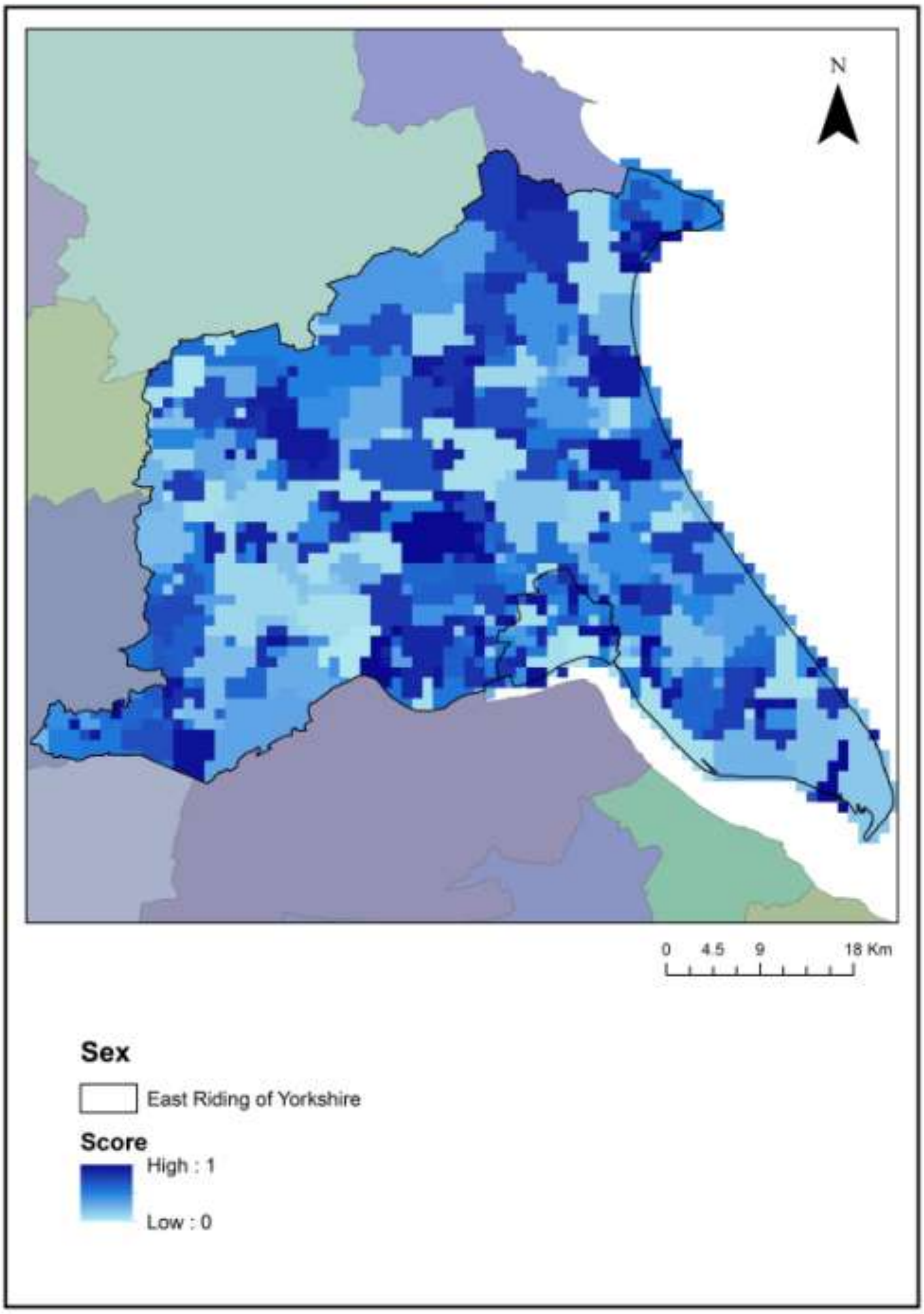


Figure 6-25: Transformed and normalised sex ratio

- Accommodation, eating and drinking services:

The location and density of accommodation, eating and drinking services is an indicator of exposure to flooding. These are places where there is a higher probability of finding crowds. The number of records in this category in each 1 km grid cell was calculated (by the “point in polygon” method) and normalised to give the score of each OA (Figure 6-26).

- Attractions:

The location and density of attractions is an important indicator of social exposure, for two reasons: firstly, these are places where there is a higher probability of finding crowds some of whose members are not local people; secondly, attraction points hold national and/or international values and are of great importance to the society. The number of attractions recorded in 1 km grid cells was calculated. Normalised values were the final score to be given to grid cells (Figure 6-27).

- Sports and entertainment venues:

The location and density of sports and entertainment venues is another indicator of social exposure, for two reasons: firstly, these are places where there is a higher probability of finding crowds; secondly, they have social values. The number of sports and entertainment venues recorded in 1 km grid cells was calculated. Normalised values were the final score to be given to grid cells (Figure 6-28).

- Health services:

The location of health services is another indicator for the coping capacity of the society since they provide a variety of treatments and medical services and general health care. The number of records in each 1 km grid cell was calculated and normalised to show the score for the grid across the area (Figure 6-29).

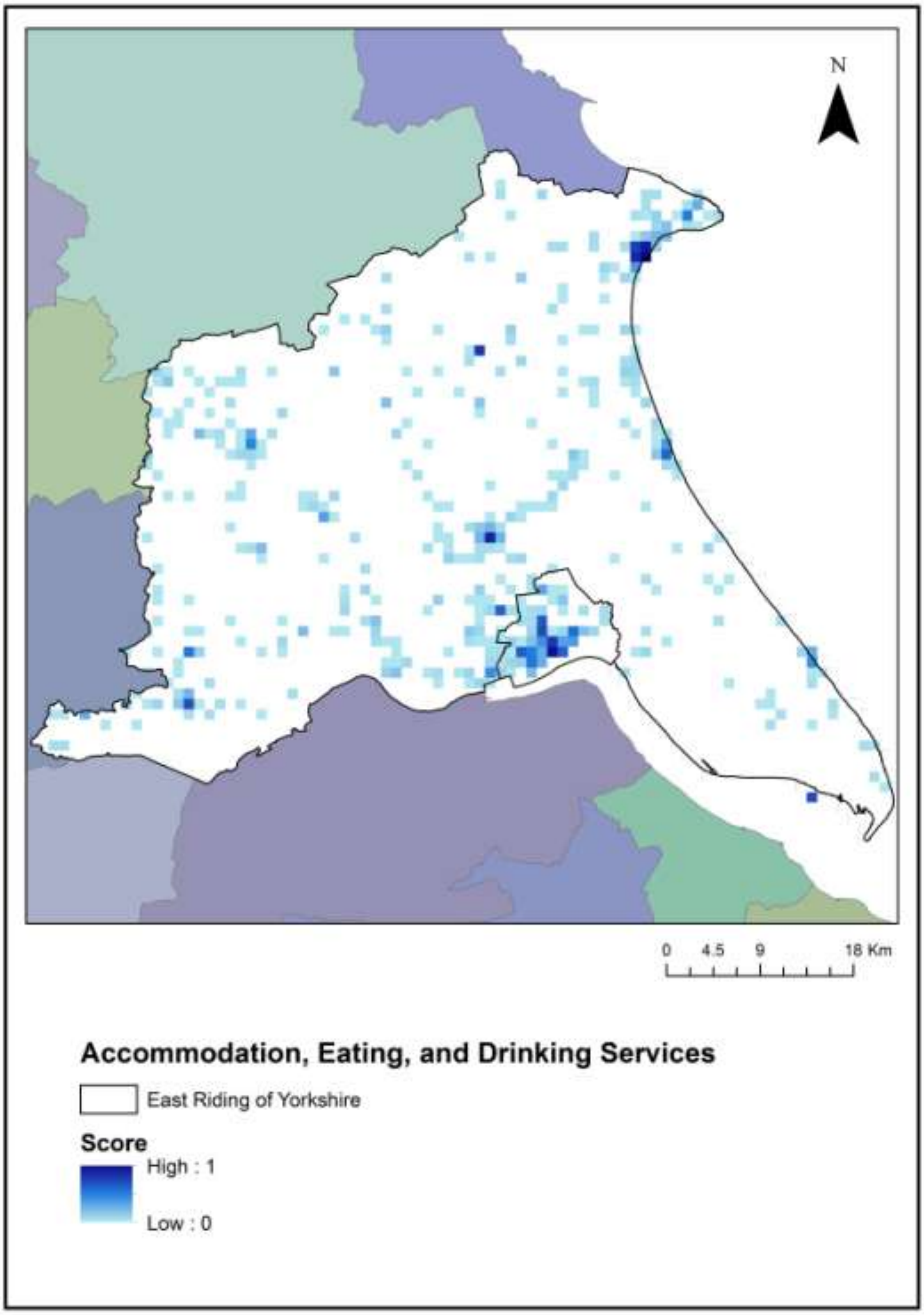


Figure 6-26: Transformed and normalised accommodation, eating, and drinking services

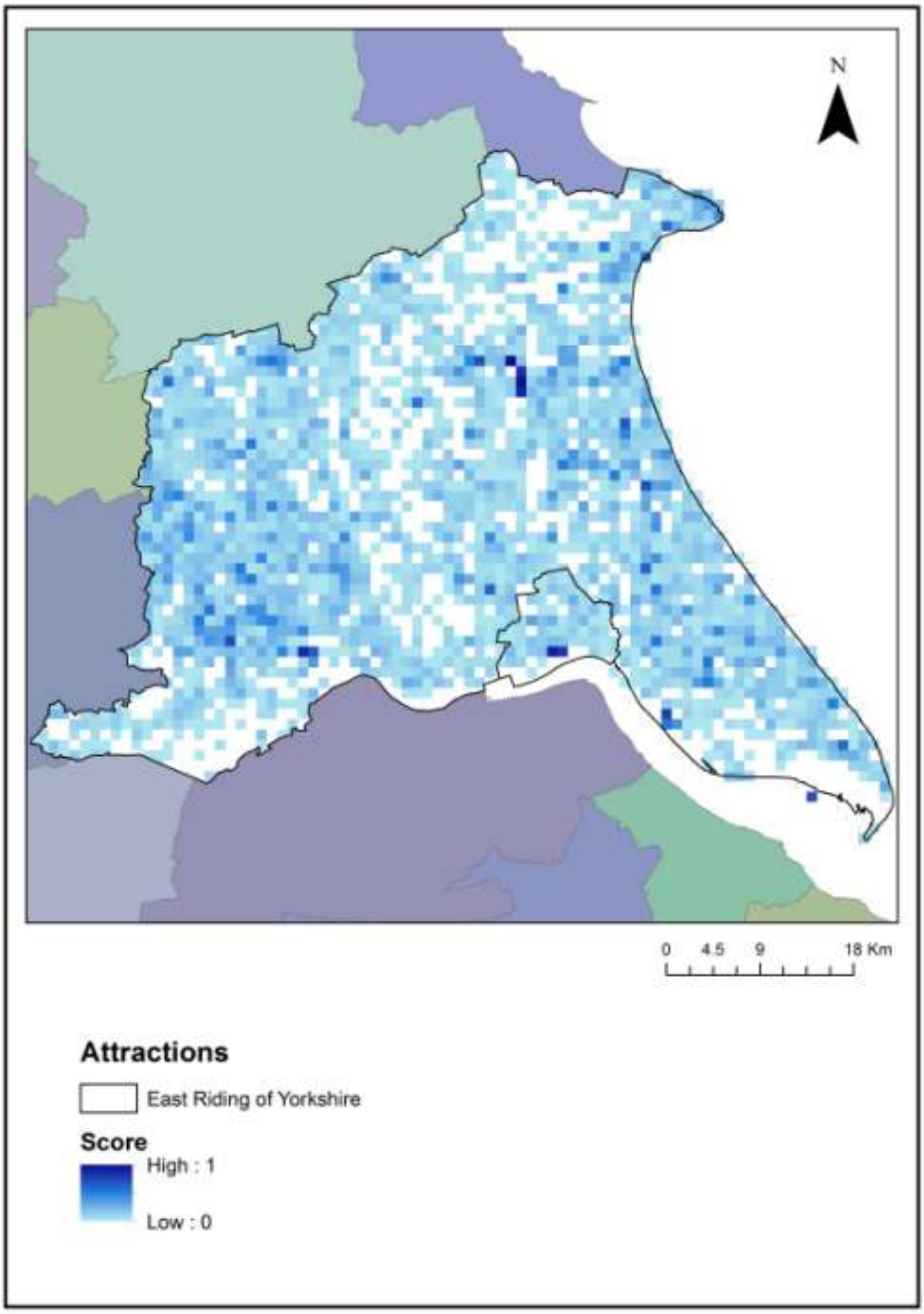


Figure 6-27: Transformed and normalised attractions

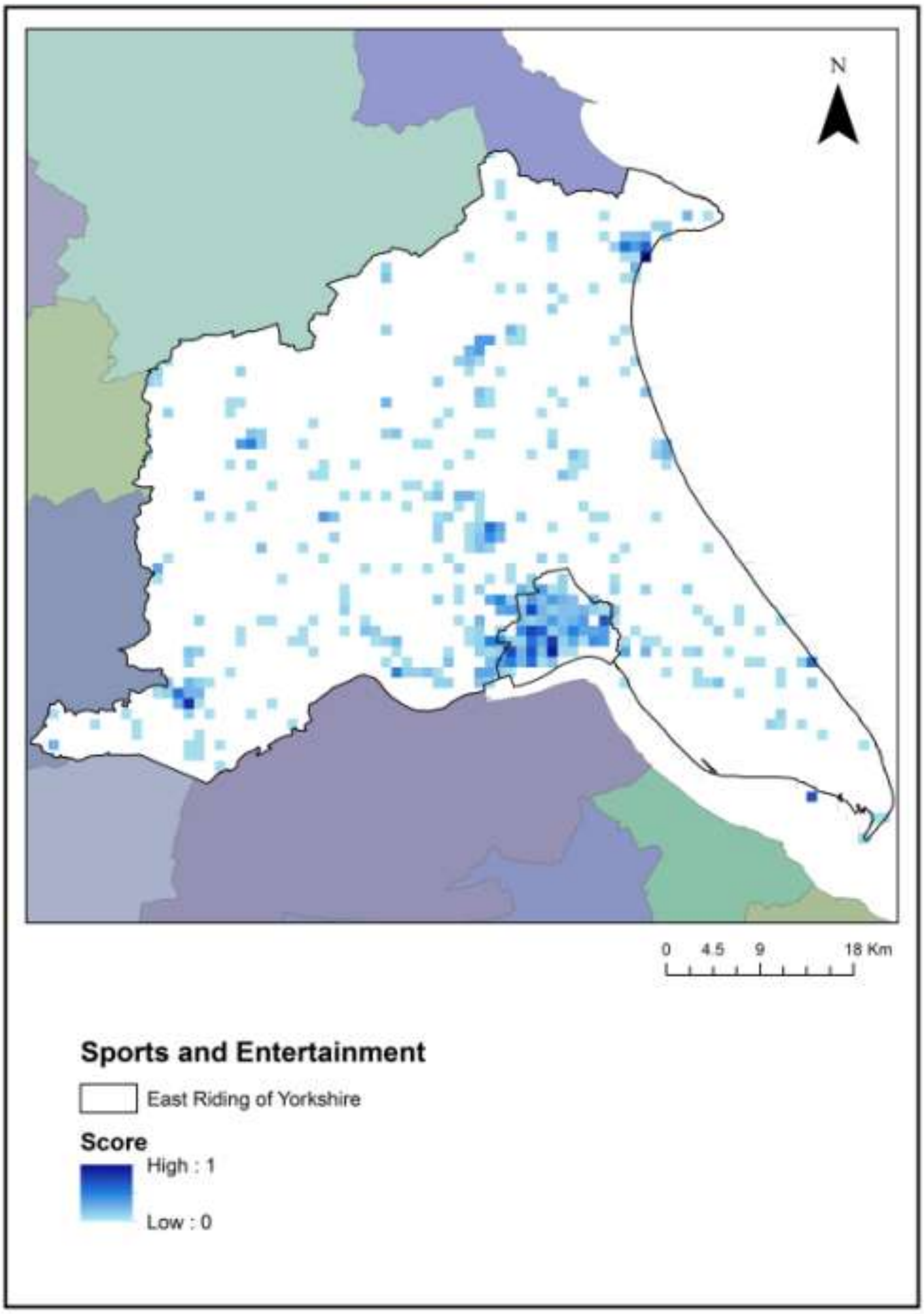


Figure 6-28: Transformed and normalised sports and entertainment

- Public infrastructure:

Places of worship, halls and community centres, and libraries shape this group of POI. These are amenities for the public in case of flooding. The number of records in 1 km grid cells was calculated and normalised. Final score are demonstrated in Figure 6-30.

- Schools:

These are locations of primary, secondary, and tertiary education. On the one hand they could be considered as factors in exposure if flooding occurs in day-time when there are students and personnel there. On the other hand, they are places of public amenity and help in case of flooding over a longer time-scale. In this study, they have been seen as a factor of coping capacity. Their density at 1 km grid level has been calculated. Normalised values were the final scores to be given to the cells (Figure 6-31).

- Retail:

These are locations of clothing, accessories, food, drink, and multi-item stores. They might be seen as factors in economic exposure to flooding; however, this study has considered them as factors of coping capacity since they are sources of essential items for people’s survival. The number of records in each 1 km grid cell has been calculated and normalised. Figure 6-32 shows the final ranks of the cells within the area.

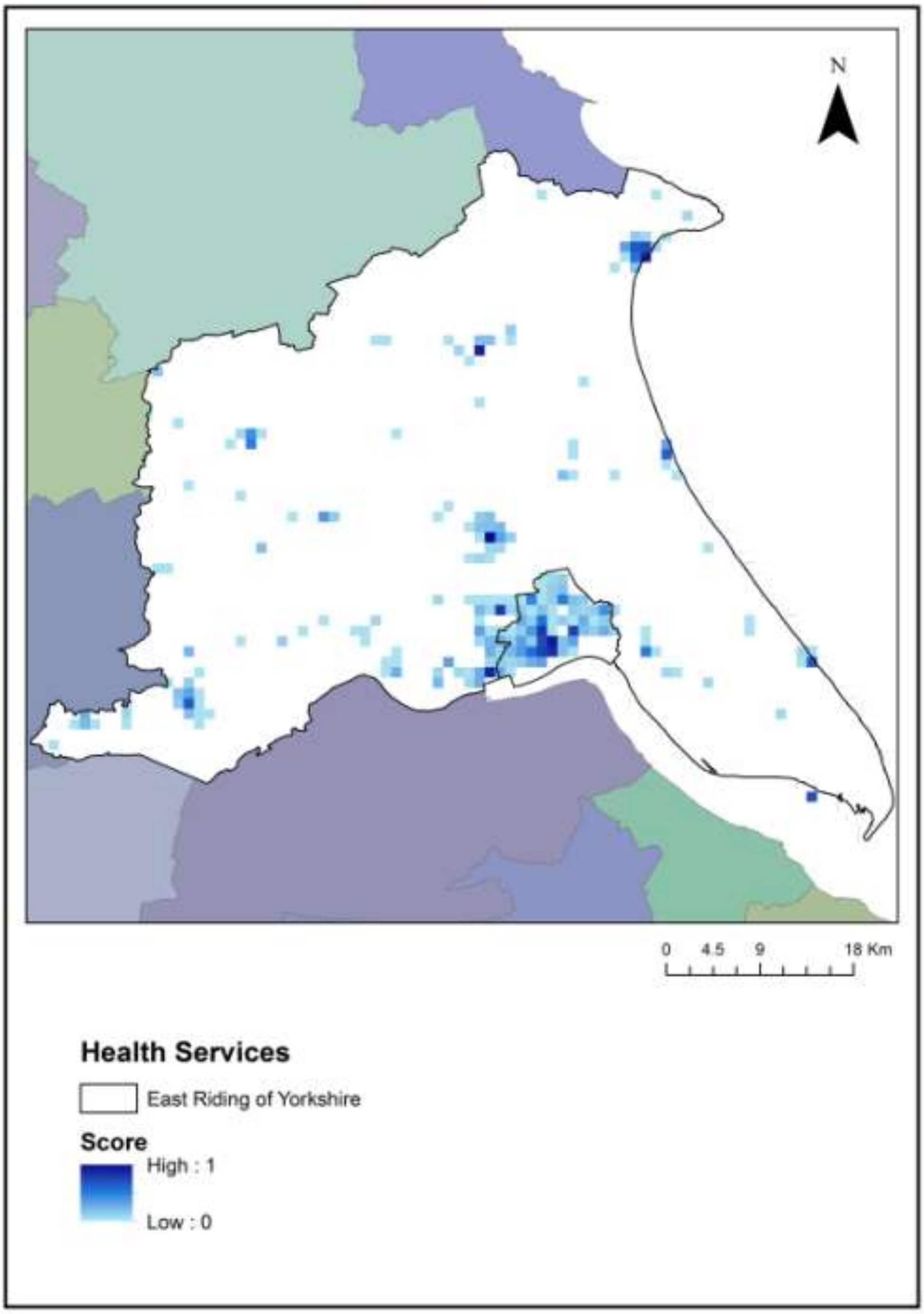


Figure 6-29: Transformed and normalised health services

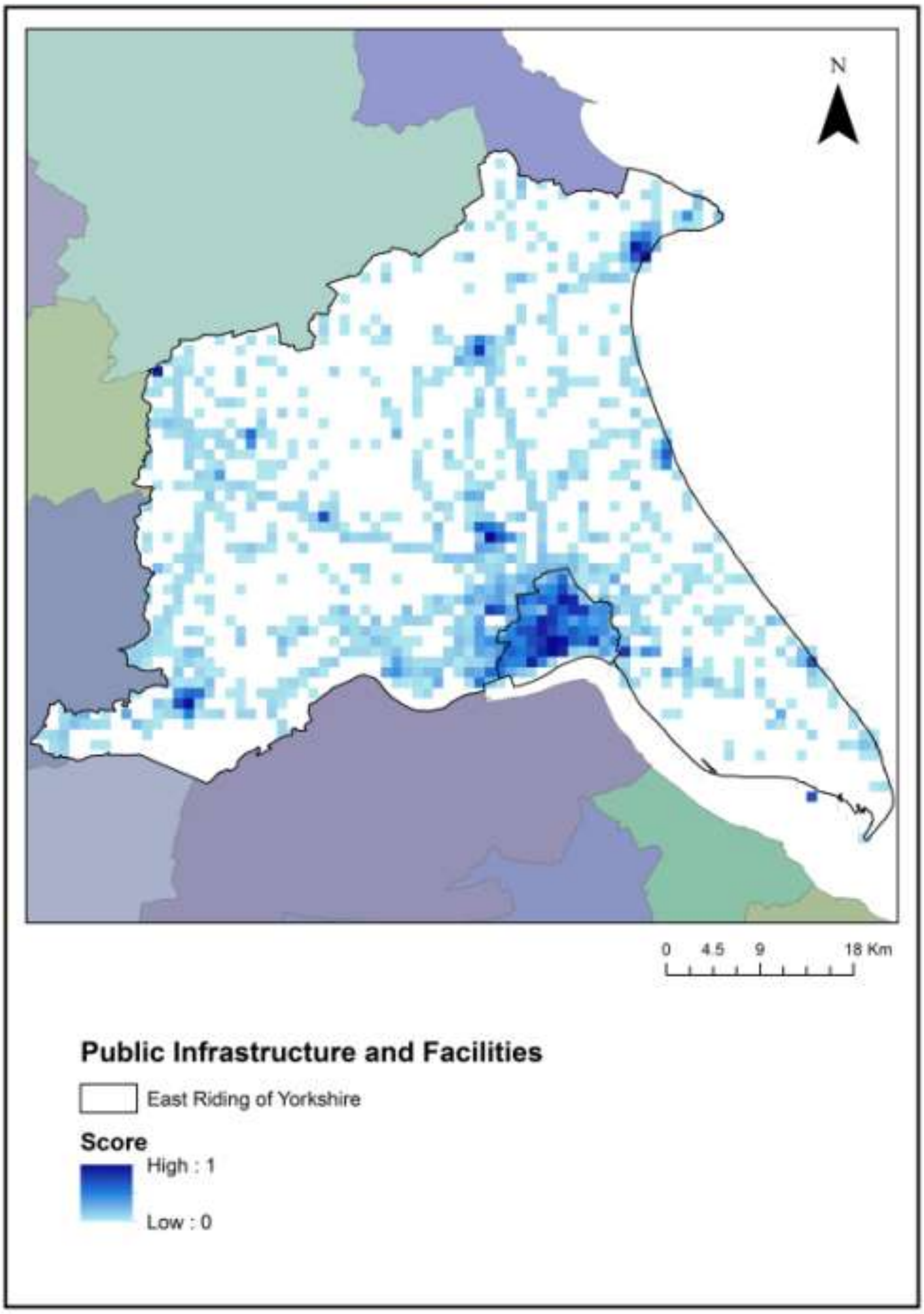


Figure 6-30: Transformed and normalised public infrastructure and facilities

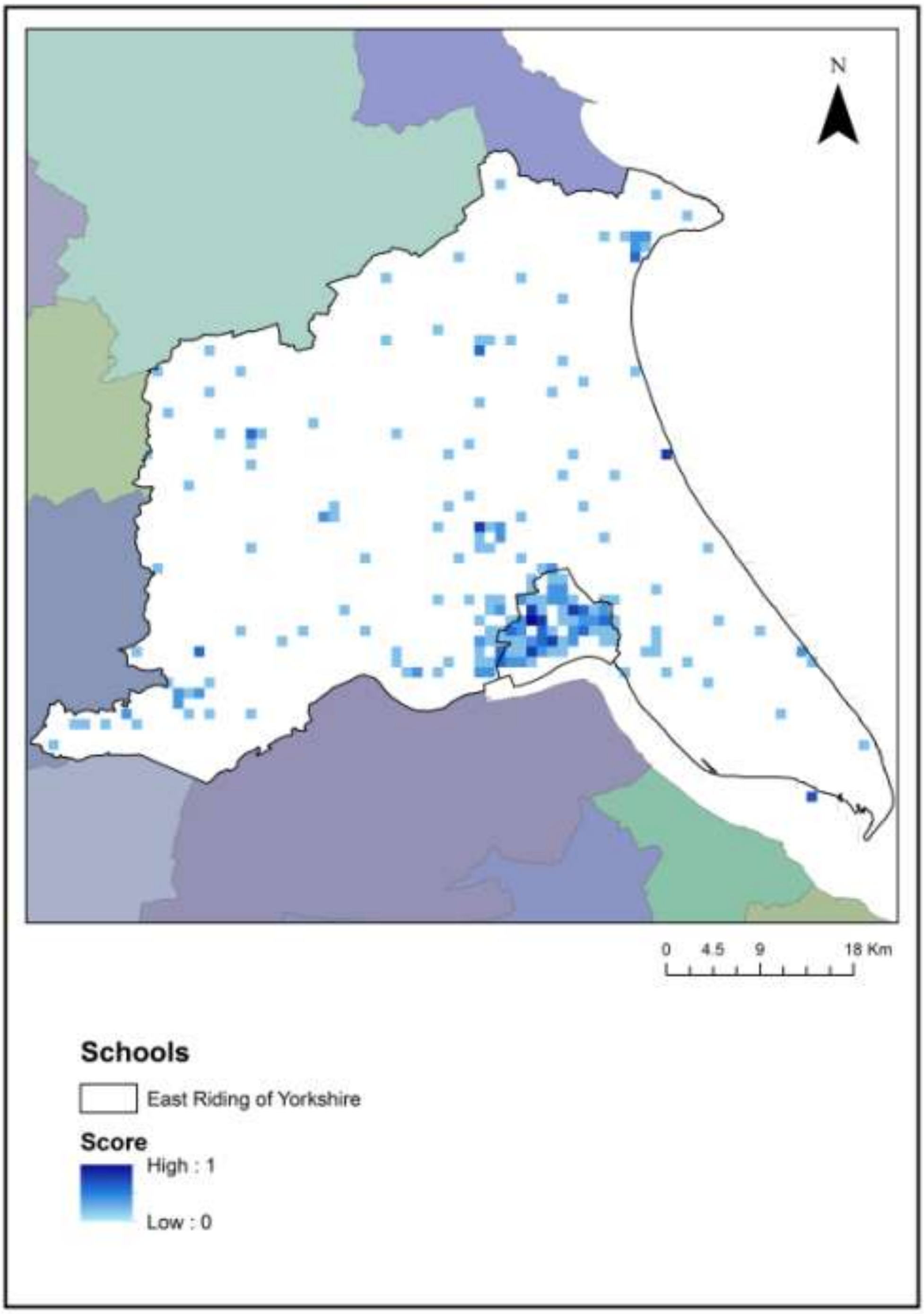


Figure 6-31: Transformed and normalised schools

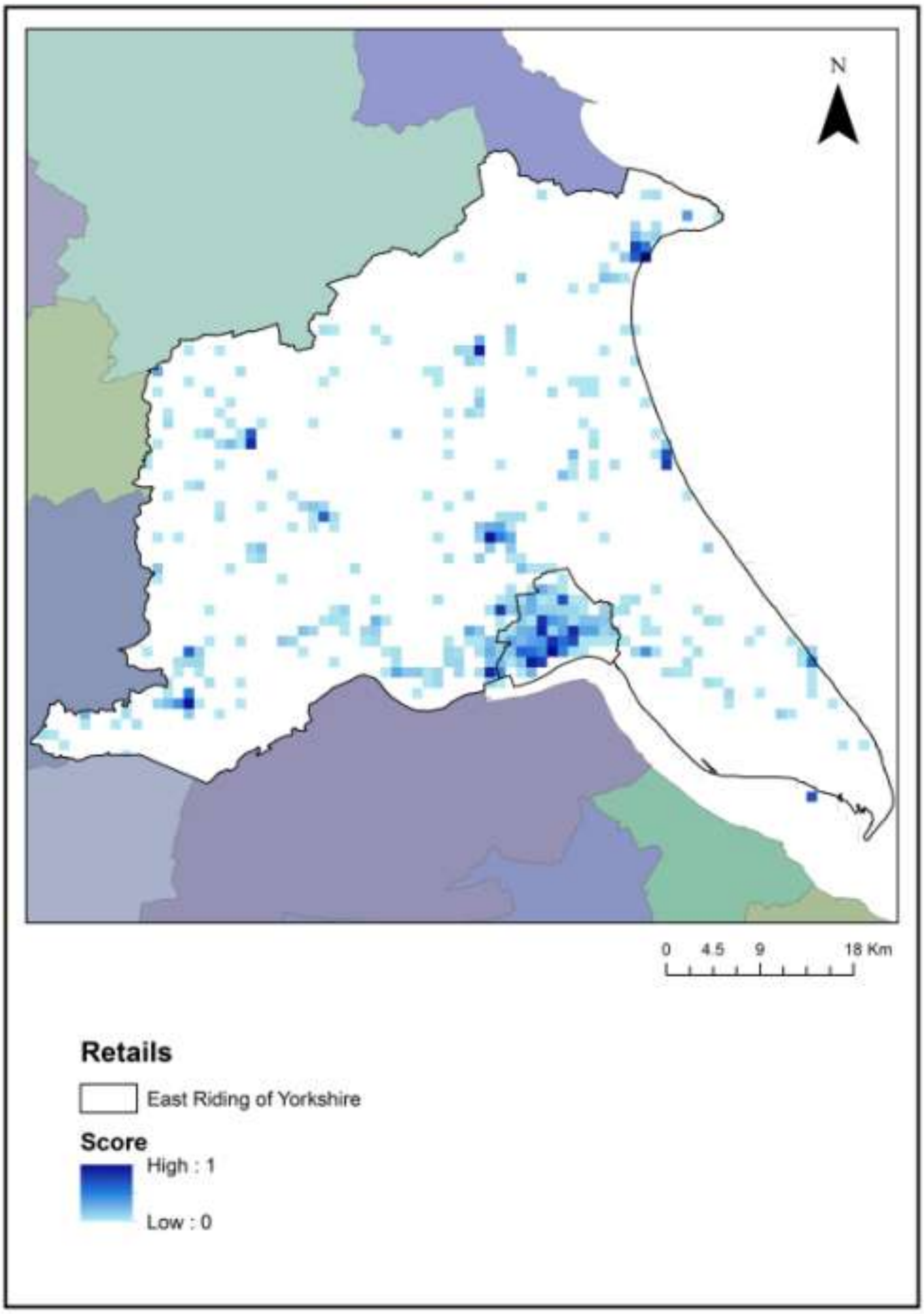


Figure 6-32: Transformed and normalised retail services

6.5.2. Data analysis

A descriptive approach has been followed to explore the vulnerability indicators of the urban sector, which means that all the statistical characteristics of indicators within and between them have been examined. This part has been structured around four vulnerability components: environmental, physical, economic, and social. For each component, firstly, tables showing the indicators' information have been set out (Table 6-3); secondly, statistical characteristics have been explored; and finally, a correlation analysis has been carried out using EViews statistical software. The correlation coefficient measures the linear relationships among the variables and is a good gauge of variables dependency. All coefficients above the threshold of r = 0.50 indicate a high correlation and are therefore assessed. The full discussion of the correlation threshold can be found in Chapter 3.

The resultant correlation coefficients are presented in the chapter on sensitivity analysis and therefore only relevant outcomes are presented here. Table 7-3 shows the correlation results for the indicators of the urban sector. From the correlation table, the following conclusions are drawn:

- The roads indicator is generally correlated with many other variables of social and physical components: physical indicators such as train stations (+0.64), construction services (+0.65), buildings (+0.87), cars (+0.58), and household lowest level (+0.61), and social indicators such as sports centres (+0.64), schools (+0.69), infrastructure (+0.77), health centres (+0.66), and population (+0.64). However, roads are an important source of help to flooded areas and therefore would not be omitted.
- Train stations are associated with other physical indicators, such as roads (+0.64), infrastructure (+0.66), construction (+0.86), and buildings (+0.62). Nevertheless, because of the importance of train stations in times of emergency, this indicator is not excluded.
- Retail is highly correlated with sports centres (+0.66), infrastructure (+0.74), health centres (+0.72), commercial services (+0.92), and accommodation/eating services (+0.83), and implicit within the other

correlated variables. Therefore, this indicator is omitted from the list of indicators.

- Buildings are linked to physical indicators such as roads (+0.87), train stations (+0.62), and construction (+0.63), and some social indicators such as sports centres (+0.62), schools (+0.69), and infrastructure (+0.74). However, buildings are an important measure of human activities and infrastructure and hence are kept in the list.
- Sports centres are a social indicator highly correlated to other social indicators – retail (+0.66), infrastructure (+0.74), health centres (+0.67), accommodation/eating services (+0.65) – and other indicators such as roads (+0.64), commercial services (+0.69), and buildings (+0.62). Since this indicator is not a primary one and has high correlation coefficients, it is removed from the list of urban indicators.
- The schools indicator is interestingly correlated with roads (+0.69) and buildings (+0.69), which indicates the position of schools in relation to roads and buildings.
- Infrastructure is another indicator which holds high correlation coefficients, with roads (+0.77), train stations (+0.66), sports centres (+0.74), retail (+0.74), health centres (+0.74), and commercial services (0.61). However, infrastructure is a key indicator of physical coping capacity and is kept.
- General health is correlated with qualifications (+0.67) and limiting long-term illness (+0.85). Since this indicator points to the same issue as LLTI it is omitted from the list of indicators.
- The population indicator has a correlation of +0.99 with household lowest level, which is aninteresting result showing the higher susceptibility of population due to living in detached houses/buildings. In addition, it has a correlation of +0.93 with cars.
- GIF is strongly correlated with flood zones (+0.79), and because they refer to the same issue, GIF has been omitted from the list of indicators.
- Health services are associated with the indicators of roads (+0.66), sports centres (+0.67), retail (+0.72), infrastructure (+0.71), commercial services

(+0.83), and accommodation/eating (+0.68). However, the indicator is kept because of its importance in providing medical services to the community.

- The commercial services indicator is correlated with sports (+0.69), retail (+0.72), health services (+0.83), and accommodation/eating services. The indicator is kept for the final aggregation because of its economic importance.

There are some other indicators with high coefficients within the correlation results which have not been mentioned here to save time. However, the most important points have been listed in the previous paragraph. Therefore, GIF has been omitted from the list of environmental indicators. In addition, retail, general health, and sports centres have been excluded from the list of social indicators.

6.5.3. Weighting and aggregation

Central to the construction of a composite indicator is the need to combine the indicators in a meaningful way, which in turn implies a decision on a specific weighting and aggregation model. The weighting and aggregation methods have been applied to the final thirty-four indicators for the urban sector as described in the methodology chapter (Chapter 3).

6.6.Results

The vulnerability index is investigated through its four components – environmental, physical, economic, and social – and its two sub-components: exposure and coping capacity. The final urban FVI is the main result of this chapter and is investigated in the final section. As the outcome of analysis, the flood vulnerability index (FVI) of the urban sector has been developed at 1 km grid resolution. In this section, the outcomes are mapped and discussed.

6.6.1. Components of vulnerability

6.6.1.1. *Environmental vulnerability index (EnVI)*

Six environmental factors of vulnerability were described and their preparation processes explained in previous sections. All indicators belong to the exposure sub-component and give rise to vulnerability. All six indicators have been remapped onto a 1 km raster grid and added together. No priority weight has been given to any of them.

The environmental vulnerability index is the resultant map illustrated in Figure 6-34. Higher vulnerability is shown as a darker green colour. In addition, Table 6-5 and Figure 6-33 show brief statistics of the environmental vulnerability index. The minimum and maximum of the index are 0 and 2.3105 respectively for 2780 grid cells. Cells generally hold low values, with a mean of 0.3143 and standard deviation of 0.2984.

Table 6-5: Summary statistics of the urban EnVI

Descriptive Statistics for the Environmental Vulnerability Index						
	Number of cases	**Range**	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
EnVI	2780	2.3105	0	2.3105	0.3143	0.2984

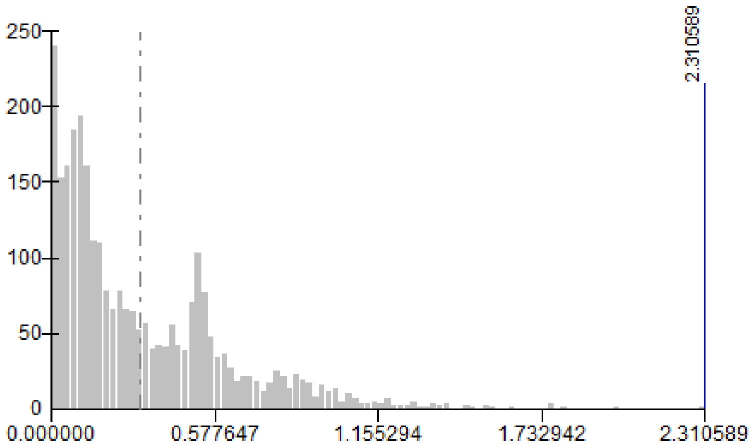


Figure 6-33: EnVI histogram of the urban sector

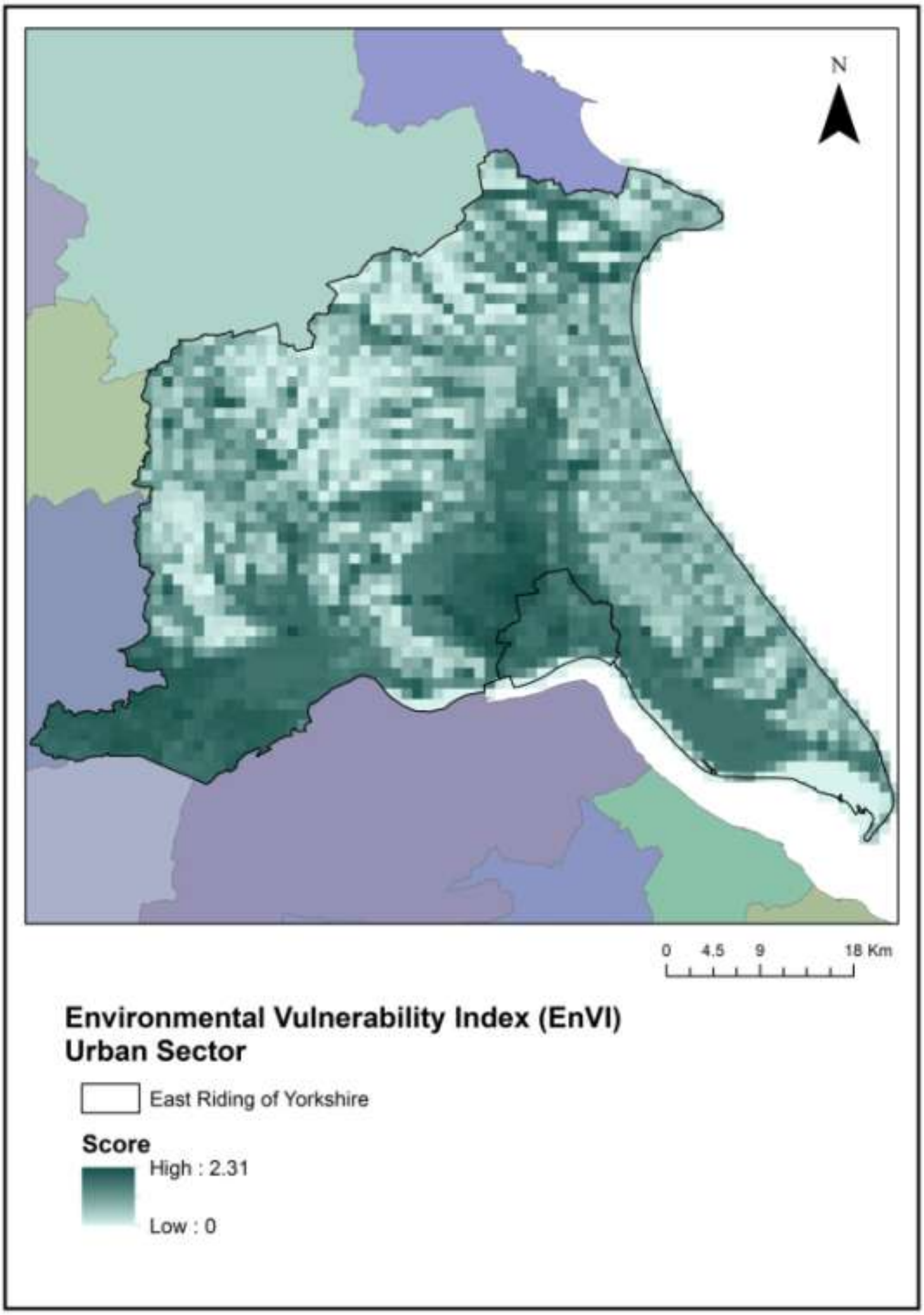


Figure 6-34: Environmental vulnerability index of the urban sector

Areas with a high environmental vulnerability index are around the River Hull, Humber Estuary, and Humberhead Levels. The Yorkshire Wolds and the eastern part of Holderness hold very low scores. This is the pattern especially seen in GIF (Geological Indicators of Flooding) and flood zones, which may indicate that these two indicators are the leading factors in shaping the environmental vulnerability index.

6.6.1.2. *Physical vulnerability index (PhVI)*

Eight indicators have been defined to measure coping capacity and exposure in relation to physical vulnerability in a built-up environment. Each indicator has been described and mapped individually and the preparation process has been explained. Table 6-6 and Figure 6-35 demonstrate the summary statistics of the PhVI. Most of the cells hold a negative value which means their coping capacity score is higher than their exposure.

Figure 6-36 shows the physical vulnerability index (PhVI) in a 1 km raster grid for the whole of the East Riding of Yorkshire. The north-west of the East Riding is particularly vulnerable owing to the rural nature of the area which means there is a lack of physical access to rescue services. Cells around large cities and built-up areas, especially the City of Kingston upon Hull, are less vulnerable.

Table 6-6: Summary statistics of the urban PhVI

Descriptive Statistics for the Physical Vulnerability Index						
	Number of cases	**Range**	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
EnVI	2780	2.3105	0	2.3105	0.3143	0.2984

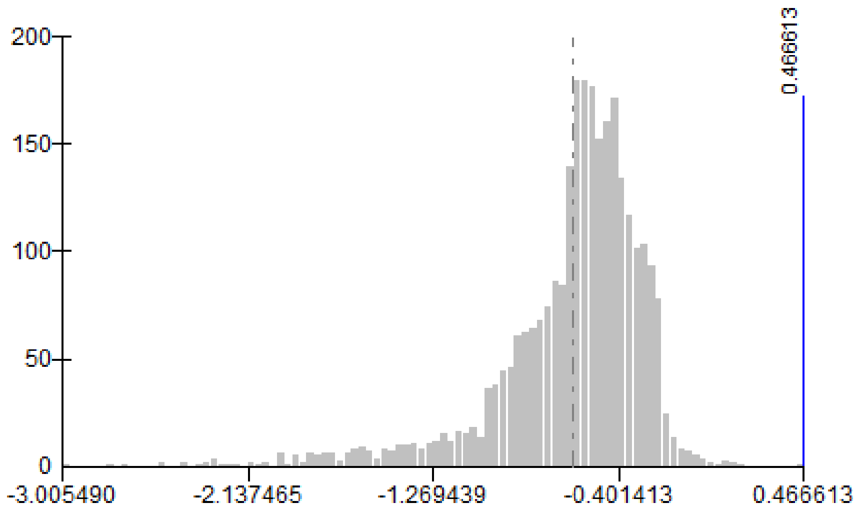


Figure 6-35: PhVI histogram of the urban sector

6.6.1.3. Economic vulnerability index (EcVI)

For economic vulnerability, seven factors have been chosen to describe the characteristics of this component. The exposure factors in this component show the distribution of economically important assets. Table 6-7 and Figure 6-37 give a brief report on the EcVI statistics. There are both positive scores (i.e. where exposure value is higher than coping capacity) and negative scores (i.e. where coping capacity value is higher than exposure).

Figure 6-38 shows EcVI scores within the East Riding of Yorkshire. The areas of high or low cells are distributed over the area and pose the shape of output areas which are the base polygons for the census data. The index is especially high in the City of Kingston upon Hull.

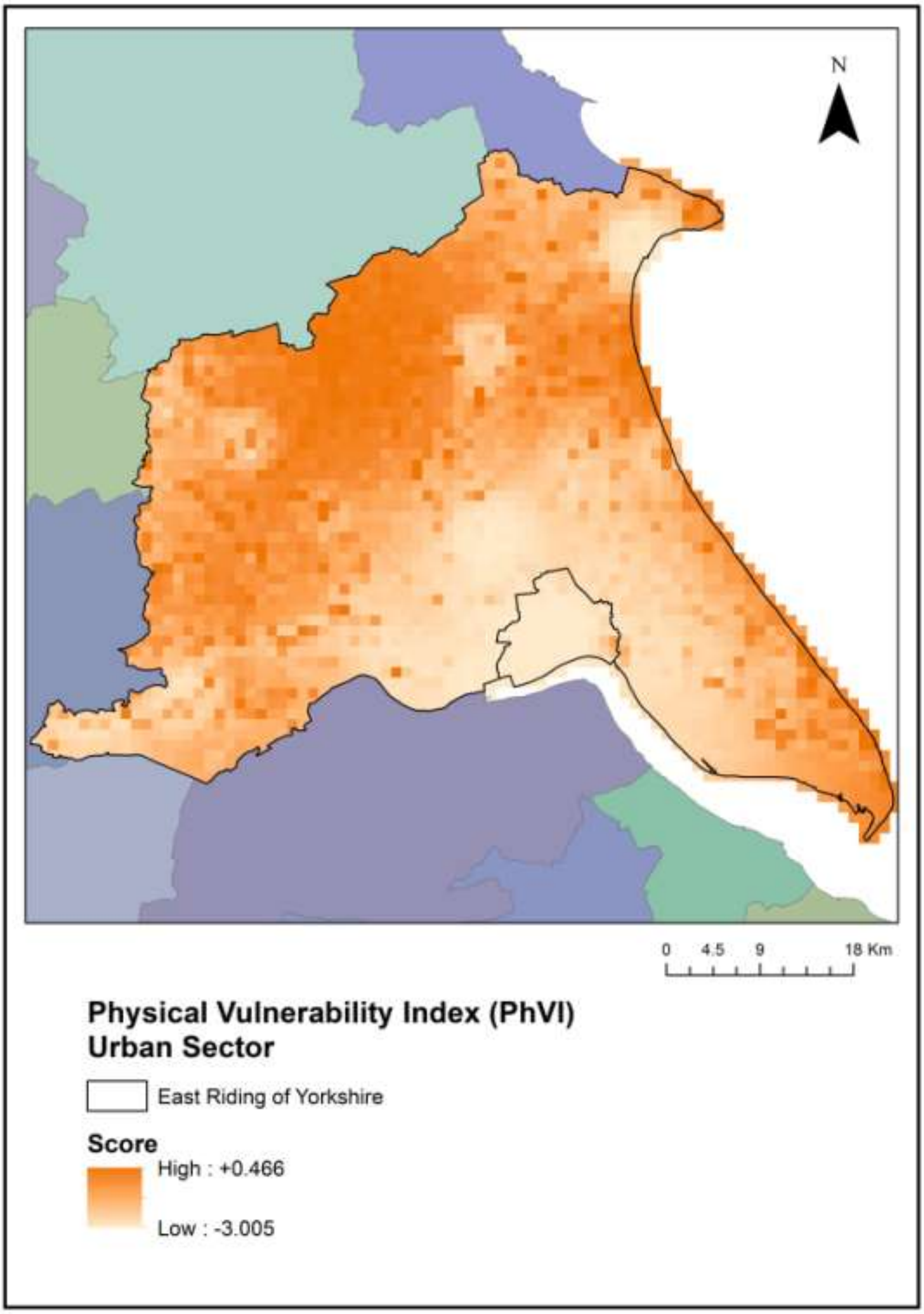


Figure 6-36: Physical vulnerability index of the urban sector

Table 6-7: Summary statistics of the urban EcVI

Descriptive Statistics for the Economic Vulnerability Index						
	Number of cases	Range	Minimum	Maximum	Mean	Standard deviation
EnVI	2780	3.2997	-1.2261	2.0736	-0.5337	0.3715

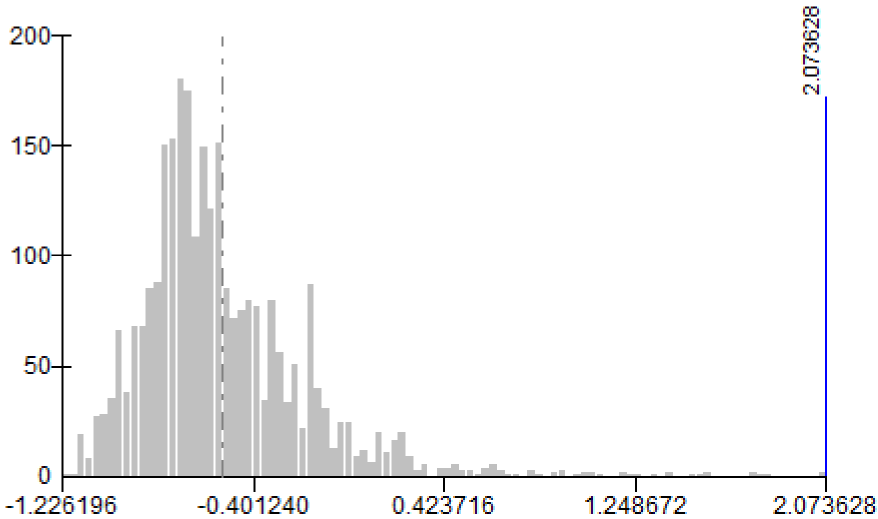


Figure 6-37: EcVI histogram of the urban sector

6.6.1.4. Social vulnerability index (SoVI)

13 indicators were identified for social vulnerability in the urbanised sector. Social factors consider people's life, health, amenity, and community. Indicators from diverse institutions and in different formats were transferred into 1 km grid cells. All values have been normalised within the East Riding of Yorkshire.

As the summary statistics for the social vulnerability index demonstrate, all values are positive, which means the sum of the exposure factors exceeds the sum of the coping capacity factors (Table 6-8 and Figure 6-39). The value distribution shows a Gaussian curve with a mean of 2.7417 and standard deviation of 0.3449.

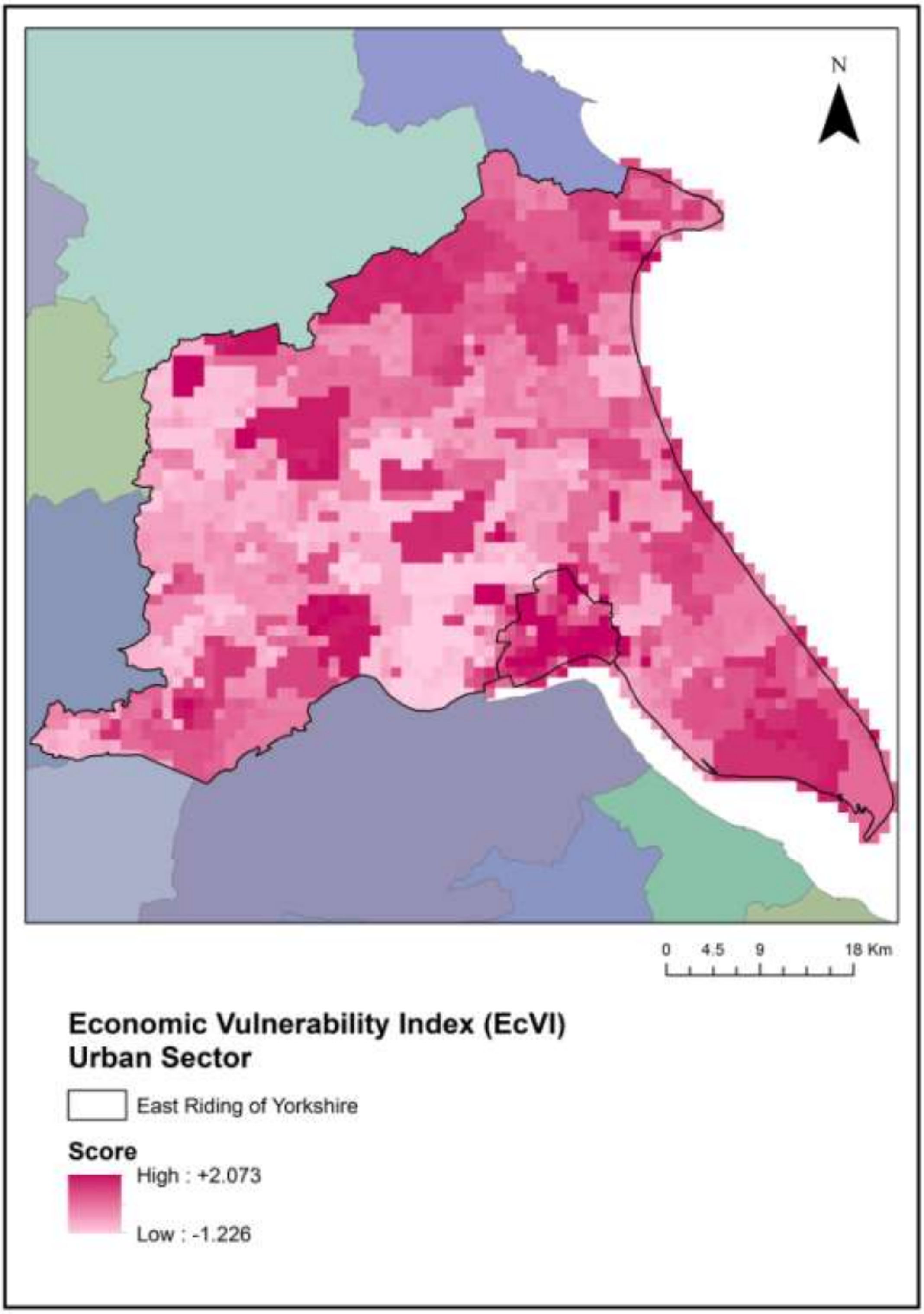


Figure 6-38: Economic vulnerability index of the urban sector

Figure 6-40 shows the SoVI within the East Riding of Yorkshire. Despite the high level of economic vulnerability in the City of Kingston upon Hull, there is not a general picture of high vulnerability in the area. Bridlington, Driffield, and Kingston upon Hull are the three most noticeable areas of cells with high SVI scores. There is not a noticeable pattern of clustering of hot or cold spots within the area.

Table 6-8: Summary statistics of the urban SoVI

Descriptive Statistics for the Social Vulnerability Index						
	Number of cases	Range	Minimum	Maximum	Mean	Standard deviation
EnVI	2780	3.2997	0	5.0849	2.7417	0.3449

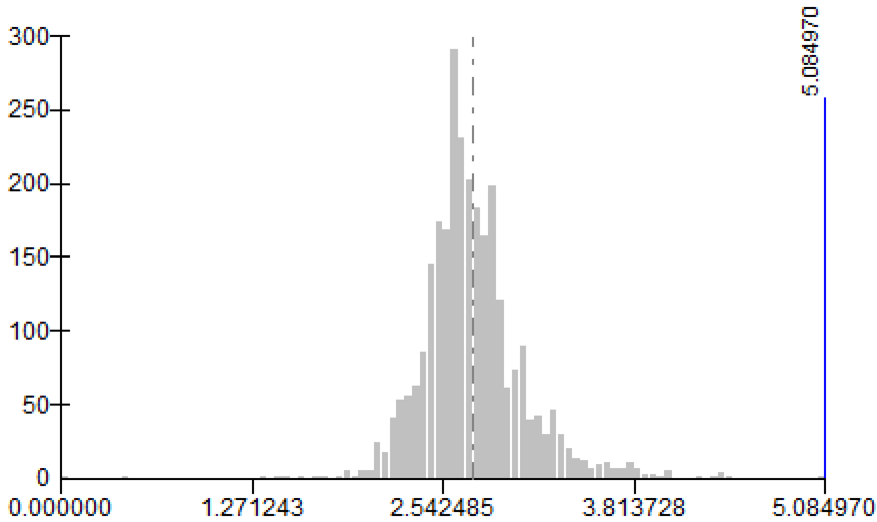


Figure 6-39: SoVI histogram of the urban sector

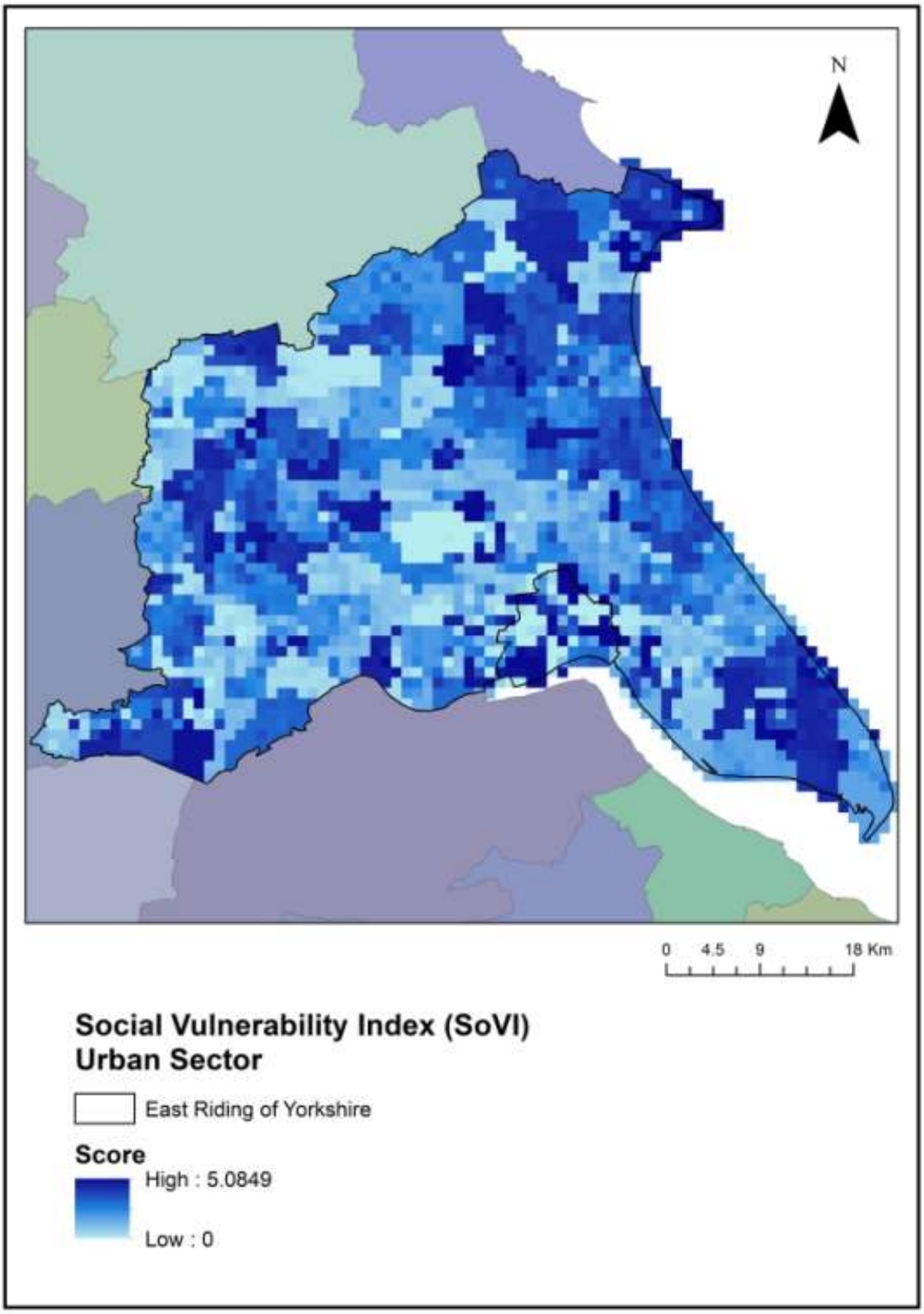


Figure 6-40: Social vulnerability index of the urban sector

6.6.2. Sub-components of vulnerability

6.6.2.1. Exposure/susceptibility

In addition to the components of vulnerability (i.e. environmental, physical, economic, and social), sub-components could be considered in order to evaluate vulnerability. This method could achieve some interesting results.

Exposure variables from the environmental, physical, economic, and social components are put together in order to obtain the overall exposure score. From a total of twenty-four exposure variables, only three are from the physical component; the environment component contributes six variables, while economic and social have five and ten respectively.

Figure 6-41 demonstrates the exposure scores within the East Riding of Yorkshire. Cells with high scores are mostly located around highly populated areas such as the City of Kingston upon Hull, Goole, and Bridlington.

6.6.2.2. Coping capacity

Figure 6-43 shows the coping capacity index in the area. Out of the ten coping capacity factors, there is no variable from the environmental component; five coping capacity indicators are from the physical component and three are social coping capacities. The area surrounding the City of Kingston upon Hull is noticeably high in the coping capacity index because of the proximity to the large centres of rescue services and facilities. The western part of the East Riding holds high values as well, which is due to its proximity to the City of York.

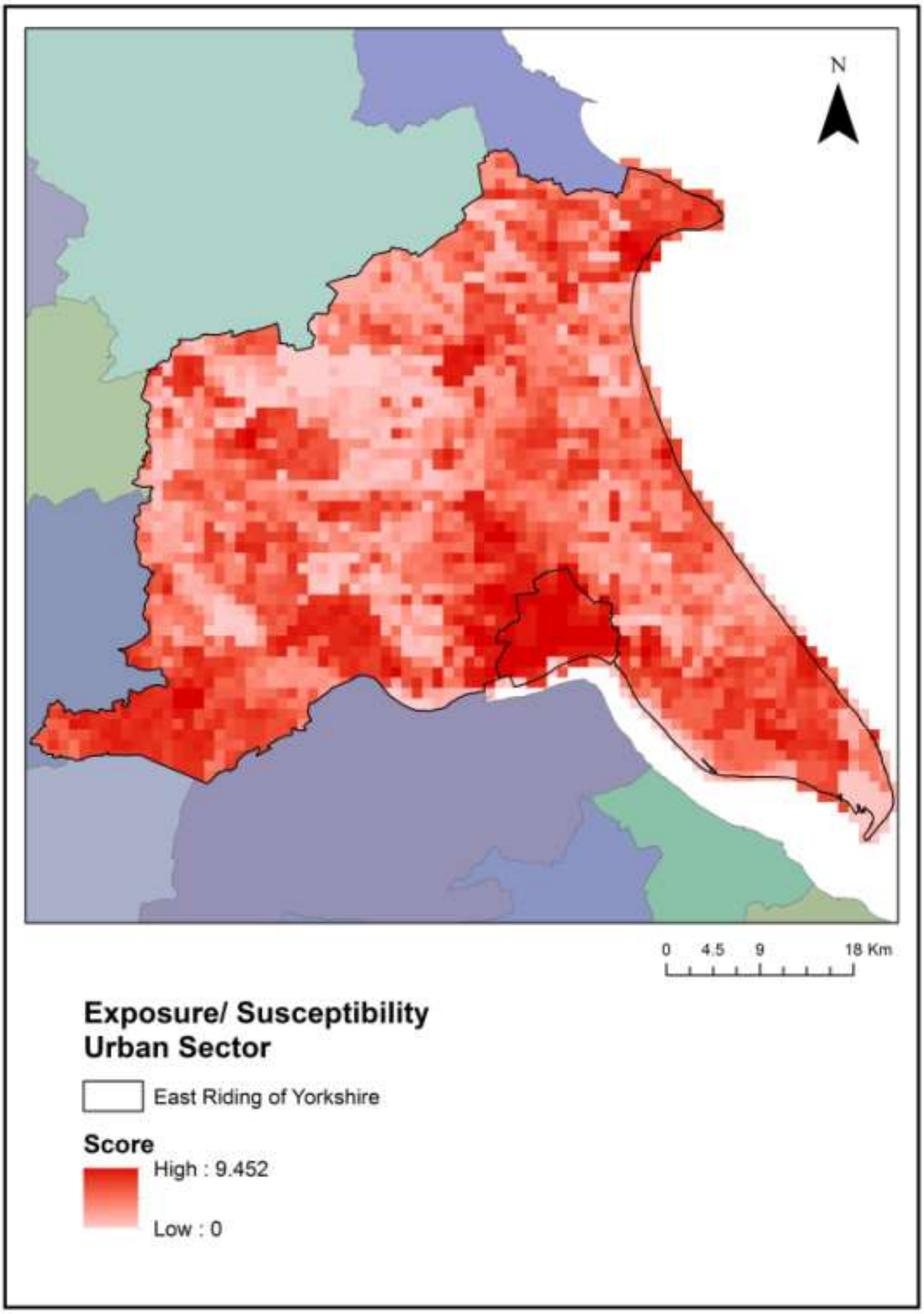


Figure 6-41: Exposure/susceptibility index of the urban sector

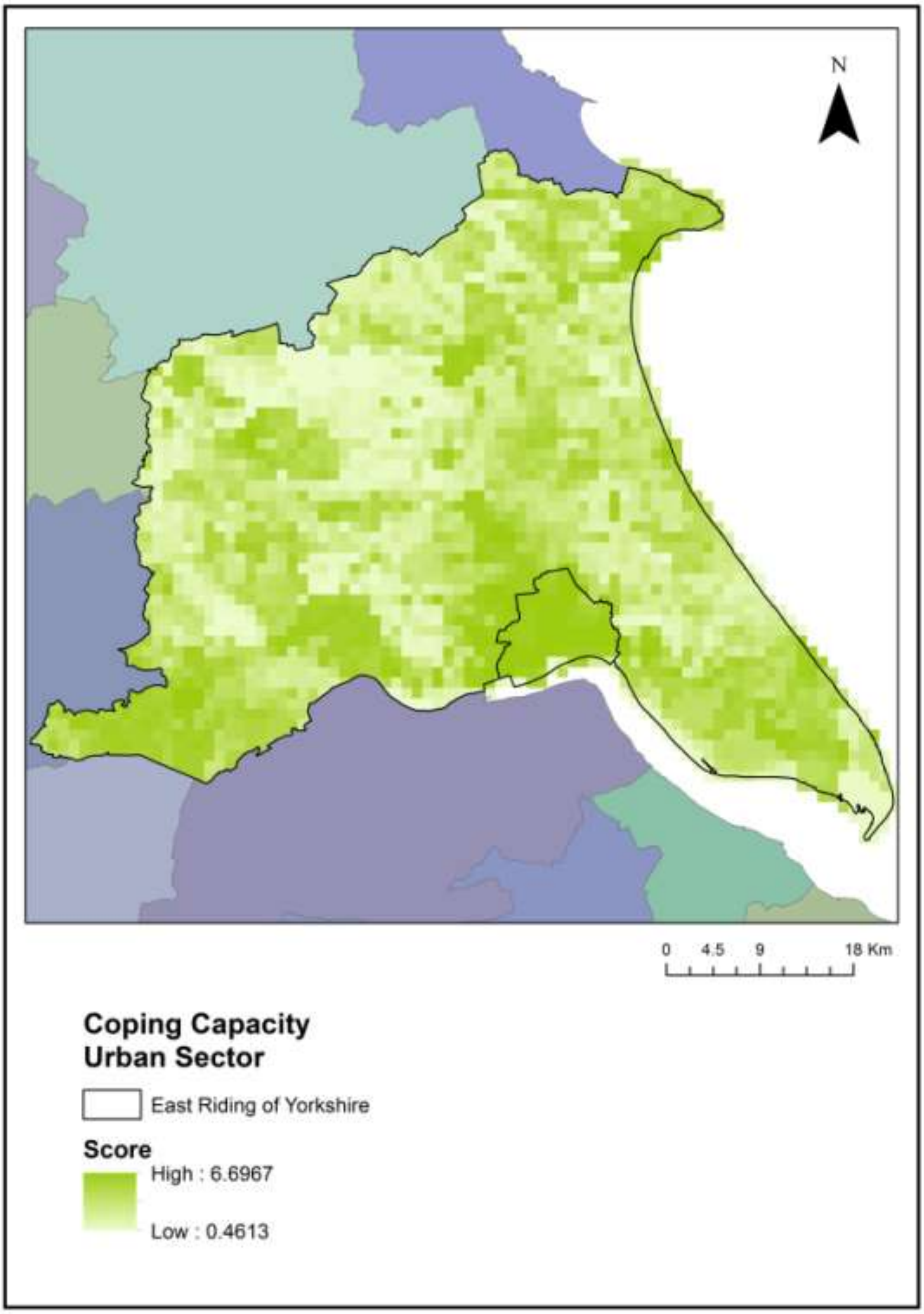


Figure 6-42: Coping capacity index of the urban sector

6.6.3. Flood vulnerability index (FVI)

Thirty-four indicators were identified in order to evaluate flood vulnerability within the East Riding of Yorkshire, based on the extensive literature on flood vulnerability assessment in urbanised land. Table 6-9 and Figure 6-43 show the statistics of the flood vulnerability index (FVI). These are places where the exposure index is less than the coping capacity and therefore the FVI is negative. The histogram of the FVI values shows a Gaussian curve with a mean of 1.9032 and standard deviation of 0.64. Blue lines symbolise the boundaries of FVI classes in Figure 6-45.

Table 6-9: Summary statistics of the urban FVI

Descriptive Statistics for the Social Vulnerability Index						
	Number of cases	**Range**	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
EnVI	2780	7.3686	-1.7812	5.5874	1.9032	0.64

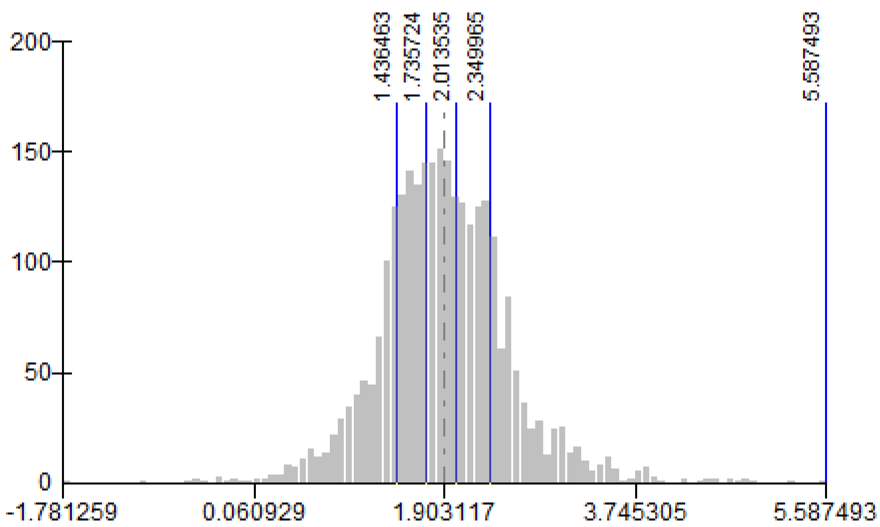


Figure 6-43: Histogram of the flood vulnerability index of the urban sector (FVI)

FVI scores are displayed in graduated colour and with no classification in Figure 6-44, which is a useful tool for showing the progression of the FVI throughout the region. However, for a better visualisation, five classes (i.e. very low, low, moderate, high, and very high) have been proposed and cells were assigned to them using the Quartile classification method.

The city of Goole and its surroundings have a very high to high level of vulnerability. In addition, the northern area from Driffield to Bridlington, the area south of Withernsea, the Pocklington area, and some cells within the City of Kingston upon Hull show high levels of vulnerability. The central East Riding has generally low to moderate vulnerability, which is due to its proximity to the large city of Kingston upon Hull. The distribution of cells with very high vulnerability can reveal the underlying reasons of vulnerability. For example, three cells at the heart of Beverley are very vulnerable whereas the surrounding area is less vulnerable.

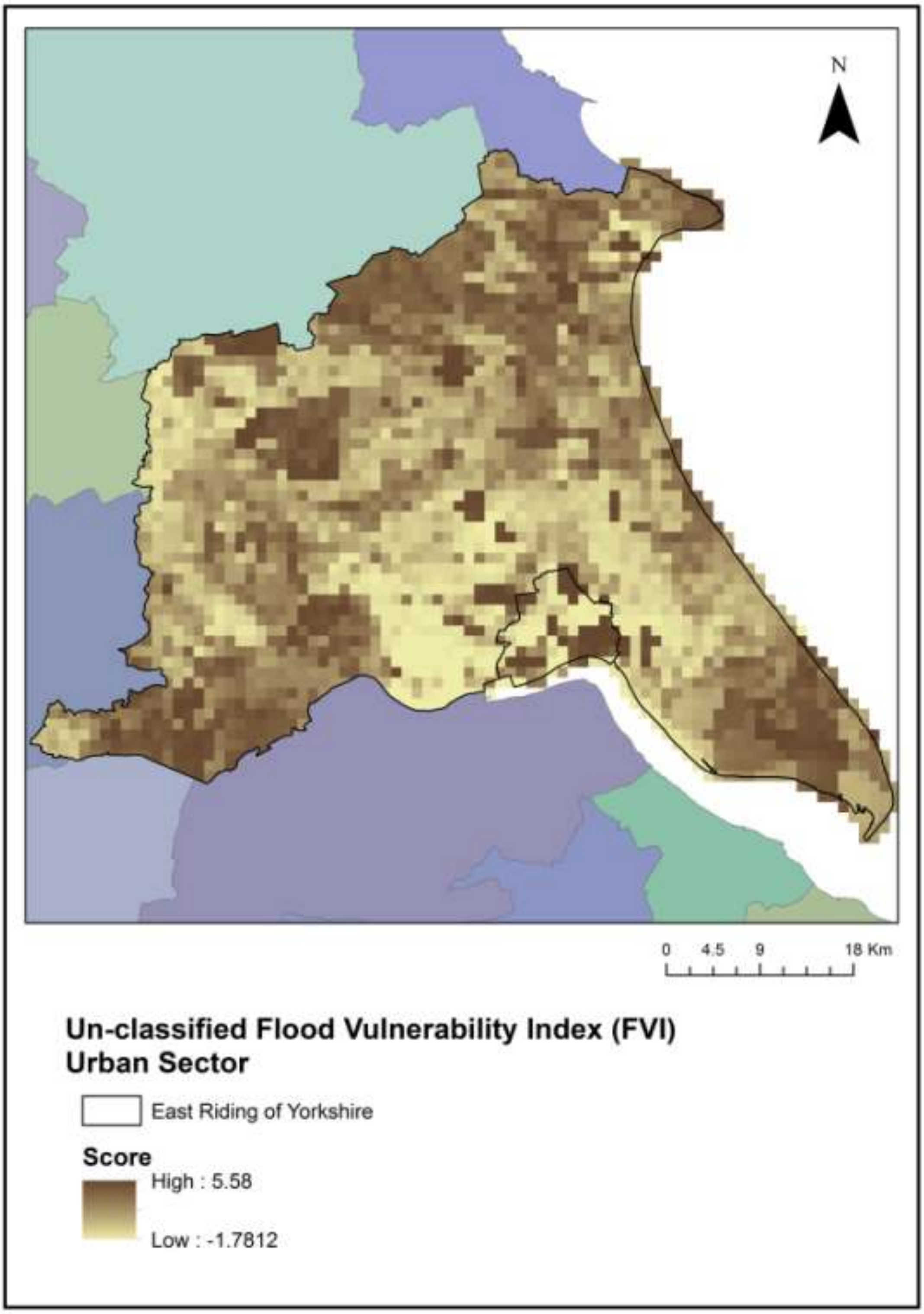


Figure 6-44: Unclassified FVI of the urban sector

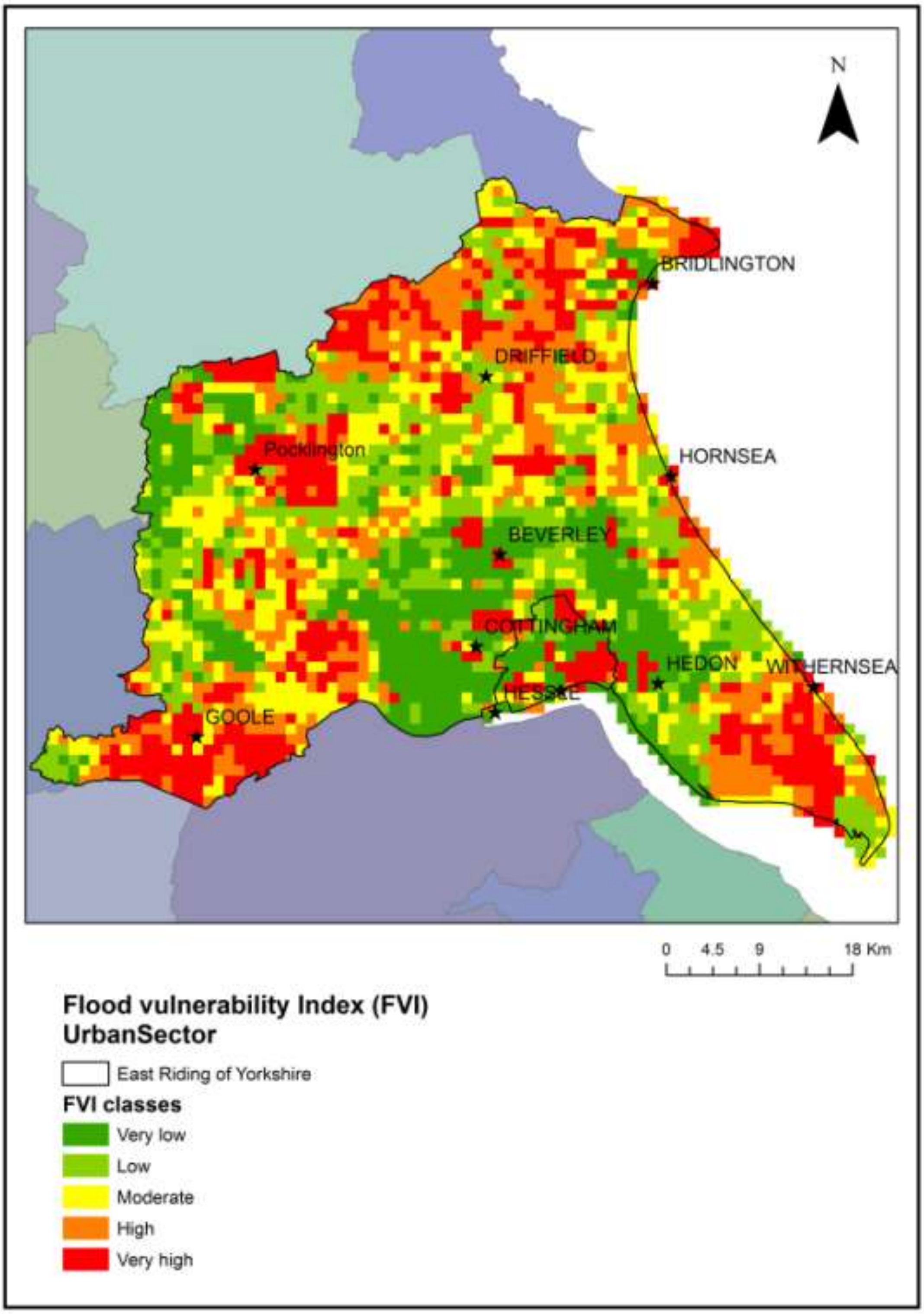


Figure 6-45: FVI classes of the urban sector

6.7.Conclusion

The vulnerability of the urban environment to flooding is one of the most frequently visited subjects in the field of flood management. A brief background about the importance of flood vulnerability assessment in an urban context was put forward in part 6-2, followed by a long list of vulnerability indicators developed by researchers. Overall, thirty-eight indicators were selected for the purpose of this study based on the criteria proposed by Birkmann. According to the statistics and characteristics of the variables, appropriate methods were applied to transfer them into 1 km grid cells. Minimum/maximum normalisation methods were used to project the values into a uniform range. Furthermore, the correlation analysis was carried out to investigate the relationships among the indicators. The results led to the exclusion of four indicators: the GIF indicator from the environmental components, and general health, sports centres, and retail from the social components. The final thirty-four indicators were mapped and discussed through the components and sub-components of vulnerability. The following conclusions were drawn:

- Environmental vulnerability presented by six indicators shows high scores at the Humberhead Levels, the bed of the River Hull, and the Humber Estuary.
- With eight physical vulnerability indicators, the scores of PhVI demonstrate that the north-east of the East Riding is noticeably high in terms of flood vulnerability. In addition, the area surrounding Kingston upon Hull is considerably low in phVI.
- Seven factors of economic vulnerability form the final EcVI of the urban sector. The cells with high scores are distributed throughout the area and no clear pattern could be recognised.
- The social component holds thirteen indicators and plays an important role in shaping the final FVI of the area. However, owing to the number of variables and the various formats from which they are derived, no significant pattern could be distinguished.
- Twenty-four variables were used to describe the exposure of the community to the impacts of flooding. Despite the diffused distribution of highly vulnerable

cells, the southern edge of the East Riding shows greater exposure and susceptibility to flooding.

- Overall, ten variables for the urban sector demonstrate the level of coping resources of the community in the event of flooding. The map shows a relatively higher level around large cities, especially Kingston and Goole.

The final FVI is a valuable tool in the investigation of vulnerability throughout the East Riding of Yorkshire (Figure 6-45). The classification of variables into components and sub-components makes it possible to understand the underlying reasons for high or low vulnerability.

Two cells from the north-east of the City of Kingston upon Hull have been selected from two extreme classes of vulnerability (very low and very high) to explore the characteristics of the FVI. Figure 6-46 shows the properties of the two cells. It is possible that the reason for the higher index of the top cell is high social exposure. In addition, the coping capacity index is much higher for the bottom cell than for the top one.

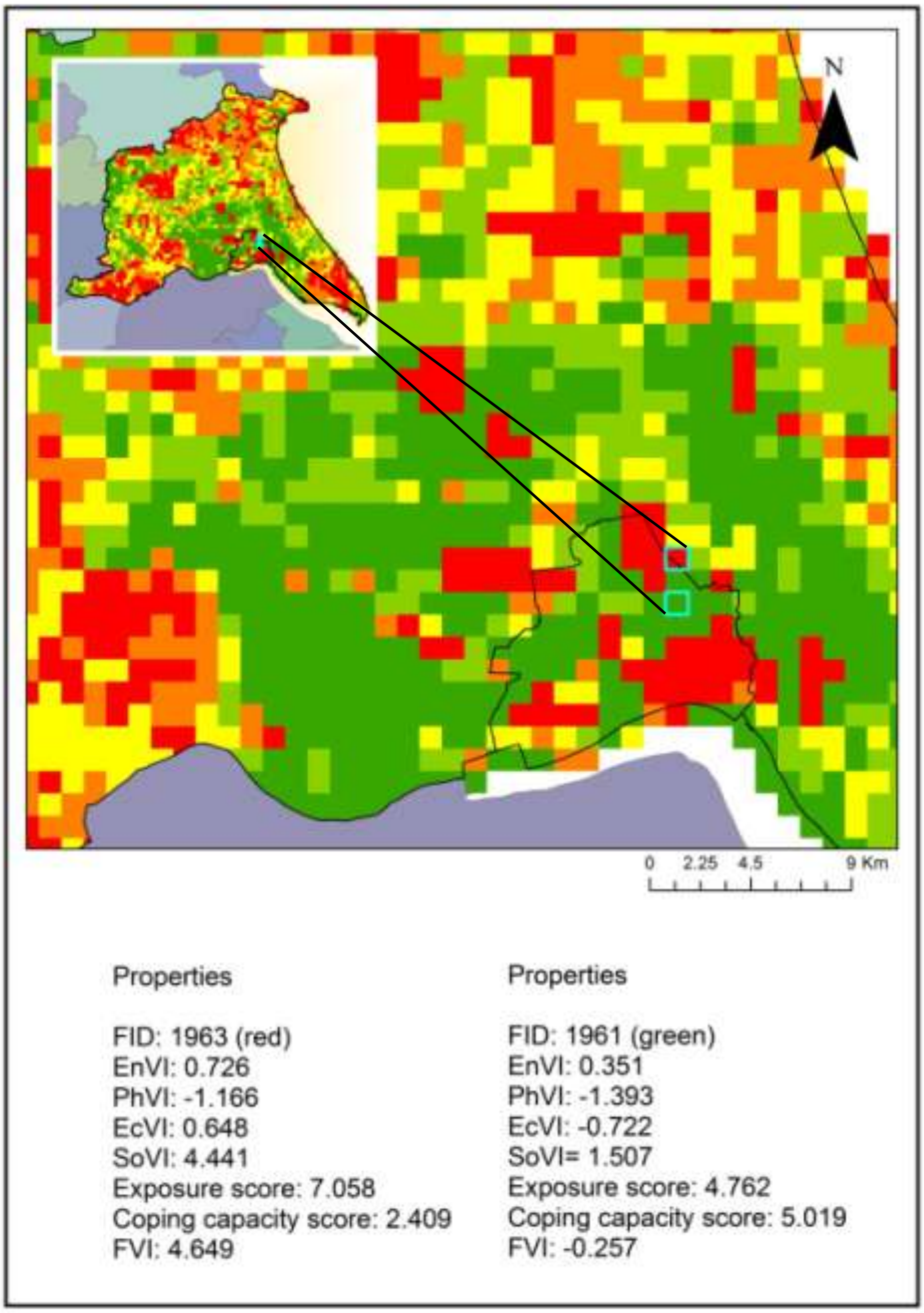


Figure 6-46: Comparison of two grid cells holding different vulnerability classes in terms of indices components and sub-components

7. Sensitivity analysis

7.1.Introduction

Composite indicators may convey a misleading or inappropriate message if they are poorly designed or interpreted. In addition, the construction of composite indicators has always been a matter of debate because it involves critical decision making at many stages. All these issues arise from many sources of uncertainty in the making of a composite indicator:

- development of components of vulnerability
- selection of indicators
- data quality
- data preparation
- data normalisation
- weighting scheme
- method of indicator integration.

Two combined tests have been considered for the evaluation of the issues mentioned: a robustness test and sensitivity analysis. The following sections investigate the robustness and sensitivity of the original composite flood vulnerability index (FVI) for each sector (i.e. arable, wildlife, and urban areas). The sensitivity of the composite index shows its flexibility in terms of any change in the input data or method, and therefore measures the reliability of the output for decision making. In addition, throughout the process, any superfluous variables would be identified.

7.2.Methodology

Sensitivity analysis is a technique which examines to what extent a dependent variable relies on a set of independent variables and information fed into it. In other words, it examines how the variations of the input variables affect the output results of the composite indicator both qualitatively and quantitatively. It is a way of forecasting the outcome of a decision if the situation turns out to be different in relation to the key indicators.

For the purpose of sensitivity analysis, three tests are employed. Firstly, an investigation is made into the relationship between variables and FVI through scatter plots and correlation results. Secondly, principal component analysis (PCA) is run for the outcomes of the FVI. Thirdly, the sensitivity of the original model of vulnerability (FVI) is examined by (a) variable omission, (b) weighting formula and (c) change in data values.

7.2.1. Correlation analysis

In this section, the relationship between the final FVI and the input variables in the three strata of vulnerability are put forward. Before we begin sensitivity analysis, it would be beneficial to see the connections between FVI and its inputs. In addition, the scatter plot of variables versus FVI can visually help the reader to understand the interrelationships between the two.

In terms of correlation analysis, setting a threshold for significant coefficients is critical. According to the correlation tables presented in many statistical books, when the sample size grows, the Pearson value (significance threshold) gets smaller (Rogerson 2001, Ebdon 1985). In the case of raster data, as in this study, the sample size gets much higher (maximum sample size in the tables is 1000, whereas this work's sample size is 2780), and hence the significance level descends to zero. As a result, any coefficient higher than zero is significant and needs to be investigated in advance.

7.2.1.1. Arable sector

The correlation results of the arable sector are provided in Table 7-1. There is much information that can be derived from the correlation analysis. For instance, it is noticeable that:

- the train station locations (TRN) are highly and positively correlated with roads (ROAD) (+0.64), construction services (CONS) (+0.86), and rescue services (RESC) (+0.47)

- the rescue services indicator is negatively correlated with farm locations (FARM) (-0.37) and the Defra livestock report (DFR) (-0.36).

It is worth mentioning that, although the mentioned coefficients are high, they do not lead to the exclusion of the variable.

Table 7-1: The correlation results for the arable sector

	AGWR	CONS	CL	FARM	LFS	PI	RESC	PRB	ROAD	SPZ	SWF	TRN	ALC	DFR	FZ
AGWR	1	0.44	0.04	-0.09	-0.02	0.18	0.16	-0.06	0.52	0.05	-0.03	0.37	-0.20	-0.15	0.04
CONS	0.44	1	0.10	-0.09	0.07	0.33	0.37	-0.18	0.65	0.24	-0.04	0.86	-0.26	-0.32	0.18
CL	0.04	0.10	1	-0.02	-0.01	0.02	0.04	-0.01	0.04	0.00	0.02	0.06	-0.02	-0.03	0.01
FARM	-0.09	-0.09	-0.02	1	0.05	-0.03	-0.37	0.38	-0.09	-0.01	0.27	-0.21	0.31	0.11	-0.20
LFS	-0.02	0.07	-0.01	0.05	1	0.19	0.05	0.04	0.02	0.07	0.02	0.03	0.01	-0.02	-0.02
PI	0.18	0.33	0.02	-0.03	0.19	1	0.18	-0.10	0.34	0.08	-0.03	0.34	-0.14	-0.09	0.12
RESC	0.16	0.37	0.04	-0.37	0.05	0.18	1	-0.36	0.33	0.31	-0.14	0.47	-0.06	-0.36	0.32
PRB	-0.06	-0.18	-0.01	0.38	0.04	-0.10	-0.36	1	-0.07	0.14	0.18	-0.25	0.29	0.24	-0.48
ROAD	0.52	0.65	0.04	-0.09	0.02	0.34	0.33	-0.07	1	0.15	0.02	0.64	-0.21	-0.19	0.14
SPZ	0.05	0.24	0.00	-0.01	0.07	0.08	0.31	0.14	0.15	1	0.02	0.13	0.11	-0.17	0.00
SWF	-0.03	-0.04	0.02	0.27	0.02	-0.03	-0.14	0.18	0.02	0.02	1	-0.12	0.15	0.11	-0.24
TRN	0.37	0.86	0.06	-0.21	0.03	0.34	0.47	-0.25	0.64	0.13	-0.12	1	-0.31	-0.33	0.24
ALC	-0.20	-0.26	-0.02	0.31	0.01	-0.14	-0.06	0.29	-0.21	0.11	0.15	-0.31	1	0.06	0.10
DFR	-0.15	-0.32	-0.03	0.11	-0.02	-0.09	-0.36	0.24	-0.19	-0.17	0.11	-0.33	0.06	1	-0.27
FZ	0.04	0.18	0.01	-0.20	-0.02	0.12	0.32	-0.48	0.14	0.00	-0.24	0.24	0.10	-0.27	1

The other instrument used in this analysis for data investigation is the scatter plot of input variables against final FVI. As illustrated in Figure 7-1, the variables of construction services (CONS), permeability (PRB), rescue services (RESC), roads (ROAD), train stations (TRN), agricultural workers (AGWR), and pollution incidents (PI) have regression lines with a negative gradient. The negative gradient of the first five indicators is concurrent with the initial assumption that they should be placed in the coping capacity sub-indicator. However, the last two variables were assumed to be exposure/susceptibility factors, but turned out to have a negative effect in the final FVI. This result is an interesting matter of discussion, where for example the indicator of agricultural workers might be assigned as a coping capacity factor.

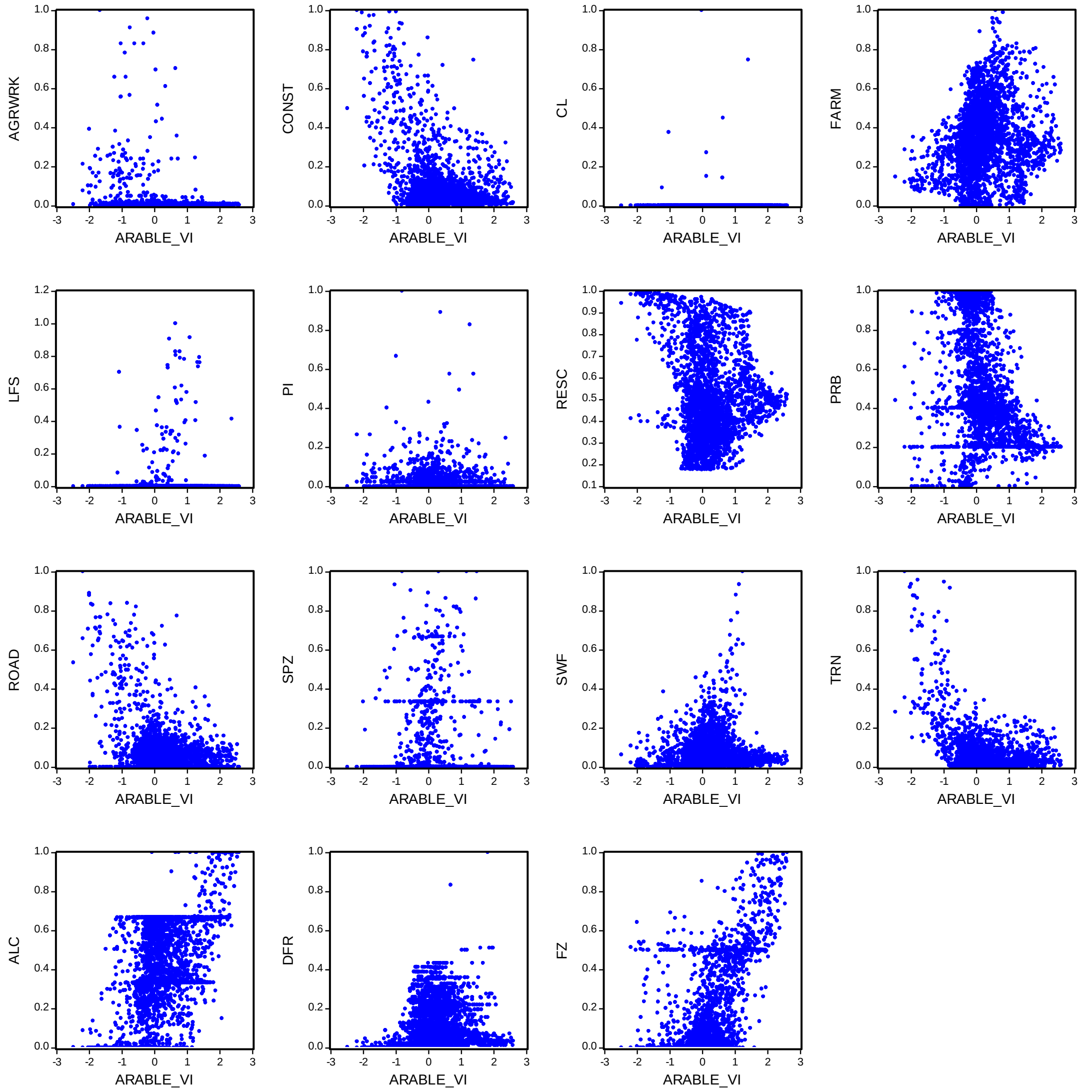


Figure7-1: The scatter plot of FVI against 15 input variables for the arable sector

7.2.1.2. Wildlife sector

Correlation analysis can improve our understanding of the interrelationships among the data sets which in turn support a better interpretation of data. The correlation analysis is demonstrated in Table 7-2, where there are fifteen indicators from all components of the vulnerability index. There are some interesting outcomes in the results:

- Pollution incidents (PI) are positively correlated with roads (ROAD) (+0.34) and train stations (TRN) (+0.34).
- The protected areas (PA) variable shows very low correlation with any other variable (-0.01 to +0.1).
- Flood zones (FZ) and permeability of the surface (PRB) show a negative coefficient (-0.48).
- Roads (ROAD) generally show a relatively high positive coefficient with factors related to human activity such as train stations (TRN) (+ 0.64), construction services (CONS) (+0.65), pollution incidents (PI) (+0.34), and forestry workers (FRWR) (+0.52).

Table 7-2: The correlation results for the wildlife sector

	FRST	ROAD	SWF	TRN	RESC	CONS	PI	PRB	LFS	PA	SPZ	FZ	FRWR	FLA	CL
FRST	1	-0.14	-0.17	0.10	0.13	0.03	-0.02	-0.22	0.00	0.21	-0.07	-0.01	-0.02	0.17	-0.02
ROAD	-0.14	1	0.02	0.64	0.33	0.65	0.34	-0.07	0.02	-0.16	0.15	0.14	0.52	-0.05	0.04
SWF	-0.17	0.02	1	-0.12	-0.14	-0.04	-0.03	0.18	0.02	-0.02	0.02	-0.24	-0.03	0.01	0.02
TRN	0.10	0.64	-0.12	1	0.47	0.86	0.34	-0.25	0.03	-0.13	0.13	0.24	0.37	-0.05	0.06
RESC	0.13	0.33	-0.14	0.47	1	0.37	0.18	-0.36	0.05	-0.16	0.31	0.32	0.16	-0.12	0.04
CONS	0.03	0.65	-0.04	0.86	0.37	1	0.33	-0.18	0.07	-0.14	0.24	0.18	0.44	-0.07	0.10
PI	-0.02	0.34	-0.03	0.34	0.18	0.33	1	-0.10	0.19	-0.04	0.08	0.12	0.18	-0.04	0.02
PRB	-0.22	-0.07	0.18	-0.25	-0.36	-0.18	-0.10	1	0.04	0.19	0.14	-0.48	-0.06	0.15	-0.01
LFS	0.00	0.02	0.02	0.03	0.05	0.07	0.19	0.04	1	-0.02	0.07	-0.02	-0.02	-0.01	-0.01
PA	0.21	-0.16	-0.02	-0.13	-0.16	-0.14	-0.04	0.19	-0.02	1	-0.09	0.08	-0.10	0.21	0.02
SPZ	-0.07	0.15	0.02	0.13	0.31	0.24	0.08	0.14	0.07	-0.09	1	0.00	0.05	-0.05	0.00
FZ	-0.01	0.14	-0.24	0.24	0.32	0.18	0.12	-0.48	-0.02	0.08	0.00	1	0.04	-0.09	0.01
FRWR	-0.02	0.52	-0.03	0.37	0.16	0.44	0.18	-0.06	-0.02	-0.10	0.05	0.04	1	-0.03	0.04
FLA	0.17	-0.05	0.01	-0.05	-0.12	-0.07	-0.04	0.15	-0.01	0.21	-0.05	-0.09	-0.03	1	-0.01
CL	-0.02	0.04	0.02	0.06	0.04	0.10	0.02	-0.01	-0.01	0.02	0.00	0.01	0.04	-0.01	1

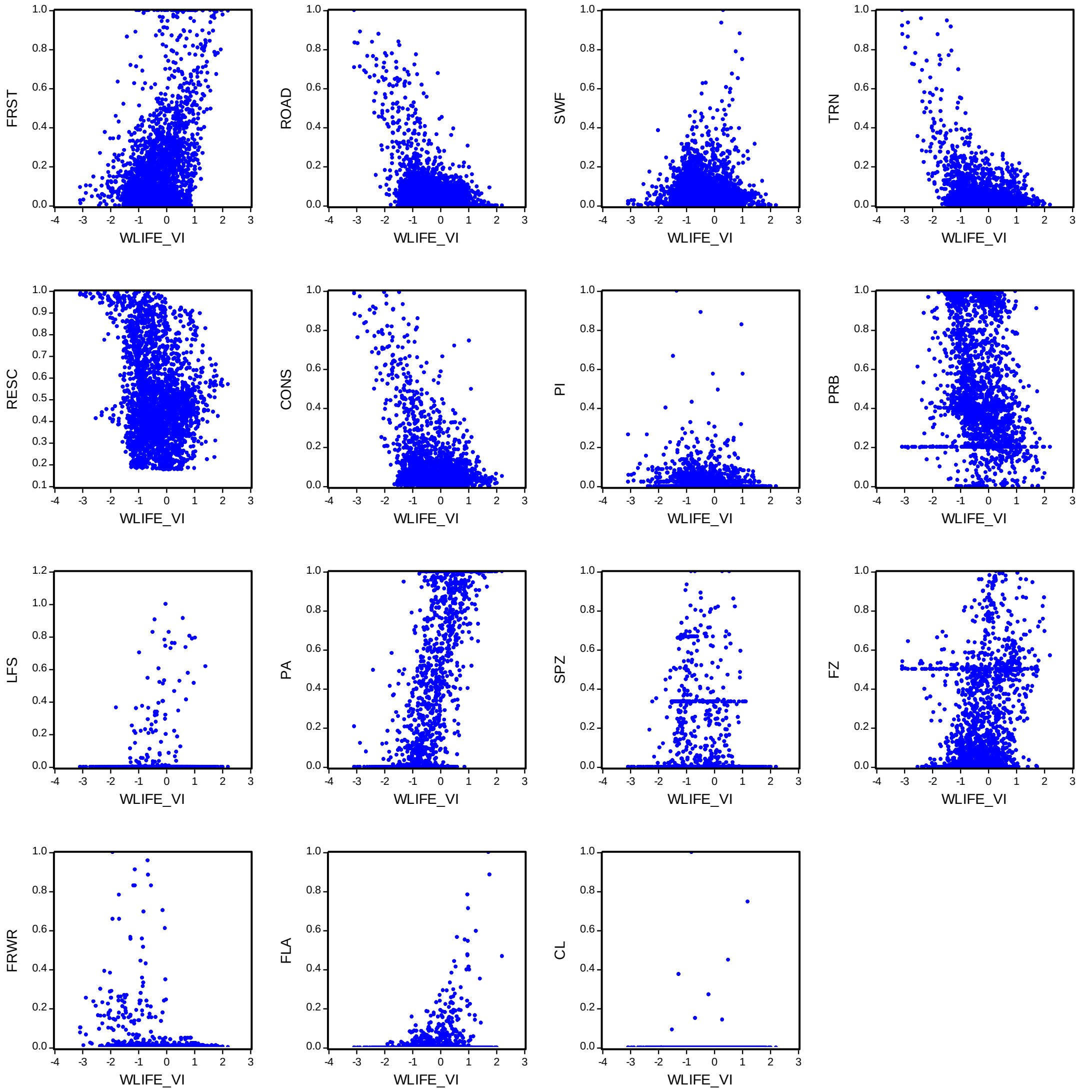


Figure 7-2: The scatter plot of FVI against 15 input variables for the wildlife sector

- Permeability (PRB) shows a negative correlation with flood zones (FZ) (-0.48), train stations (TRN) (-0.25), rescue services (RESC) (-0.36), and forestry workers (FRWR) (-0.22).

The scatter plots show the distribution of FVI and individual inputs. Roads (ROAD), train stations (TRN), rescue services (RESC), construction services (CONS), permeability (PRB), pollution incidents (PI), source protection zones (SPZ), and forestry workers (FRWR) show a regression line with a negative gradient. The first five factors with a negative gradient correspond to the preliminary hypothesis which allocated them to the coping capacity sub-component. However, the other three factors (pollution incidents, source protection zones, and forestry workers) raise some challenging questions here. For instance, source protection zones are geologically permeable lands, leading to a negative regression line.

7.2.1.3. Urban sector

The correlation results for the urban sector are presented in Table 7-3 and the following comments are made:

- The physical indicator of roads (ROAD) in the urban sector is highly and positively associated with train stations (TRN) (+0.64), school locations (SCHL) (+0.69), manufacturing services (MANU) (+0.45), infrastructure (INFR) (+0.77), health centre locations (HLTH) (+0.66), extent of buildings (BLD) (+0.87), commercial services (CMRC) (+0.59), and construction services (CONS) (+0.65).
- The economic indicator of income (INCM) is positively linked to students away from home (STWY) (+0.26), while negatively related to unemployment (UNEP) (-0.31), people with no qualifications (QUAL) (-0.49), and limiting long-term illness (LLTI) (-0.43).
- The social indicator of population density (POP) is highly and positively correlated with roads (ROAD) (+0.64), train stations (TRN) (+0.6), rescue services (RESC) (+0.33), manufacturing (MANU) (+0.36), infrastructure (INFR) (+0.55), health centres (HLTH) (+0.47), extent of buildings (BLD) (+0.6), construction services (CONS) (+0.58), household lowest level (LWL) (+0.99), and number of cars/vehicles (CAR) (+0.99). The extreme correlation between population and house lowest level shows that most of the houses in the area are bungalows or detached, while the extreme correlation between population and cars/vehicles indicates that most of the population have access to personal cars or vans.
- Furthermore, the economic variable of unemployment (UNEP) is associated with two social factors: qualifications (QUAL) (+0.44) and limiting long-term illness (LLTI) (+0.31).

Table 7-3: The correlation results for the urban sector

	ROAD	UNEP	TNUR	SWF	STWY	SPZ	SEX	QUAL	TRN	SCHL	RESC	MNU	INFR	HLTH	AGE	BLD	CER
ROAD	1	0.14	0.00	0.02	-0.10	0.15	0.02	-0.01	0.64	0.69	0.33	0.45	0.77	0.66	0.09	0.87	0.15
UNEM	0.14	1	-0.23	-0.02	-0.16	-0.14	-0.12	0.44	0.19	0.12	0.01	0.16	0.13	0.10	0.08	0.14	0.08
TNUR	0.00	-0.23	1	-0.01	0.14	0.10	0.07	-0.30	-0.04	-0.02	0.19	-0.06	-0.04	-0.04	-0.06	0.05	-0.07
SWF	0.02	-0.02	-0.01	1	0.10	0.02	0.04	-0.06	-0.12	-0.03	-0.14	-0.03	-0.04	-0.03	0.02	0.01	0.00
STWY	-0.10	-0.16	0.14	0.10	1	0.00	0.09	-0.34	-0.16	-0.09	-0.12	-0.10	-0.12	-0.05	0.07	-0.10	-0.14
SPZ	0.15	-0.14	0.10	0.02	0.00	1	0.09	-0.21	0.13	0.09	0.31	0.02	0.11	0.06	-0.02	0.13	0.09
SEX	0.02	-0.12	0.07	0.04	0.09	0.09	1	-0.21	-0.07	0.04	-0.05	-0.08	-0.01	0.02	0.47	0.00	-0.47
QUAL	-0.01	0.44	-0.30	-0.06	-0.34	-0.21	-0.21	1	0.06	0.00	-0.08	0.09	0.00	-0.01	0.08	0.01	-0.03
TRN	0.64	0.19	-0.04	-0.12	-0.16	0.13	-0.07	0.06	1	0.51	0.47	0.51	0.66	0.50	-0.01	0.62	0.23
SCHL	0.69	0.12	-0.02	-0.03	-0.09	0.09	0.04	0.00	0.51	1	0.26	0.27	0.59	0.53	0.09	0.69	0.11
RESC	0.33	0.01	0.19	-0.14	-0.12	0.31	-0.05	-0.08	0.47	0.26	1	0.20	0.32	0.19	-0.05	0.34	0.18
MNU	0.45	0.16	-0.06	-0.03	-0.10	0.02	-0.08	0.09	0.51	0.27	0.20	1	0.54	0.37	0.01	0.52	0.12
INFR	0.77	0.13	-0.04	-0.04	-0.12	0.11	-0.01	0.00	0.66	0.59	0.32	0.54	1	0.71	0.04	0.74	0.17
HLTH	0.66	0.10	-0.04	-0.03	-0.05	0.06	0.02	-0.01	0.50	0.53	0.19	0.37	0.71	1	0.06	0.56	0.11
AGE	0.09	0.08	-0.06	0.02	0.07	-0.02	0.47	0.08	-0.01	0.09	-0.05	0.01	0.04	0.06	1	0.10	-0.49
BLD	0.87	0.14	0.05	0.01	-0.10	0.13	0.00	0.01	0.62	0.69	0.34	0.52	0.74	0.56	0.10	1	0.14
CER	0.15	0.08	-0.07	0.00	-0.14	0.09	-0.47	-0.03	0.23	0.11	0.18	0.12	0.17	0.11	-0.49	0.14	1
CL	0.04	0.09	-0.08	0.02	-0.03	0.00	0.02	0.09	0.06	0.01	0.04	0.00	0.04	0.05	0.08	0.04	0.00
CAR	0.58	0.07	0.12	-0.06	-0.09	0.13	0.09	-0.03	0.51	0.44	0.32	0.26	0.47	0.41	0.16	0.56	-0.01
HHSZ	0.12	-0.09	0.21	-0.01	0.16	0.08	0.04	-0.22	-0.09	0.13	0.13	-0.08	0.02	0.02	0.29	0.10	-0.07
LWL	0.61	0.17	0.02	-0.08	-0.13	0.08	0.08	0.08	0.58	0.48	0.32	0.36	0.52	0.44	0.20	0.58	0.00
MOHS	0.00	0.08	-0.01	-0.02	-0.06	0.12	0.03	0.06	0.03	0.00	0.05	0.01	0.03	0.01	-0.05	0.03	0.09
POP	0.64	0.17	0.01	-0.08	-0.13	0.09	0.07	0.08	0.60	0.51	0.33	0.36	0.55	0.47	0.19	0.60	0.03
FZ	0.14	0.02	0.09	-0.24	-0.18	0.00	-0.04	0.18	0.24	0.14	0.32	0.14	0.18	0.10	0.04	0.16	0.03
INCM	-0.03	-0.31	0.11	0.11	0.26	0.20	0.00	-0.49	-0.09	-0.06	0.10	-0.07	-0.06	-0.06	-0.04	-0.04	0.14
LFS	0.02	-0.02	0.06	0.02	0.01	0.07	0.00	-0.06	0.03	-0.02	0.05	0.05	0.02	0.00	0.03	0.03	-0.01
LLTI	0.00	0.31	-0.01	-0.03	-0.22	-0.11	0.00	0.65	0.09	0.00	-0.04	0.06	0.02	0.03	0.11	0.04	0.04
LNPR	0.21	0.42	-0.31	-0.04	-0.12	-0.03	-0.03	0.29	0.24	0.18	0.13	0.13	0.18	0.15	0.30	0.19	0.03
MGR	0.19	0.01	-0.14	-0.01	-0.16	0.13	-0.27	-0.13	0.33	0.17	0.20	0.17	0.24	0.15	-0.39	0.19	0.72
PI	0.34	0.04	0.07	-0.03	-0.02	0.08	0.00	0.00	0.34	0.18	0.18	0.41	0.31	0.20	0.03	0.40	0.05
ACDR	0.39	0.06	-0.04	0.00	-0.04	0.01	0.01	0.01	0.33	0.24	0.06	0.27	0.60	0.68	0.00	0.32	0.08
ATTR	0.14	-0.02	0.09	0.05	0.06	-0.07	0.00	-0.06	0.06	0.07	-0.05	0.09	0.18	0.12	0.00	0.18	0.01
CMRC	0.59	0.10	-0.05	-0.02	-0.07	0.03	-0.02	0.00	0.51	0.40	0.17	0.53	0.80	0.83	0.01	0.51	0.13
CONS	0.65	0.15	0.06	-0.04	-0.11	0.24	0.02	0.00	0.86	0.50	0.37	0.42	0.61	0.51	0.08	0.63	0.17

	CL	CAR	HHSZ	LWL	MOHS	POP	FZ	INCM	LFS	LLTI	LNPR	MGR	PI	ACDR	ATTR	CMRC	CONS
ROAD	0.04	0.58	0.12	0.61	0.00	0.64	0.14	-0.03	0.02	0.00	0.21	0.19	0.34	0.39	0.14	0.59	0.65
UNEP	0.09	0.07	-0.09	0.17	0.08	0.17	0.02	-0.31	-0.02	0.31	0.42	0.01	0.04	0.06	-0.02	0.10	0.15
TNUR	-0.08	0.12	0.21	0.02	-0.01	0.01	0.09	0.11	0.06	-0.01	-0.31	-0.14	0.07	-0.04	0.09	-0.05	0.06
SWF	0.02	-0.06	-0.01	-0.08	-0.02	-0.08	-0.24	0.11	0.02	-0.03	-0.04	-0.01	-0.03	0.00	0.05	-0.02	-0.04
STWY	-0.03	-0.09	0.16	-0.13	-0.06	-0.13	-0.18	0.26	0.01	-0.22	-0.12	-0.16	-0.02	-0.04	0.06	-0.07	-0.11
SPZ	0.00	0.13	0.08	0.08	0.12	0.09	0.00	0.20	0.07	-0.11	-0.03	0.13	0.08	0.01	-0.07	0.03	0.24
SEX	0.02	0.09	0.04	0.08	0.03	0.07	-0.04	0.00	0.00	0.00	-0.03	-0.27	0.00	0.01	0.00	-0.02	0.02
QUAL	0.09	-0.03	-0.22	0.08	0.06	0.08	0.18	-0.49	-0.06	0.65	0.29	-0.13	0.00	0.01	-0.06	0.00	0.00
TRN	0.06	0.51	-0.09	0.58	0.03	0.60	0.24	-0.09	0.03	0.09	0.24	0.33	0.34	0.33	0.06	0.51	0.86
SCHL	0.01	0.44	0.13	0.48	0.00	0.51	0.14	-0.06	-0.02	0.00	0.18	0.17	0.18	0.24	0.07	0.40	0.50
RESC	0.04	0.32	0.13	0.32	0.05	0.33	0.32	0.10	0.05	-0.04	0.13	0.20	0.18	0.06	-0.05	0.17	0.37
MNU	0.00	0.26	-0.08	0.36	0.01	0.36	0.14	-0.07	0.05	0.06	0.13	0.17	0.41	0.27	0.09	0.53	0.42
INFR	0.04	0.47	0.02	0.52	0.03	0.55	0.18	-0.06	0.02	0.02	0.18	0.24	0.31	0.60	0.18	0.80	0.61
HLTH	0.05	0.41	0.02	0.44	0.01	0.47	0.10	-0.06	0.00	0.03	0.15	0.15	0.20	0.68	0.12	0.83	0.51
AGE	0.08	0.16	0.29	0.20	-0.05	0.19	0.04	-0.04	0.03	0.11	0.30	-0.39	0.03	0.00	0.00	0.01	0.08
BLD	0.04	0.56	0.10	0.58	0.03	0.60	0.16	-0.04	0.03	0.04	0.19	0.19	0.40	0.32	0.18	0.51	0.63
CER	0.00	-0.01	-0.07	0.00	0.09	0.03	0.03	0.14	-0.01	0.04	0.03	0.72	0.05	0.08	0.01	0.13	0.17
CL	1	0.04	0.03	0.06	0.00	0.06	0.01	0.00	-0.01	0.06	0.17	0.01	0.02	0.01	0.00	0.00	0.10
CAR	0.04	1	0.13	0.93	0.01	0.93	0.15	-0.01	0.00	-0.02	0.20	0.03	0.23	0.21	0.03	0.33	0.54
HHSZ	0.03	0.13	1	0.11	-0.03	0.13	0.11	0.18	0.04	-0.38	0.13	-0.04	0.00	-0.06	0.03	-0.05	-0.02
LWL	0.06	0.93	0.11	1	0.01	0.99	0.18	-0.06	-0.01	0.03	0.31	0.04	0.24	0.24	0.03	0.37	0.56
MOHS	0.00	0.01	-0.03	0.01	1	0.02	0.01	-0.06	-0.01	0.10	0.09	0.14	0.00	0.00	0.00	0.01	0.06
POP	0.06	0.93	0.13	0.99	0.02	1	0.18	-0.07	-0.01	0.03	0.32	0.07	0.24	0.28	0.04	0.39	0.58
FZ	0.01	0.15	0.11	0.18	0.01	0.18	1	-0.11	-0.02	0.10	0.08	0.02	0.12	0.03	-0.04	0.11	0.18
INCM	0.00	-0.01	0.18	-0.06	-0.06	-0.07	-0.11	1	0.07	-0.43	-0.15	0.05	0.04	-0.07	0.01	-0.07	-0.04
LFS	-0.01	0.00	0.04	-0.01	-0.01	-0.01	-0.02	0.07	1	-0.03	-0.01	-0.02	0.19	0.00	0.07	0.00	0.07
LLTI	0.06	-0.02	-0.38	0.03	0.10	0.03	0.10	-0.43	-0.03	1	0.06	-0.09	0.01	0.04	-0.06	0.02	0.09
LNPR	0.17	0.20	0.13	0.31	0.09	0.32	0.08	-0.15	-0.01	0.06	1	0.10	0.07	0.08	-0.03	0.11	0.22
MGR	0.01	0.03	-0.04	0.04	0.14	0.07	0.02	0.05	-0.02	-0.09	0.10	1	0.07	0.14	0.02	0.18	0.25
PI	0.02	0.23	0.00	0.24	0.00	0.24	0.12	0.04	0.19	0.01	0.07	0.07	1	0.12	0.11	0.26	0.33
ACDR	0.01	0.21	-0.06	0.24	0.00	0.28	0.03	-0.07	0.00	0.04	0.08	0.14	0.12	1	0.17	0.77	0.35
ATTR	0.00	0.03	0.03	0.03	0.00	0.04	-0.04	0.01	0.07	-0.06	-0.03	0.02	0.11	0.17	1	0.17	0.07
CMRC	0.00	0.33	-0.05	0.37	0.01	0.39	0.11	-0.07	0.00	0.02	0.11	0.18	0.26	0.77	0.17	1	0.47
CONS	0.10	0.54	-0.02	0.56	0.06	0.58	0.18	-0.04	0.07	0.09	0.22	0.25	0.33	0.35	0.07	0.47	1

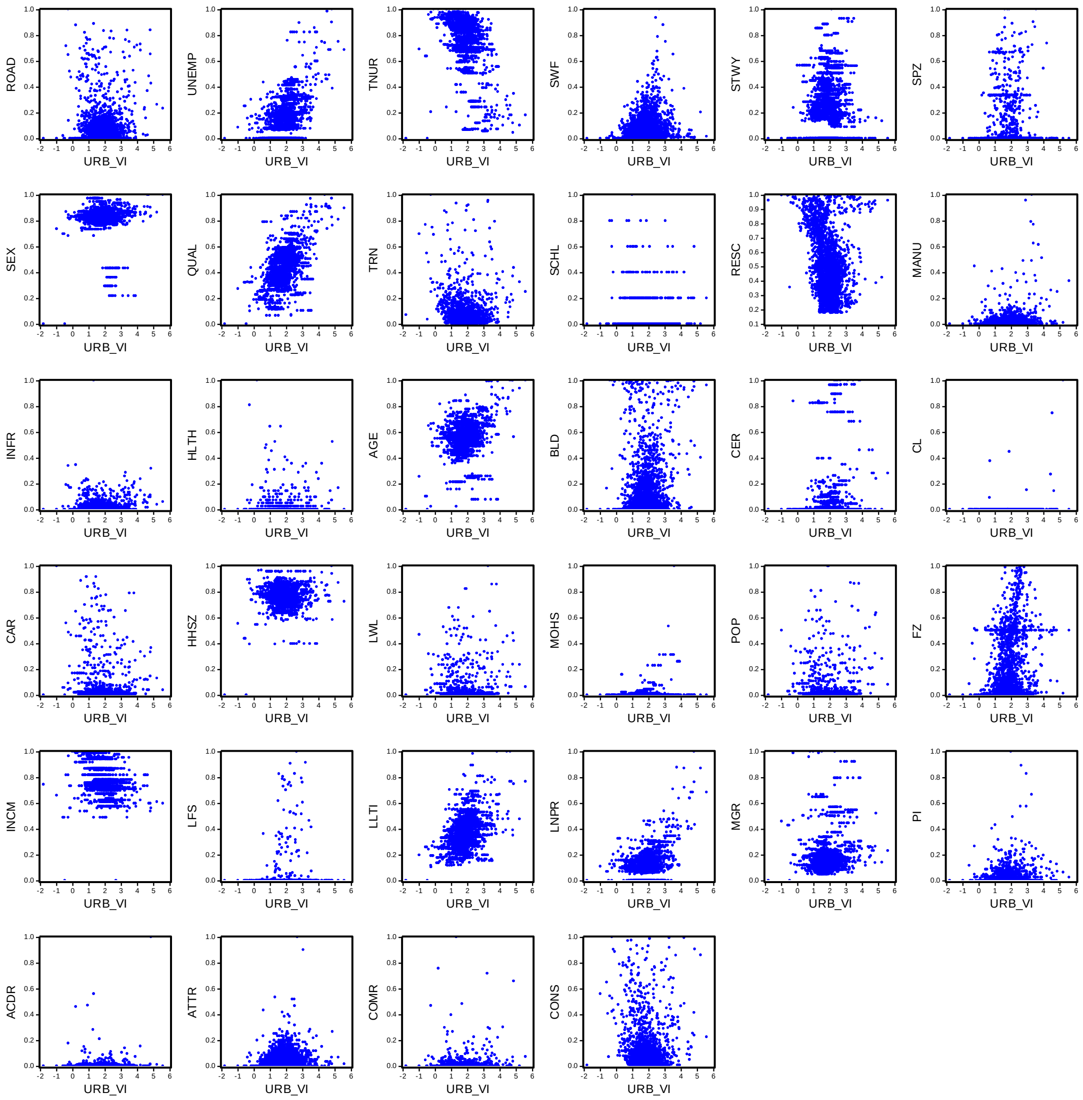


Figure 7-3: The scatter plot of FVI against 34 input variables for the urban sector

- Attraction (ATT) points have a very low correlation with any other factors (-0.07 to +0.18).

Figure 7-3 shows the scatter plot of the urban variables. Indicators of household tenure (TNUR), rescue services (RESC), train stations (TRN), cars/vehicles (CAR), income (INCM), and construction services (CONS) show a negative gradient, which is consistent with the initial assumption of the model (i.e. that they should be considered as coping capacity factors). However, some other coping capacity indicators such as health centres (HLTH), roads (ROAD), sex ratio (SEX), infrastructure services (INFR), accommodation/eating/drinking services (ACDR), commercial services (COMR), and schools (SCHL) show a gradient very close to flat, which again raises the question of indicator assignment. In future work, they might be assigned to exposure/susceptibility (or vice versa) to see how the result would change.

7.2.1.4. Intermediate conclusion

The correlation results give an insight into the relationships between the variables and final composite indicators. The results are used in the preceding sections for variable weighting and interpretation of results. For instance, in the arable sector the negative correlations between rescue services and livestock and farm location show the high exposure of arable lands to diverse impacts of flooding. Another example is the protected areas in the wildlife sector, which do not display much correlation with any other variable; this indicates that their distribution within the area is not associated with any other factors and is therefore independent of other factors. Also, the extreme correlation between population in the urban sector and car/vehicle numbers and household lowest level indicates that (a) most of the houses are bungalows or detached and (b) most of the population own a car or van.

In addition, the scatter plots show some of the variables which are a matter of discussion for further work in that they might be assigned to a different sub-component of vulnerability (coping capacity or exposure/susceptibility). These variables are: (a) agricultural workers and pollution incidents for the arable sector; (b) SPZ, forestry workers, and pollution incidents for the wildlife sector; (c) health centres, roads, sex, infrastructure, commercial services, accommodation/eating services, and schools for the urban sector.

7.2.2. Principal component analysis

"The central idea of Principal Component Analysis (PCA) is to reduce the dimensionality of a data set consisting of a large number of interrelated variables, while retaining as much as possible of the variation present in the data set. This is achieved by transforming to a new set of variables, the Principal Components (PCs), which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables" (Jolliffe 1986).

PCA is a widely used mathematical tool which has a variety of applications. There are a number of scientific works which have tried to simplify and explain the content of PCA. For instance, Jeong and colleagues designed an interactive visual analytic tool that supports the visualisation and understanding of the results of PCA by the user (Jeong, Ziemkiewicz et al. 2009).

Although PCA is a great exploratory tool for summarising a large set of indicators while preventing loss of data variation, it also has some limitations. PCA tends to minimise the influence of sub-indicators which do not correlate with others. In addition, the PCA result is sensitive to outliers in the data and the problems of a small sample. It is important to bear in mind that the correlation coefficients do not necessarily show the real influence of the variable on the composite indicator (Nardo, Saisana et al. 2005, Roberts, Martin 2006).

As for how many factors should be retained while least information lost, there are many diverse opinions. The main methods highlighted here are based on the discussion in (Dunteman 1989): Kaiser criterion, scree plot, variance explained criteria, Joliffe criterion, and comprehensibility. The Kaiser criterion and scree plot are used in this work. The Kaiser criterion states that any factor with an eigenvalue below 1.0 should be dropped on the basis that it doesn't make sense to include a factor that explains less variance than is contained in one indicator. The scree plot method is based on the eigenvalue plot at the point where it drops off sharply and then tends to level off. The scree plot suggests retaining all the eigenvalues in the sharp descent before it starts to level off.

The framework of this study considers a variety of environmental, social, economic, and physical indicators in forming the composite FVI. Therefore, a large set of variables has been developed for each sector. The PCA results show the contribution of each variable in terms of explaining the final composite indicator, and therefore:

1. PCA can greatly help to explore the primary causes of vulnerability in each sector by highlighting the factors which cause the most variation of the output FVI.
2. PCA impressively improves model simplification by reducing the number of input variables, as the PCA results state which factors to retain and which ones to drop.

7.2.2.1. Arable sector

To decide on the number of principal components, the PCA is firstly applied to all fifteen variables of the arable sector. The red line in Figure 7-4 shows the Kaiser criterion which expresses the number of PCs as six. However, the elbow point of the graph refers to four PCs. Therefore four PCAs are selected for the arable sector.

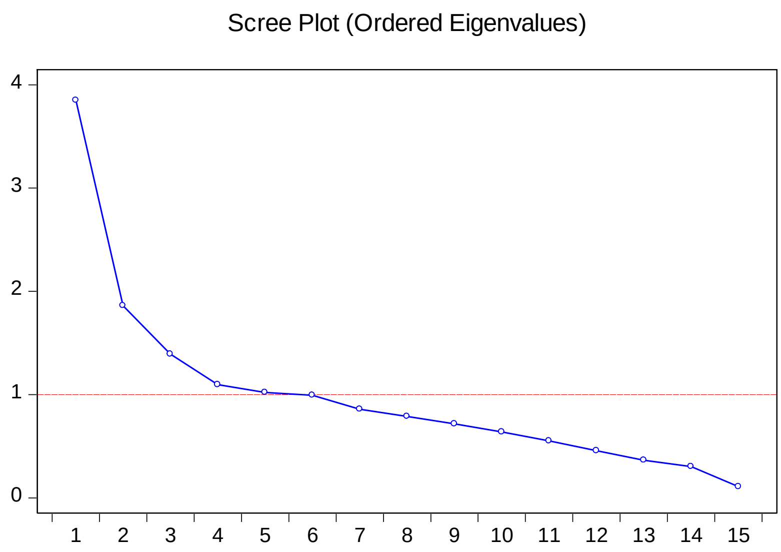


Figure 7-4: Scree plot for the arable sector

Table 7-4: Eigenvector results for 4 PCs of the arable sector

Variable	PC 1	PC 2	PC 3	PC 4
AGWR	0.27	0.24	-0.23	-0.20
CONST	0.42	0.25	-0.02	-0.06
CL	0.05	0.04	-0.02	-0.16
FARM	-0.20	0.40	0.17	0.02
LFS	0.03	0.13	0.16	0.78
PI	0.22	0.18	-0.02	0.50
RESC	0.33	-0.16	0.31	-0.04
PRB	-0.23	0.47	0.08	-0.09
ROAD	0.37	0.30	-0.10	-0.09
SPZ	0.12	0.20	0.50	-0.12
SWF	-0.11	0.35	0.06	-0.08
TRN	0.44	0.13	-0.06	-0.04
ALC	-0.19	0.08	0.58	-0.11
DFR	-0.25	0.11	-0.32	0.11
FZ	0.21	-0.37	0.29	0.03
proportion	0.26	0.12	0.09	0.07
accumulative proportion	0.26	0.38	0.47	0.54

For the next step, the eigenvectors of the first four principal components are derived (Table 7-4). The first PC is mostly explained by four physical components of vulnerability in the arable sector: construction services (CONS) (+0.42), rescue services (RESC) (+0.33), roads (ROAD) (+0.37), and train stations (TRN) (+0.44). In contrast, the second PC is mainly derived from environmental components: permeability (PRB) (+0.47), surface water flooding (SWF) (+0.35), and flood zones (FZ) (-0.37), as well as one economic indicator of farm locations (FARM) (+0.4). The third and fourth components mainly comprise environmental and economic variables: source protection zones (SPZ) (+0.5), land productivity (ALC) (+0.58), Defra livestock (DFR) (-0.32), landfill sites (LFS) (+0.78), and pollution incidents (PI) (+0.5).

7.2.2.2. Wildlife sector

The two main outcomes of the PCA are presented in Figure 7-5 and Table 7-5. The first run of the PCA used all fifteen variables of the wildlife sector. The scree plot demonstrates the eigenvalues of the PCA. The red line which is based on the Kaiser criterion implies the desirability of six indicators; however, the elbow point of the graph can be identified at four PCs. Therefore, the number of PCs is set as four.

The PCA results of the wildlife sector are outlined in Table 7-5. The first PC, which shows the most variation in the dataset, is mainly based on the physical variables: roads (ROAD) (+0.41), train stations (TRN) (+0.47), rescue services (RESC) (+0.34), and construction services (CONS) (+0.46). The second PC is based on the combination of three environmental variables and one economic variable: forest area (FRST) (-0.37), surface water flooding (SWF) (+0.39), permeability (PRB) (+0.52), and flood zones (FZ) (-0.44). The last two PCs are greatly reliant on economic and environmental factors.

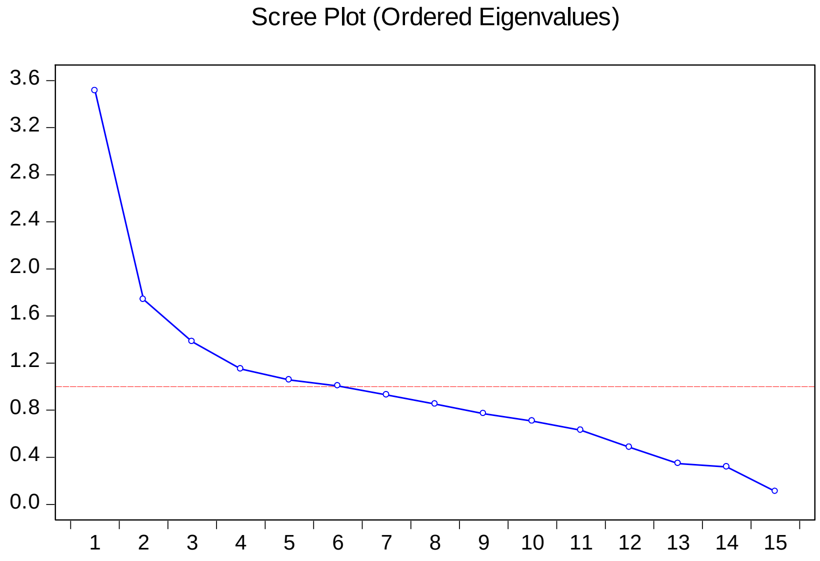


Figure 7-5: Scree plot for the wildlife sector

Table 7-5: Eigenvector results for 4 PCs of the wildlife sector

Variable	PC 1	PC 2	PC 3	PC 4
FRST	0.02	-0.37	0.45	0.12
ROAD	0.41	0.25	0.07	-0.17
SWF	-0.09	0.39	-0.07	-0.04
TRN	0.47	0.02	0.15	-0.06
RESC	0.34	-0.21	-0.12	0.28
CONS	0.46	0.14	0.13	-0.04
PI	0.25	0.10	0.10	0.23
PRB	-0.21	0.52	0.21	0.11
LFS	0.04	0.10	0.03	0.62
PA	-0.13	-0.11	0.54	0.06
SPZ	0.14	0.21	-0.10	0.53
FZ	0.21	-0.44	-0.12	-0.01
FRWR	0.29	0.21	0.13	-0.34
FLA	-0.09	0.02	0.58	0.03
CL	0.05	0.03	0.06	-0.11
proportion	0.23	0.12	0.09	0.08
accumulative proportion	0.23	0.35	0.44	0.51

7.2.2.3. Urban sector

The Kaiser criterion is much clearer in the case of the vulnerability indicators for the urban sector. The Kaiser criterion states the number of PCs for the urban sector as eleven. However, the Scree plot of the eigenvalues suggests that two PCs are strong enough to describe the whole of the data, while there is another elbow point distinguishable in the graph at point number 5 or even 8. Considering all the aspects, eight PCs have been considered for the urban sector.

Table 7-6 is based on the first eight principle components. The first PC of the urban sector has four main explanatory variables of the physical component of vulnerability: roads (ROAD) (+0.3), train stations (TRN) (+0.29), infrastructure (INFR) (+0.3), and extent of buildings (BLD) (+0.29). However, interestingly, the second PC is defined by five social variables: unemployment (UNEP) (-0.34), qualifications (QUAL) (-0.49), income (INCM) (+0.38), and limiting long-term illness (LLTI) (-0.4).

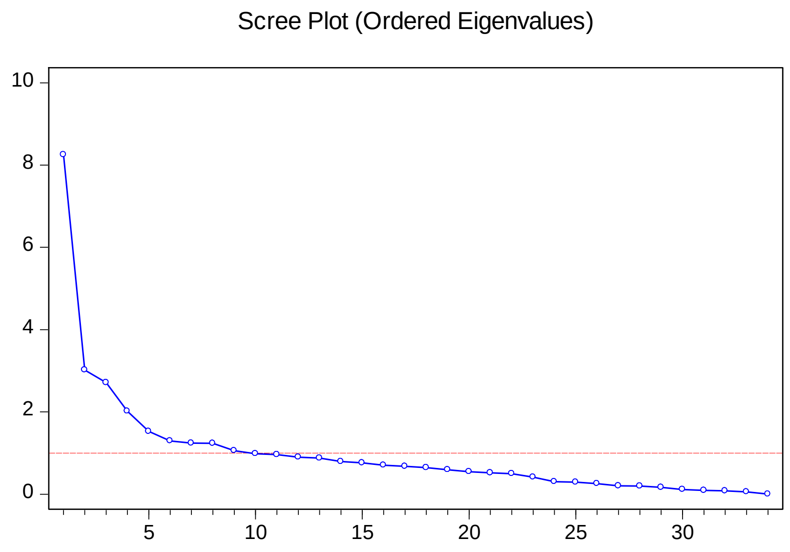


Figure 7-6: Scree plot for the urban sector

PC3 is again derived from sex (SEX), age (AGE), residents in communal establishments (CER), and migration (MGR). The fourth PC is basically associated with rescue services (RESC), locations of accommodation/eating/drinking services (ACDR), and commercial services (CMRC). The last four components are related to tenure (TNUR), flood zones (FZ), lone parents with dependent children (LNPR), landfill sites (LFS), pollution incidents (PI), surface water flooding (SWF), household size (HHSZ), source protection zones (SPZ), and mobile houses (MOHS).

The PCA tables were powerful tools in terms of finding out the most effective variables for each composite indicator. In addition, the correlation coefficients were used to discover the interrelations among the variables. The scatter plots of the variables show that some indicators may be assigned to other sub-components of vulnerability for further work. The results of the PCA are used in the next section for sensitivity analysis of the final FVIs of the sectors.

Table 7-6: Eigenvector results for 4 PCs of the urban sector

Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8
ROAD	0.30	0.06	0.01	-0.04	0.05	0.02	-0.03	-0.04
UNEP	0.08	-0.34	0.03	0.04	0.22	0.14	0.05	-0.07
TNUR	0.00	0.25	0.06	0.09	-0.43	-0.02	-0.03	-0.11
SWF	-0.03	0.06	0.00	-0.16	0.24	0.22	-0.40	-0.10
STWY	-0.06	0.25	0.09	-0.15	0.12	0.07	0.01	-0.11
SPZ	0.06	0.20	-0.05	0.19	-0.06	0.20	-0.19	0.45
SEX	0.00	0.11	0.36	-0.12	-0.08	0.10	-0.16	0.36
QUAL	0.02	-0.49	0.06	0.03	-0.06	0.03	0.04	-0.07
TRN	0.29	-0.03	-0.08	0.10	-0.07	0.08	-0.03	0.03
SCHL	0.24	0.04	0.03	0.01	0.08	-0.09	0.00	0.00
RESC	0.15	0.10	-0.06	0.33	-0.18	0.06	0.15	0.19
MNU	0.21	-0.05	-0.08	-0.10	-0.09	0.23	0.07	-0.14
INFR	0.30	0.02	-0.07	-0.18	-0.02	-0.01	0.08	0.07
HLTH	0.26	0.02	-0.03	-0.29	0.02	-0.14	0.07	0.15
AGE	0.03	-0.02	0.47	-0.05	0.12	0.16	0.14	0.16
BLD	0.29	0.05	0.01	-0.01	0.00	0.10	-0.03	-0.11
CER	0.07	-0.02	-0.48	0.17	0.14	-0.03	-0.02	-0.05
CL	0.03	-0.07	0.05	0.06	0.21	0.18	0.10	0.14
CAR	0.25	0.07	0.19	0.20	0.01	-0.20	-0.24	-0.18
HHSZ	0.02	0.24	0.17	0.15	0.22	-0.04	0.44	-0.04
LWL	0.27	0.01	0.20	0.19	0.06	-0.18	-0.19	-0.17
MOHS	0.02	-0.06	-0.07	0.09	0.02	0.14	-0.17	0.39
POP	0.28	0.01	0.18	0.18	0.07	-0.18	-0.18	-0.15
FZ	0.09	-0.07	0.03	0.22	-0.32	-0.10	0.45	0.07
INCM	-0.03	0.38	-0.08	0.06	0.17	0.10	0.00	-0.01
LFS	0.01	0.07	0.00	0.00	-0.09	0.50	0.08	-0.15
LLTI	0.02	-0.40	0.04	-0.02	-0.28	0.11	-0.20	0.06
LNPR	0.11	-0.21	0.12	0.15	0.44	0.13	0.22	0.09
MGR	0.09	0.02	-0.44	0.14	0.19	-0.01	-0.02	0.11
PI	0.14	0.05	-0.02	0.00	-0.17	0.47	0.08	-0.23
ACDR	0.18	0.00	-0.08	-0.41	-0.02	-0.15	0.10	0.19
ATTR	0.05	0.07	-0.03	-0.23	-0.02	0.14	0.10	-0.27
COMC	0.25	0.01	-0.10	-0.37	-0.04	-0.08	0.12	0.12
CONS	0.28	0.02	-0.02	0.08	-0.06	0.14	-0.11	0.09
proportion	0.24	0.09	0.08	0.06	0.04	0.04	0.03	0.04
accumulative proportion	0.24	0.33	0.41	0.47	0.51	0.55	0.59	0.62

7.2.2.4. Intermediate conclusion

The PCA results from this section will be used in the sensitivity analysis. The most effective factors are retained and the others dropped as superfluous, as follows:

- In the arable sector: train stations, construction services, roads, rescue services, permeability, farm locations, flood zones, surface water flooding, farm land productivity, Defra livestock report, SPZs, pollution incidents, and landfill sites are the factors to be retained.
- In the wildlife sector: train stations, construction services, roads, rescue services, permeability, forested areas, flood zones, surface water flooding, forestry workers, protected areas, SPZs, landfill sites, and felling licence applications are the indicators to stay on the list.
- For the urban sector: contaminated land, vehicles, household level, manufacturing and production, students away from home, attractions, and school location are excluded from the list of urban vulnerability indicators.

In addition, the coefficients of the first PC of each sector are used as an alternative form of weighting in the sensitivity analysis.

7.2.3. Evaluation of results

A sensitivity analysis is conducted to work out how the FVI result is expected to vary with respect to the variation/exclusion of the input indicators. Nardo et al. (2005) presented numbers of ways to examine the sensitivity of the modelled data. For the sake of this work the modelling has been done four times, based on the following:

- a weighting method inspired by the analytical hierarchy process (AHP); hierarchy assessment
- a PCA-based weighting system
- variable omission
- replacing the value of some inputs with the mean value of those factors.

A combination of the changes in the input variables listed above facilitates the evaluation of the reliability and soundness of the FVI. Moreover, the results will be presented as both statistical and graphical illustrations, which improve transparency and start a discussion of the output.

The following sections summarise the results of the sensitivity analysis for the three vulnerability sectors. Subsequently, the results are discussed and underlying grounds are argued.

7.2.3.1. Arable sector

First, the sensitivity of the FVI for the arable sector is examined by alternative weighting schemes. Table 7-7 below shows the result of a hierarchical weighting system which is based on correlation results, data quality, and analytical accuracy of the data. For the arable sector, equal loads have been assigned to all three components of vulnerability, with the assumption that environmental, economic and physical indicators make the same contribution to overall vulnerability. The negative sign points to on the coping capacity side of the variable.

Table 7-7: Weightings for a hierarchical assessment of arable indicators

	Weight	Component	Weight	Indicator	Final weight
Composite VI	1/3	Environmental	3/13	FZ	0.077
			1/13	PRB	-0.028
			1/13	PI	0.026
			2/13	LFS	0.051
			2/13	SPZ	0.051
			3/13	SWF	0.077
			1/13	CL	0.026
	1/3	Physical	3/7	RESC	-0.14
			1/7	ROAD	-0.05
			1/7	TRN	-0.048
			2/7	CONS	-0.095
	1/3	Economic	1/7	AGWR	0.048
			1/7	FARM	0.048
			3/7	ALC	0.14
			2/7	DFR	0.095

Another alternative for the weighting system is the results of the PCA. The first PC of the arable vulnerability dataset (Table 7-4) explained the largest portion of the variation and could be used as the alternative to the original variables for the sake of sensitivity analysis.

The next option in exploring the sensitivity of the FVI model is to exclude some of the indicators to see how the output changes. PCA has been used as the ancillary aid for this step. According to Table 7-3 the most significant variables for the arable stratum are train stations, construction services, roads, rescue services, permeability, farm locations, flood zones, surface water flooding, farm land productivity, Defra livestock report, SPZs, and landfill sites. As a result, two variables, contaminated lands and agricultural workers, have been nominated for omission. The last option is the matter of uncertainty in the data. To examine this issue, the mean value of rescue services has been assigned to all grids instead of their real value. This decision is based on two ideas: (a) to see how the outcome of the model changes with change in the input, and (b) to examine how the pattern of flood vulnerability would change if government rescue services were relocated.

After implementation of the extra four models of the composite VI, the first step towards comparison of results is the visual evaluation. All five models show a similar pattern, although they show more variance at the negative scores (Figure 7-7).

Table 7-8: Summary statistics of the VI models of the arable sector

	ARABLE_FVI	ARABLE_PCA	ARABLE_OMI	ARABLE_AHP	ARABL_MEAN
Mean	0.0013	-0.0382	0.0002	0.0123	0.0013
Median	0.0037	-0.0295	0.0036	0.0237	0.0021
Maximum	0.1072	0.0841	0.1235	0.1558	0.1117
Minimum	-0.2124	-0.4033	-0.2510	-0.2787	-0.1802
Std. Dev.	0.0409	0.0548	0.0489	0.0621	0.0377
Skewness	-1.0493	-2.2948	-1.1885	-1.3479	-0.5182
Kurtosis	6.0813	10.9380	6.4256	6.0121	4.5988

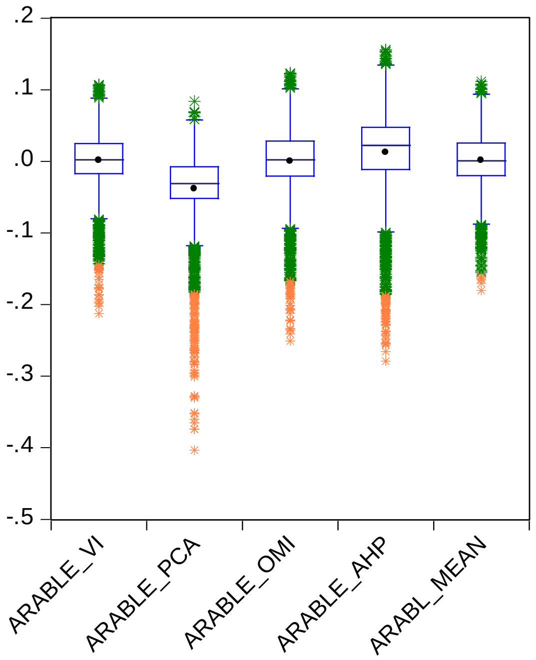


Figure 7-7: Box plot display of VI models of the arable sector

Table 7-8 and Figure 7-7 show statistical descriptions of the alternative models. Mean and median values of the five schemes are similar. In addition, the standard deviations are close. Consideration of all three statistical characteristics of models (i.e. mean, median, and standard deviation) reveals a consistent trend for all five models. The skewness and kurtosis values appear to be close to the original results of the study (ARABLE_FVI). In the box plot, the negative outliers call for attention. The positive outliers are close to the whiskers, but not the negatives. This may refer to the fact that negative grids (showing low vulnerability) are more inconsistent with the overall form of the models (true for all five models). In addition they are more sensitive to changes of input data.

The Gap statistical test has been applied to the results of four additional models of VI to explore the sensitivity of the results. The statistical measurements of the Gap test are provided in Table 7-9, and are based on the results of the Gap test between four additional models and the preliminary model of the work (VULNERABILITY_FVI). Since the means and medians of the four Gap tests are close to zero, and they ensure a small standard deviation, the sensitivity of the original FVI is concluded.

Table 7-9: Gap summary statistics for the arable sector

	GAP_AHP	GAP_MEAN	GAP_OMI	GAP_PCA
Mean	-0.0109	0.0000	0.0013	0.0013
Median	-0.0131	0.0031	0.0037	0.0037
Maximum	0.1033	0.0216	0.1072	0.1072
Minimum	-0.0802	-0.0333	-0.2124	-0.2124
Std. Dev.	0.0305	0.0138	0.0409	0.0409

7.2.3.2. Wildlife sector

A combination of expert opinion and hierarchical assessment technique is used to extract the variables' weight as presented in Table 7-10. The effects of the three components of vulnerability are assumed to be equal; however, the individual variables are assigned different weights. The first column on the right side of the table holds the final weights of each variable. In addition, the PCA results of eigenvalues (Table 7-5) are used as an alternative for the weighting scheme.

The PCA eigenvalues are also taken as the basis of the exclusion of some indicators. As the results show, thirteen variables play a part in explaining most of the variation in the data through the first four PCs. Pollution incidents and contaminated lands are the two which have not played any significant role in the PCs and are therefore set aside. In addition, the mean value of rescue services is assigned to all grid cells in another run of the model. The last two alternative models explore the sensitivity of the FVI in term of data change or data uncertainty.

As Figure 7-8 shows, all five models of VI in the wildlife sector have a similar pattern. However the points linked to the PCA weighting model are more distant from those of the other four, especially on the grids with negative VI. This effect shows that the PCA weighting system has given the coping capacity variable more power than the exposure/susceptibility factors. On the other hand, hierarchical weighting scheme poses higher distance from ground model at the positive VI. The other two models linked to alterations in datasets display a pattern very close to that of the original model (Wildlife_FVI).

Table 7-10: Weightings for a hierarchical assessment of wildlife indicators

	Weight	Component	Weight	Indicator	Final weight
Composite VI	1/3	Environmental	3/13	FZ	0.077
			2/13	PRB	0.051
			2/13	PI	0.051
			1/13	LFS	0.026
			1/13	SPZ	0.027
			3/13	SWF	0.077
			1/13	CL	0.026
	1/3	Physical	3/9	RESC	0.11
			2/9	ROAD	0.074
			1/9	TRN	0.037
			3/9	CONS	0.11
	1/3	Economic	1/8	FRWR	0.041
			2/8	FRST	0.084
			2/8	FLA	0.083
			3/8	PA	0.126

Table 7-11: Summary statistics of the VI models of the wildlife sector

	WILDLIFE FVI	WILDLIFE PCA	WILDLIFE AHP	WILDLIFE MEAN	WILDLIFE OMI
Mean	-0.0228	-0.0844	-0.0169	-0.0228	-0.0277
Median	-0.0281	-0.0756	-0.0353	-0.0290	-0.0334
Maximum	0.1476	0.0288	0.2140	0.1522	0.1703
Minimum	-0.2049	-0.4659	-0.2610	-0.1736	-0.2568
Std. Dev.	0.0489	0.0575	0.0768	0.0478	0.0569
Skewness	0.1912	-1.9584	0.2289	0.4168	0.1537
Kurtosis	3.2651	9.6444	2.6600	3.1850	3.3418

Statistical reports either by graph (Figure 7-8) or by table (Table 7-11) demonstrate a clear consistency between the FVI and the hierarchical assessment, mean, and omission models. However, the PCA weighting system does not show any consistency with the original FVI. The mean and median of the hierarchical assessment, mean, and omission models are much closer to those of the original model. If the non-significant difference between the skewness and kurtosis values of the different models is added, it can be concluded that the original model of the study (WLIFE_FVI) is not sensitive.

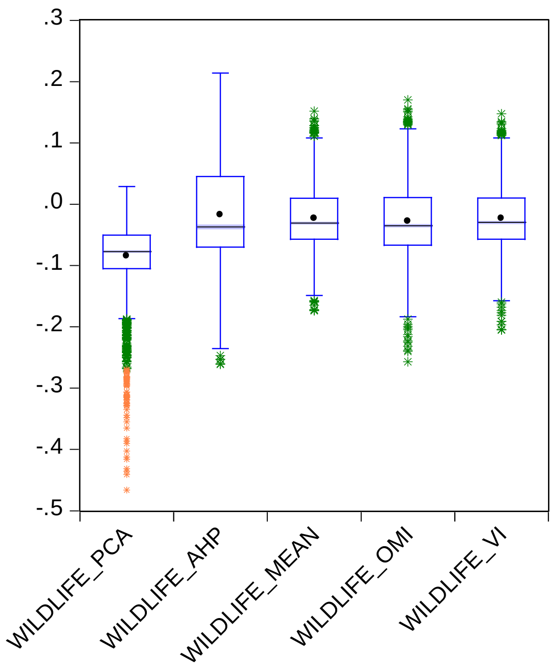


Figure 7-8: Box plot display of VI models of the wildlife sector

The Gap statistical test has also been applied to measure the sensitivity of the model to alternative schemes. Here again, the graph is close to zero and has a very low mean, median and standard deviation for the three models of hierarchical assessment, mean, and omission. The PCA Gap results are also not considerable compared to zero. To sum up, it could be concluded that the FVI model in the wildlife sector is not sensitive to the change in the input data base. However, it poses some sensitivity to the alternative weighting schemes.

Table 7-12: Gap summary statistics for the wildlife sector

	GAP_AHP	GAP_MEAN	GAP_OMI	GAP_PCA
Mean	-0.0059	0.0000	0.0049	0.0615
Median	0.0041	0.0031	0.0052	0.0536
Maximum	0.1000	0.0216	0.0906	0.2610
Minimum	-0.0956	-0.0333	-0.0227	0.0083
Std. Dev.	0.0342	0.0138	0.0090	0.0348

7.2.3.3. Urban sector

In the urban sector, the social component of vulnerability contributes a great proportion of the indicators, and in fact humans are at the core of the factors under consideration. The original vulnerability index (FVI) of the work has been discussed in Chapter 6. However, for the sake of sensitivity analysis, four alternative models have been discussed in this part.

Table 7-13 shows the alternative weighting system derived from the hierarchical assessment. Four components of vulnerability and their associated variables are assigned different scores. A higher weight is given to the social component. In addition, PCA results in the urban sector (Table 7-6) are used as the second alternative weighting scheme. The coefficients of the variables for the first PC have been set as the weights of the indicators to shape the final composite VI.

The third model makes use of the first eight PCs of the urban sector in order to decide on the number of variables to exclude from the list of indicators. By this action, the sensitivity of the FVI model to its indicators will be investigated. Therefore, six variables are excluded from the list of urban vulnerability indicators: contaminated land, vehicles, household level, manufacturing and production, students away from home, and school location. The last alternative evaluates the sensitivity of the FVI model to the change of data input. The mean value of rescue services has been allocated to the grid cells instead of the real score of accessibility of rescue services.

Table 7-13: Weightings for a hierarchical assessment of urban indicators

	Weight	Component	Weight	Indicator	Final weight
Composite VI	1/4	Environmental	3/13	FZ	0.077
			2/13	PI	0.051
			1/13	LFS	0.026
			1/13	SPZ	0.027
			3/13	SWF	0.077
			1/13	CL	0.026
	1/4	Physical	3/15	RESC	0.05
			2/15	ROAD	0.033
			1/15	MOHS	0.017
			2/15	CAR	0.033
			1/15	LWL	0.017
			1/15	BLD	0.017
			2/15	TRN	0.033
			3/15	CONS	0.05
	1/4	Economic	1/13	CER	0.027
			2/13	TNUR	0.051
			3/13	HHSZ	0.077
			1/13	UNEP	0.027
			1/13	COMC	0.027
			1/13	MANU	0.027
			3/13	INCM	0.077
	2/4	Social	3/24	POP	0.0625
			1/24	AGE	0.02
			1/24	STWY	0.02
			2/24	LNPR	0.042
			2/24	MGR	0.042
			2/24	LLTI	0.042
			1/24	QUAL	0.02
			1/24	ACDR	0.02
			2/24	ATTR	0.042
			3/24	HLTH	0.0625
			3/24	INFR	0.0625
			2/24	SEX	0.042
			1/24	SCHL	0.02

The summary statistics of the alternative models (Table 7-14) show that, apart from the PCA model, the other three are close to the FVI, and therefore no considerable sensitivity of the model would be claimed. The measures of skewness and kurtosis also present a consistent pattern in the FVI and the first three models. However, the PCA model is further away from the FVI.

Table 7-14: Summary statistics of the VI models of the urban sector

	URBAN_VI	URBAN_AHP	URBAN_MEAN	URBAN_OMI	URBAN_PCA
Mean	0.0560	0.0475	0.0560	0.0596	0.0000
Median	0.0553	0.0476	0.0545	0.0581	0.0026
Maximum	0.1643	0.1521	0.1779	0.1939	0.0745
Minimum	-0.0524	-0.1025	-0.0388	-0.0636	-0.1705
Std. Dev.	0.0188	0.0259	0.0181	0.0230	0.0178
Skewness	0.3755	-0.3468	1.1134	0.5587	-1.9140
Kurtosis	5.7784	4.6657	7.5864	5.7612	12.3349

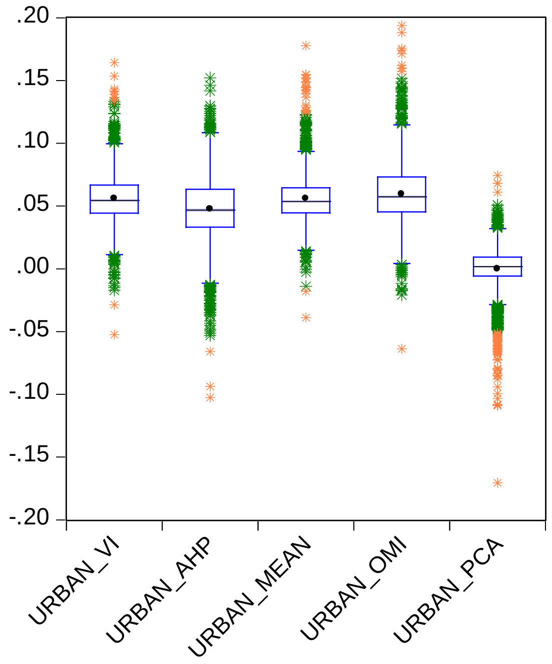


Figure 7-9: Box plot display of VI models of the urban sector

The box plot of VI models may prove the non-sensitivity characteristic of the FVI (Figure 7-9). The overall patterns are close and similar, although two alternatives based on different weighting systems show a patchier distribution in comparison to the FVI model. The elements of the graph are close, with comparable width and stretch in whiskers and outliers. In addition, the Gap statistics test of four alternative models and the FVI model indicates that the difference between model and ground index is very close to normal and pose small standard deviation (Table 7-15).

Table 7-15: Gap summary statistics for the urban sector

	GAP_AHP	GAP_PCA	GAP_OMI	GAP_MEAN
Mean	0.0085	0.0560	0.0560	0.0560
Median	0.0077	0.0553	0.0553	0.0553
Maximum	0.1088	0.1643	0.1643	0.1643
Minimum	-0.0196	-0.0524	-0.0524	-0.0524
Std. Dev.	0.0112	0.0188	0.0188	0.0188

7.3.Conclusion

Four alternative models have been applied to all three sectors of vulnerability. Firstly, a hierarchical weighting system was altered to the equal weighting scheme. Secondly, the PCA results have been taken as the basic measurements for weighting the indicators. Thirdly, the eigenvalues of the PCA table were taken into consideration in deciding on the number of variables to be excluded from the list of indicators. Finally, the value of accessibility of rescue services was assumed to be equal to its mean value.

In addition to the visualisation of model outputs in the form of a box plot, and the summary statistics, the skewness, kurtosis, and Gap tests were applied. The skewness test is a measure of dispersion of data sets and shows the lack of symmetry of data sets; kurtosis characterises the relative peakedness or flatness of the data distribution compared to a normal distribution; and the Gap test measures the difference between the alternative models and the original FVI model (Tibshirani, Walter et al. 2001).

The correlation and PCA analysis result in very useful information in terms of data mining. The outcomes vary between the three strata, as there are different factors with different statistics and spatial distributions. The GIF is closely correlated with flood zones (FZ) and therefore is omitted from the list of indicators in all three sectors. In the urban sector, retail (RTL), general health (GHLT), and sports centres (SPRT) from the social component are also deleted. The correlation outcome shows that in the arable sector physical indicators are correlated. The rescue services locations do not correspond to the economic factors of farms and livestock reports, which draws attention towards the matter of the vulnerability of economic assets. The wildlife sector correlation result indicates that protected areas are not correlated with any other factors, which in turn points out the isolation of this factor. Pollution incidents are linked with roads and train stations, which demonstrates the effect of human presence in environmental pollution.

The principle component results are valuable tools in determining the most effective indicators participating in a composite indicator. For the arable sector, four PCs were identified as presenting 54 per cent of the data variation. The most important factors were recognised to be: construction services (CONS), rescue services (RESC), roads (ROAD), train stations (TRN), permeability (PRB), surface water flooding (SWF), flood zones (FZ), farm locations (FARM), source protection zones (SPZ), land productivity (ALC), Defra livestock (DFR), landfill sites (LFS), and pollution incidents (PI). The wildlife sector displays four PCs, describing 51 per cent of data variation, and the most cooperative factors are: roads (ROAD), train stations (TRN), rescue services (RESC), construction services (CONS), forest area (FRST), surface water flooding (SWF), permeability (PRB), and flood zones (FZ). The urban sector holds eight PCs representing 62 per cent of data variation. The main factors are roads (ROAD), train stations (TRN), infrastructure (INFR), extent of building (BLD), unemployment (UNEP), qualifications (QUAL), age (AGE), income (INCM), limiting long-term illness (LLTI), sex (SEX), age (AGE), residents in communal establishments (CER), migration (MGR), rescue services (RESC), locations of accommodation/eating/drinking services (ACDR), commercial services (CMRC), tenure (TNUR), flood zones (FZ), lone parents with dependent children (LNPR), landfill sites (LFS), pollution incidents (PI), surface water flooding (SWF), household size (HHSZ), source protection zones (SPZ), and mobile houses (MOHS).

In conclusion, the sensitivity analysis of three strata of vulnerability revealed that the composite indicator does indeed involve different sensitivity characteristics for each of the three strata (arable, wildlife, and urban). From the figures and tables of resultant alternative models and the original FVI, it can be concluded that

1. The arable sector FVI did not display sensitivity to changes in the weighting system, number of indicators, and data uncertainty.
2. The wildlife sector was generally non-sensitive to changes in indicators and data uncertainty, although the weighting system raised some questions. We may conclude that the FVI in wildlife is sensitive to weighting schemes, and therefore more investigation into the issue is required, in order to arrive at the best weighting system validated by expert opinion.
3. The urban sector is the most complicated stratum of VI since it takes many variables into account (thirty-four variables). The FVI model, however, showed a consistent response to changes in indicators and data uncertainty, although the variation in weighting schemes posed some higher distance to the FVI. Again, the importance of the weighting system is highlighted in the urban sector of vulnerability.

8. Discussion of results

The importance of Comprehensive Emergency Management (CEM) in recent years has been reported by international reports on disasters. As the number and severity of extreme events worldwide are increasing, attempts have been made to achieve better emergency management. The focus of this work is on the vulnerability phase of CEM, which aims at reduction of disaster damage. The devastating natural hazard of flooding has been chosen as the case to which the vulnerability assessment is to be applied. In the following parts the critical points of the work and the results of the vulnerability assessment for the three land strata are discussed.

8.1. Vulnerability framework

The selected conceptual framework (see Figure 3-3) shows vulnerability as an emergent phenomenon of a multi-dimensional system of environmental, physical, economic and social factors. The pillars of vulnerability as well as coping capacities, exposure/susceptibilities, and the characteristics of the scale and place of analysis determine the overall vulnerability.

The validity of the proposed framework is summarised in this part. First, the relationship between vulnerability and risk reduction is clearly verified, which shows the added value of vulnerability analysis within the community. Second, another key element of the framework deals with the dynamic characteristics of vulnerability, where the issues of time and feedback in the framework are highlighted. For example, assessment and adjustment of rescue services within the region is a pre-event activity, whereas efficiency assessment of the help services is a post-event activity which feeds back to the conceptual framework for the next potential event.

Third, vulnerability is defined through four components – environmental, physical, economic, and social – where each component comprises coping capacity and exposure/susceptibility. Recognition of vulnerability through its components and sub-components enables the user to identify the underlying reasons more clearly and more meaningfully. Fourth, the capability of the framework is to offer intervention systems based on the feedback of the vulnerability loop and results. For example, the improvement of the Early Warning System in the region might be suggested as an intervention tool to enhance the coping capacity. Fifth, the dependency of the vulnerability analysis on scale and location is demonstrated in the modified version of the BBC framework. For example, access to radio/TV is a social coping capacity factor for Bangladesh, but not in a developed country such as England, while GDP is an economic factor if the level of analysis is at national level, but income might be a better surrogate for economic exposure in a sub-regional analysis. Finally, the simple interface of the framework is an advantage which encourages non-professional users to become involved and to understand the process of analysis.

Despite all advantages of the selected framework, there are some analytical constraints:

- The analytical differentiation between the components and sub-components is not clear. The findings show that, for instance, better health conditions in the society exhibit higher capacities to cope with flooding; or the number of cars and vans in an area might have social, physical, or economic significance.
- The framework does not account for cross-scale interactions (i.e. the dynamics that take place across various scales). For example, decisions on land use management take place at national level, but have consequences at sub-regional level.
- The existence of external perturbations and stressors that might have considerable impacts on the system has been neglected. The hazards and stressors emerge not only from within the system but also from the external environment.
- Another important issue which is not clearly resolved in the model is the discrimination between exposure and susceptibility components. The vulnerability research community has not yet agreed on a common definition of the two terms. However, in the BBC framework, they have been understood as one component and are placed within the concept of vulnerability.
- The concept of risk might be defined within the framework which is necessary for identification of wider approach of vulnerability which is risk reduction. By selecting and embedding a widely used definition of risk the gap could be filled.

8.2.The complexity of scale

The matter of scale in vulnerability assessment was in debate about a decade ago. However, in recent years this issue has been settled and the discussion has shifted to the implications of multi- and cross-scale approaches. The major challenge in this work, however, was to combine the data from various scales and resolutions and transform them into the unit of analysis (i.e. 1 km grid cells). The decision that the level of analysis should be sub-regional (i.e. the county of the East Riding of Yorkshire) followed the analysis of data availability and relevancy, and end-user demands. While acknowledging the high interactivity across scales, this work cannot claim to have covered all the interlinkages. This study has shown that it is possible to overcome the always-used administrative boundaries with steady, homogeneous units. The technical mismatches of scales were corrected by up- and down-scaling of data into the unit of analysis. Regrettably, the loss of information in the process of data transformation is inevitable. However, this fact has been considered in the weighting process of indicators.

8.3.Indicator selection

Following the methodological approach described in Chapter 3, indicators were selected for the three sectors of land use: 15 indicators for the arable sector, 15 indicators for the wildlife sector, and 34 indicators for the urban sector. The experience of this study shows that there are obstacles in the way of selecting reliable and representative indicators. A perfect indicator hardly exists, owing to data availability and quality and methodological trade-offs between technical feasibility and systemic consistency. Therefore, many challenges have had to be faced to overcome these limitations: (a) proper information on data quality, availability, type, source, and scale; (b) consideration of data inconsistency; (c) the collection process of various datasets; and (d) work preferences regarding data characteristics.

In conclusion, the selection of appropriate indicators required a sequence of steps:

1. building vulnerability categories
2. developing the potential list of indicators

3. evaluation of indicators
4. indicator selection.

8.4. Land stratification

It has been recognised by the author that the indicators participating in the vulnerability index vary with regard to the context of the environment in which the analysis is taking place. Therefore, the region of the East Riding of Yorkshire has been stratified into three sectors of land use: arable, wildlife, and urban. This classification might be a matter of debate since one may say that the forests and wildlife are two separate phenomena to be evaluated in terms of flooding, or that another class such as 'industrial' should be added. These points are all reasonable; however, the approach which has been taken by the present work is an acceptable approach and gives an overview of the situation.

8.5. Flood vulnerability index

A composite vulnerability index was developed to map and visualise vulnerability. Indicators were normalised and weighted in order to form the final composite index. The results, however, are prone to subjective decisions throughout the assessment. The selection of indicators, normalisation method, weighting schemes, and aggregation technique are all subject to scholars' decisions and therefore should be evaluated with extra care. GIS has been widely used in this part, to organise, operate, and map individual indicators and the final composite index.

The vulnerability index is only one aspect of disaster risk. Therefore, for a risk index, the hazard part of the disaster should be considered as well. However, the calculation of flood hazard is not an easy task and involves factors such as flood velocity and duration which in turn require another field of research.

Since the main objective of this work was to map vulnerability in a meaningful way, one natural disaster was used to apply a hazard-specific approach to vulnerability. In this work the flood is defined as a body of water from runoff, river, or tidal origin which rises to overflow onto normally dry land. Therefore, all sources of river, tidal flow, and run-off have been considered as the sources of flooding.

8.5.1. FVI for the arable sector

The methodological process described in Chapter 3 was applied to the arable sector. Indicator selection, normalisation, weighting, and aggregation were carried out in order to extract the final composite indicator. GIS has been successfully used in all phases of assessment and in particular in terms of visualisation of the FVI.

The arable sector is of great importance in the economy of the East Riding. The FVI in this sector shows the most vulnerable parcels in case of flooding. The vulnerability of the region is evaluated through components and sub-components of vulnerability. The components of vulnerability provide the following results:

- Environmental vulnerability (EnVI) is high mostly in the Hull River bed, Humberhead Levels, and Humber Estuary. However, the Yorkshire Wolds (south to north) accommodate cells with remarkably low EnVI.
- The physical vulnerability index (PhVI) is considerably high in the north-east of the Wolds, where there is not sufficient access to coping resources and sources of help (lighter green colour). In contrast, the City of Kingston upon Hull and its surroundings, the northern and eastern part of the Humber Estuary, and the Wolds show very low PhVI. The low PhVIs of the urbanised areas are also noticeable.
- The economic vulnerability index (EcVI) is marked as 'high' in cells in the Humberhead Levels, the north and east of the Estuary, and the Yorkshire Wolds. This index is low in the urbanised areas where the reports of land productivity and livestock are negligible.

The overall FVI of the arable land demonstrates a heterogeneous pattern for the study area (Figure 4-28). There are three main clusters of highly vulnerable cells: the central East Riding, Humberhead Levels, and north of the Humber Estuary. The visualised FVI in the arable sector not only shows the vulnerability within the area and the highest vulnerable parcels in particular, but also identifies the underlying reasons for a high or low index (see Figure 4-29), as the map is associated with a table of components and sub-components index values.

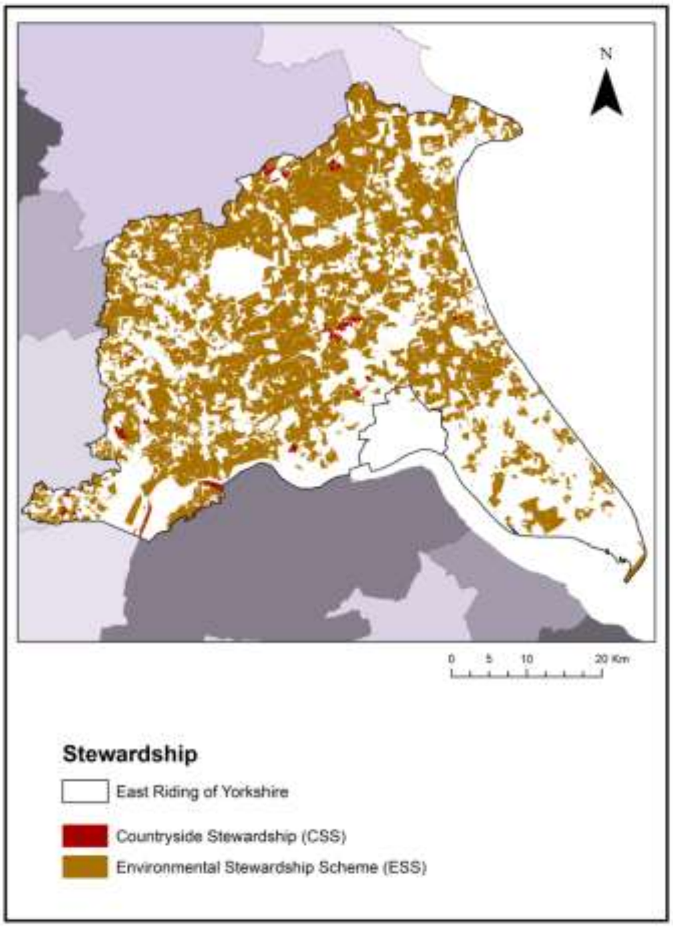


Figure 8-1: Grant incentives for the arable sector

Another benefit of FVI maps is their use by decision makers, who could take the map as the basis for disaster management policies. One example of such usage is the allocation of incentives for arable lands. Figure 8-1 shows an example of grants assigned to farmers. Two grants are displayed; 1) Countryside Stewardship (CSS) was introduced as a pilot scheme in England in 1991 in which payments were made to farmers and other land managers to enhance and conserve English landscapes, their wildlife and history and to help people to enjoy them. This scheme closed to new applicants in 2004 and has been superseded by 2) the Environmental Stewardship scheme (ESS).

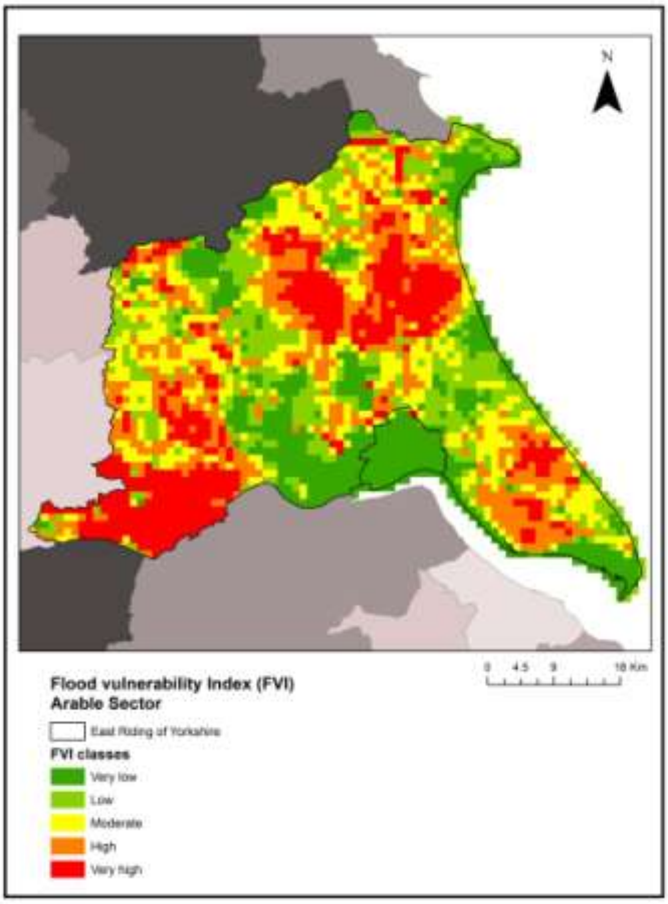


Figure 8-2: FVI for the arable sector

The allocation and amount of grants, however, might be revisited on the basis of Figure 8-2, which shows the most vulnerable arable lands. Furthermore, some special grants might be planned, in particular for farmers whose lands are in "very high" vulnerability zones.

In addition, one may argue that the detailed response of the arable sector to flood water is more complicated than presumed in this work, which uses a general perspective and in which publicly available datasets are employed.

8.5.2. FVI for the wildlife sector

One of the land stratification classes in the area of the East Riding is wildlife, which holds important environmental and economic values, especially because of the massive areas of biodiversity conservation throughout the area. The following conclusions were drawn from the vulnerability analysis in the wildlife sector (Chapter 5):

- The EnVI is high at the Humberhead Levels, Humber Estuary bed, and the surroundings of the River Hull.
- The PhVI is noticeably high in the north, east, and north-east of the region.
- The EcVI is high in the western part of the region, which coincides with the areas of protected natural habitat.
- It is noticeable from Figure 5-16 that the protected areas are mostly classed as “very high”, which is a concern in terms of natural habitat management.
- The urbanised areas are classed as “very low”, because there is less natural habitat and higher access to physical resources.

Currently, there are some grants operated by the Forestry Commission which aim to create and provide stewardship for forests. The English Woodland Grant Scheme (EWGS) offers six grants (Forestry Commission 2013). Figure 8-3 shows the areas supported by EWGS within the East Riding of Yorkshire. Comparing the two maps (Figure 8-3 and Figure 8-4) reveals that there is very little consistency between the two. However, it is recommended from the experience of this work that the pattern of forest parcels with "high" and "very high" vulnerability levels be considered in the allocation of incentives. In addition, extra thought might be given to planning for flood-specific financial support with regards to the resultant map of this research (Figure 8-4).

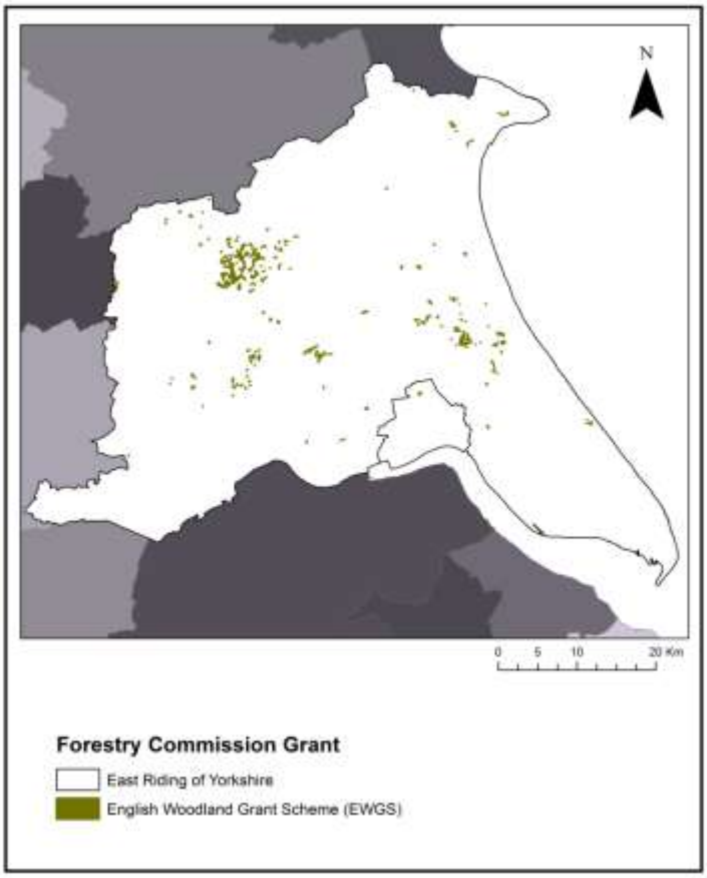


Figure 8-3: EWGS for the wildlife sector

Overall, fifteen indicators of environmental, physical, and economic aspects were used in order to map the vulnerability within the region. However, one may claim that there are more issues and details with regard to natural habitat, woodlands, and wildlife. This study acknowledges the limitations in this regard, since the purpose of the work is a general mapping of vulnerability for wildlife, and the author does not hold any special qualifications in wildlife or woodland subjects. For example, tree species might be included in terms of susceptibility to the impacts of flood water, which calls for special knowledge in this field.

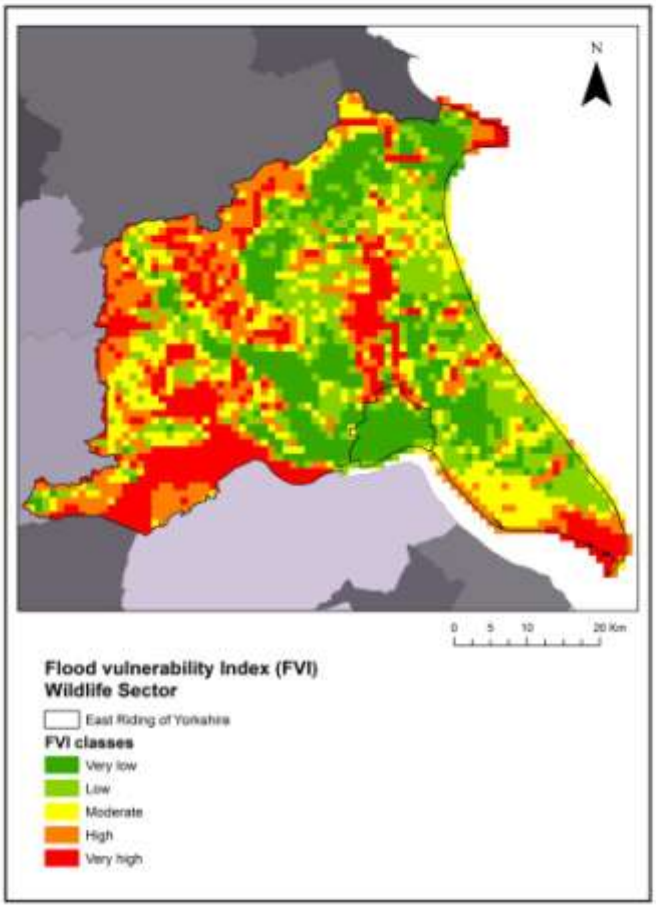


Figure 8-4: FVI for the wildlife sector

8.5.3. FVI for the urban sector

The importance of a flood vulnerability assessment in the context of urban areas has been highlighted by the value of human lives. Overall, thirty-four indicators were selected for the purpose of this work on the basis of the criteria proposed by Birkmann (part 6-5). The following conclusions were drawn:

- Environmental vulnerability presented by six indicators shows high scores at the Humberhead Levels, River Hull bed, and Humber Estuary.
- With eight physical vulnerability indicators, the scores of the PhVI demonstrate that the north-east of the East Riding is noticeably high in terms of flood vulnerability. In addition, the area surrounding Kingston upon Hull is low in phVI.

- Seven factors of economic vulnerability form the final EcVI of the urban sector. The cells with high scores are distributed throughout the area and no clear pattern could be recognised.

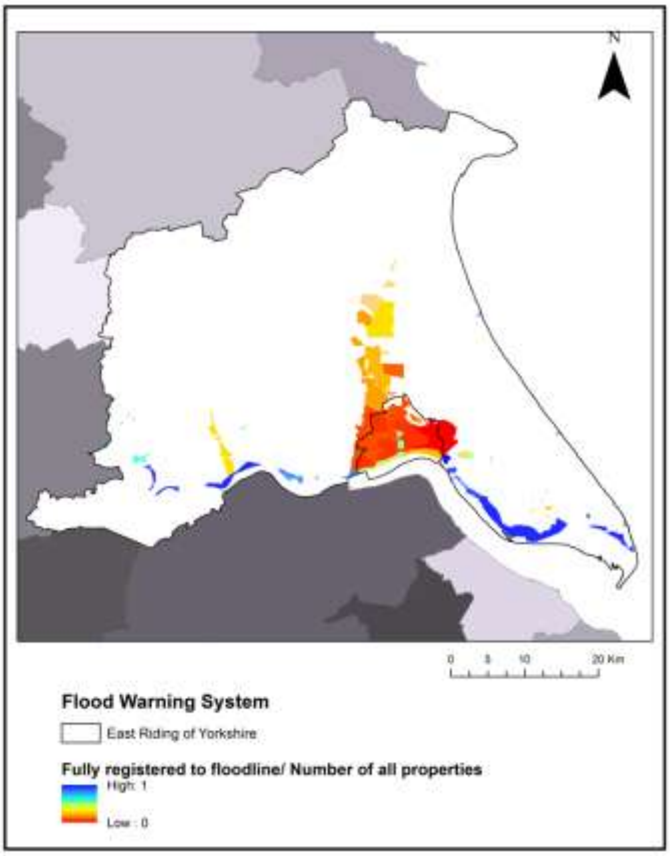


Figure 8-5: Flood Early Warning System

- The social component comprises thirteen indicators and plays an important role in shaping the final FVI of the area. However, owing to the number of variables and the various formats from which they are derived, no significant arrangement could be discerned.
- Twenty-four variables were set up to describe the exposure of communities to the impacts of flooding. Despite the diffused distribution of highly vulnerable cells, the southern edge of the East Riding shows greater exposure and susceptibility to flooding.
- Overall, ten variables of the urban sector demonstrate the level of coping resources of the community in relation to flooding. The map shows relatively higher levels around large cities, especially Kingston and Goole.

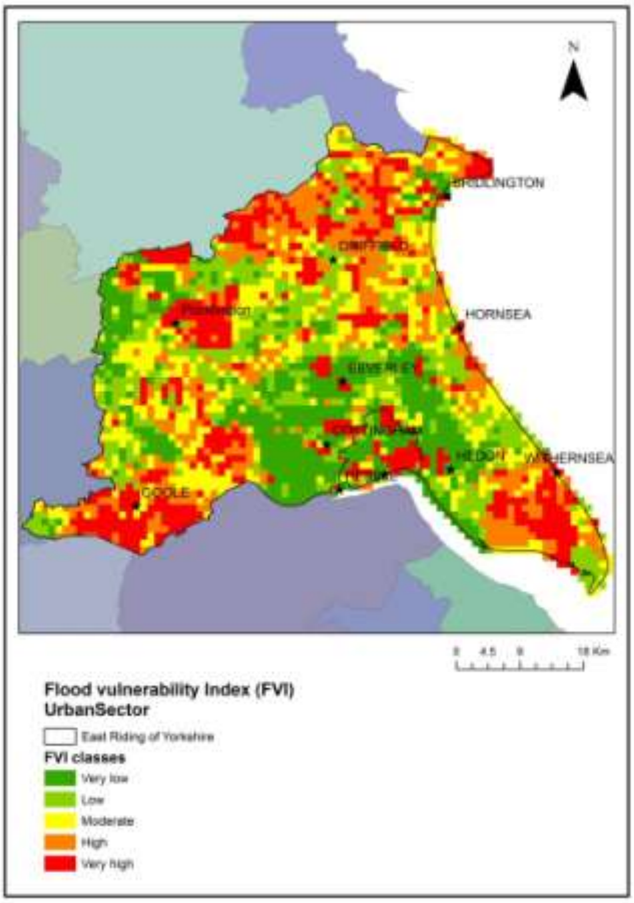


Figure 8-6: FVI for the urban sector

One of the contributions of this work is to recommend highly vulnerable urbanised lands for further flood management. Figure 8-5 shows the extent of areas in the East Riding covered by the Environment Agency's Flood Early Warning System. Compared to the final map of the FVI of the urban sector (Figure 8-6), the FWS does not fully correspond to the lands recognised as "highly" or "very highly" vulnerable. In addition, Figure 8-5 shows that not all properties in the existing FWS zones are fully registered with the flood line. It is recommended by this work that the FVI map (Figure 8-6) be taken as the reference for defining the FWS zones. In addition, the vulnerability classes might be considered as the level of importance of getting people into the flood line.

The flood vulnerability in an urban environment has been studied in more detail at finer spatial resolution (Adelekan 2011, Muller, Reiter et al. 2011, Liao, Chang 2011, Barroca, Bernardara et al. 2006, Adelekan 2010, De Graaf 2008). However, the aim of this work is not an urban-specific assessment but a sub-regional analysis with three sectors of vulnerability. The methods used in this work are based on widely used and general methods, and the indicators are at sub-regional level and based on publically available datasets.

8.6.Evaluation of results

Evaluation of the approach is of great importance since analytical shortcomings and technical uncertainties are part of every work. Therefore, a chapter has been dedicated to a sensitivity analysis of the results.

Four alternative models have been applied to all three sectors of vulnerability. Firstly, a hierarchically based weighting system was altered to the equal weighting scheme. Secondly, the PCA results have been taken as the basic metrics for weighting the indicators. Thirdly, the eigenvalues of the PCA table were considered when the number of variables to be excluded from the list of indicators was being decided. Finally, the value of access to rescue services was assumed to be equal to its mean value.

The correlation and PCA analysis result in very useful information in terms of data mining. The outcomes vary between the three strata, as there are different factors with various statistics and spatial distributions. The GIF is closely correlated with flood zones (FZ) and is therefore omitted from the list of indicators in all three sectors. In the urban sector, retail (RTL), general health (GHLT), and sports centres (SPRT) from the social component are also deleted. The results, however, show the degree of correspondence between the indicators.

The principal component results are valuable tools in determining the most effective indicators contributing to a composite indicator. For the arable sector, four PCs were identified, presenting 54 per cent of the data variation. The wildlife sector displays four PCs, describing 51 per cent of the data variation. The urban sector holds 8 PCs, presenting 62 per cent of the data variation. In addition, the statistical box plot and the skewness, kurtosis, and Gap tests were applied to support the decision made by the sensitivity analysis.

In conclusion, the sensitivity analysis of the three strata of vulnerability revealed that the composite indicator does indeed face different sensitivity characteristics for each of the strata (arable, wildlife, and urban). By looking at the figures and tables of resultant alternative models and the original FVI, it can be concluded that

1. The arable sector FVI did not display sensitivity to change in the weighting system, number of indicators, and data uncertainty.
2. The wildlife sector was generally non-sensitive to change in indicators and data uncertainty; however, the weighting system raised some issues. We may conclude that the FVI for wildlife is sensitive to weighting schemes, and therefore more investigation into the issue is required, in order to get to the best and expertly validated weighting system.
3. The urban sector is the most complicated stratum of VI since it takes into account many variables (thirty-four variables). The FVI model, however, showed a consistent response to changes in indicators and data uncertainty, although the variation in weighting schemes posed some higher distance to the FVI. Again, the importance of the weighting system is highlighted in the urban sector of vulnerability.

Statistical methods were applied (as discussed in Chapter 7: Sensitivity analysis) to assess the quality of the results. However, the robustness of the vulnerability index depends not only on the technical side, but also on the conceptual framework behind the decisions. Therefore, the conceptualisation aspects of the approach need to be evaluated as well. For this purpose, a different framework would be taken, which would then change the point of view from which the phenomenon was examined.

9. Research conclusions and outlook

9.1.Conclusions

A great amount of information has been collected to measure and map vulnerability. The great complexity of the issue and lack of appropriate methods to explore vulnerability in England and with regard to flooding as the hazardous event required the development of a methodology.

One conclusion derived from the review of the literature is that it is not possible and not recommended to establish a universal definition for vulnerability. It is more realistic to define vulnerability, the conceptual framework, related terms, and working definitions on the basis of the characteristics and demands of the approach.

The conceptual framework selected and modified by this research offers a valuable basis for assessing vulnerability and conceiving its characteristics. The BBC framework (Birkmann 2006b) is relatively simple to understand and straightforward to apply. Despite the simplicity, it involves and defines all relevant concepts, and is integrative and practical. The framework highlights the four pillars of sustainable development defined by UN-ISDR, which in fact refer back to the multi-dimensional characteristics of vulnerability. In addition, vulnerability is defined through its two sub-components of exposure/susceptibility and coping capacity.

The components and sub-components cover different aspects of vulnerability and provide a unique insight into the results. Although the BBC framework has been chosen based on the mentioned advantages, but one may argue that other frameworks such as the holistic approach (Cardona 2003, Cardona 2001, Cardona 1999) or Turner's model (Turner, Kasperson et al. 2003) are better choices as they emphasise on other issues such as global environmental change or economic-political aspects of the society. In addition various conceptual frameworks (chapter 2, part 2-4-6) introduce extra concepts within the vulnerability framework such as global environmental change (Turner, Kasperson et al. 2003), risk (Cutter, Boruff et al. 2003), or political economy (Blaikie, Cannon et al. 2004). Therefore it is acknowledged by this research that there are other frameworks for vulnerability assessment which may end up in different results. The comparison of vulnerability results from different models is motivating as a further work.

Indicators play a valuable role in assessing vulnerability. Nevertheless, their selection is not straightforward and relies on the characteristics of the approach, scale, study location, data availability, data accessibility and target group. Consequently, sufficient effort and time need to be dedicated to this phase of the work in order to assure the best possible list of indicators. The proposed approach to indicator development is a method which is sufficient to present the maximum amount of information for decision makers and stakeholders. The integration of environmental, physical, economic, and social indicators portrays a map of flood vulnerability. Overall 15, 15, and 34 indicators were chosen to present vulnerability of the arable, wildlife, and urban sectors respectively. The quantity of the indicators might be a matter of debate as it may get extended or compressed based on the research objectives and/or data availability. It should be stated here that there are some indicators such as insurance which were omitted in this research due to data access restriction. In addition, an adequate questionnaire could be a valuable source of qualitative indicators which was omitted in this research due to work time limitations.

The resultant map reflects the vulnerability scores of the East Riding of Yorkshire. The composite vulnerability index provides valuable information about the underlying components and sub-components of vulnerability. Not only the map of vulnerability index but also the details of the scores for components and sub-components are provided for the target groups. However, there are more options to be added to the vulnerability maps if time permitted. Designing interactive maps, online maps, maps which make use of up-to-date data, and 3D maps are some extra opportunities that could be applied. The quality and applicability of the resultant maps can be evaluated by a series of meetings with decision makers and local governors which again is missed in the present study due to time limits. However, this sort of evaluation is strongly recommended by the author as a further objective.

Sensitivity analysis is a way of forecasting the outcome of a decision if the situation turns out to be different in relation to the key indicators. The variety of tests and their quantity have proved to improve the result of the validation. However due to timetable limitations of the work only three tests were applied on data and results were discussed (chapter 7).

In response to the first research question (i.e. how can the concepts of vulnerability and flood management be linked to each other?) and the second one, (i.e. which conceptual framework facilitates best the assessment of vulnerability?) (see chapter 1, part 1-3), it is concluded from the literature that reducing the vulnerability of the community can greatly lessen flood damage and risk. So, the assessment of vulnerability is one of the key elements of flood management. However, the evaluation of other related concepts such as flood risk and hazard in separate chapters could greatly enrich this research. The United Nations framework (BBC framework) has been chosen for the purpose of this work, although some modifications were made to make the framework appropriate as suggested in research question 2.

In order to answer the third research question (i.e. what are the indicators of vulnerability?), a list of potential indicators was extracted from the extensive literature on vulnerability. On the basis of the selection criteria (discussed in the methodology chapter), the final indicators were chosen, normalised, weighted, and integrated to form the final vulnerability index. The composite indicator of vulnerability therefore gives a comprehensive insight into vulnerability and reveals the underlying reasons (research question 5, i.e. what is the best methodology to create a vulnerability index?). However, it is an important point to consider that there are much more options in terms of indicator's selection criteria, normalisation methods, weighting schemes, and integration formula which in turn are matters of further study to validate the results of vulnerability scores and maps. However, the choices made by the author in this work are the most recommended and applied.

GIS has been taken as the basis of some of the contributions of this research in order to answer the fourth research question (i.e. how can GIS thinking and functions be implemented to overcome the technical issues in datasets?). The stratification of vulnerability based on the land use sectors is one of the most important contributions of the present work. In addition, the presentation of vulnerability scores as a rasterised map is a unique advantage of this research. The implementation then requires specific methods of data transformation. The process of visualisation of the indices is a critical step towards the presentation of the research results. Although a raster map with 1 km cell size has been chosen as the output map but there are other options such as administrative boundaries, finer resolution cells, or coarser grid cells which might be considered in the evaluation of results.

A variety of statistical tests have been performed in order to evaluate the results of the approach (research question 6, i.e. how the quality of results can be evaluated?). Correlation and PCA analysis were used to explore the results. Sensitivity analysis was applied to explore the change in outcomes which occurs if the input data or methodology changes. The approach which was taken showed a method of surveying the sensitivity of the composite vulnerability index. However it is noteworthy to mention the variety of sensitivity analysis methods. In addition, number of tests and their variation could get improved in order to make more certain decision in terms of sensitivity of the proposed approach. The applied tests in the sensitivity chapter are only most recommended and therefore are matter of further study.

The last research question, (i.e. is the developed approach transferable to other countries?), deals with the transferability of the findings of the research. This approach and the selected methods and datasets are easy to transfer across the English districts as the model is modified to suit the vulnerability assessment for the whole of England and data sets are accessible throughout the country. Transferability at the international level has to be made stepwise, since the characteristics of the work would change.

- The modified framework can be applied anywhere around the world. Since the framework is relatively new, few studies have actually used it for vulnerability assessment, therefore the modified version can provide added value to the analysis.
- In general, the indicator-based approach can be applied anywhere. However, the selection criteria and methodology for indicator development should be adopted on the basis of the characteristics of the study.

- The method used to build the composite indicator is applicable for any other work. The choice of normalisation, transformation, weighting, and aggregation methods should always be based on the underlying data and purpose of the study.

Evaluation of results is a part of every vulnerability analysis. Sensitivity analysis, which is applicable to any other analysis, was carried out in this work. Though, evaluation of mapping the result was not included in this work due to time limitation. Maps could be evaluated by experts, decision makers, and local governors.

Despite all the advantages of the present work, there are further works that could have been carried out if time permitted. The next part discusses these options in more detail.

9.2.Research outlook and further work

This research aimed to assess vulnerability on the basis of GIS techniques. The present approach holds great advantages that have been discussed in the previous parts. Nevertheless, there are some applications which could be counted as possibilities for further study of the present work.

Further study could look into the technical and analytical aspects of the approach. Although this work endeavoured to cover all the components of vulnerability, temporal and financial limitations left some issues for future pursuit.

Throughout the work it was found that the exploration of geological traces of flooding and the relationship between risk, vulnerability and the geology of a place could open up a great field of research.

One of the most interesting fields of future research is taking the FVI maps as the basis of the location-allocation of rescue and help services throughout the region. This study holds unique value for emergency management and flooding in particular.

Further research could look into the GIS implementation. First, the present work has made the unit of analysis a 1 km grid cell. However, improving the cell size or even switching to administrative boundaries could provide some extra information about vulnerability and its components. Second, the choice of kernel density buffer applied in transforming the point data into grid cells might vary and an optimum radius might be suggested. Third, the unit of analysis might be altered to administrative boundaries.

One of the main limitations of the present work was the time. If more time was allocated, the validity of the data could be further investigated and hence the outcome could be enhanced. For example, farm locations from Ordnance Survey datasets need to be verified to ascertain if they are active and at what time of year.

The role of indicators and their participation in forming the final index has been proven. Therefore, the alternation of the methods used for normalisation, transformation, weighting, and integration is of great interest to further research in vulnerability assessment.

Vulnerability is the least-studied component of risk and therefore has been selected as the focus of this study. However, the findings of this study could well be used in further research into risk assessment in the region. In addition, moving to other vulnerability assessments for other hazardous events and even a non-hazard-specific approach could be relevant.

The effect of climate change on natural disasters has been studied by many researchers (Adger 1999, Penning-Rowsell, Peerbolte et al. 1992, Fussel 2007, Keogh, Apan et al. 2011, EEA 2008, Intergovernmental Panel on Climate Change (IPCC) 2001, Wilbanks 2002, Walls, Barichivich et al. 2013, Cooper, Hunt et al. 2009, Glaas, Juhola 2013). The evaluation of the contribution of climate change to the vulnerability of a community is yet to be assessed, however, and therefore is a great topic for further research.

Appendix 1

Flood history in the East Riding of Yorkshire.

Source: East Riding of Yorkshire Council, 2011b: Preliminary Flood Risk Assessment.

Flood ID	Summary description	Location	Location description	Start date	Main source of flooding	Main mechanism of flooding
Events of national significance						
1	1256. A 'great storm' (date unknown) affected much of the east coast of England. Signifcant changes appear to have been caused to the Humber frontage, particularly to the east of Hull. Records describe the washing away of embankments and the flooding of large areas of farmland by the sea. Several hamlets also appear to have been washed away. It is likely to have been caused by a breach of Spurn Point. As well as the loss of farmland loss of safe haven where watecourses enter the Humber are also recorded.	East Yorkshire	Farmland and hamlets in south Holderness	1256	The sea	Defence exceedance
2	1947, 20th March. Major national event (30 of 40 counties suffered severe floods). Earlier flooding on west/north/south Yorkshire rivers moved eastwards causing extensive flooding around Selby as the Ouse, Wharf, Aire, Derwent and Don all burst their banks. Within this region regarded as the worst flood since 1831.	East/ North Yorkshire	Greatest effects between Goole and Selby and along the Derwent	1947-03-20	Main rivers	Defence exceedance
3	1953 31st January. A major depression over the northern North Sea caused a storm surge that affected large parts of the east coast, leading to the breaching, overtopping and washing away of coastal defences. There was significant loss of life, particulary in Lincolnshire and Essex, as the surge struck at night.	East Yorkshire	Much of the east coast of England, from the Humber to the Thames. Flooding around Kilnsea, Skeffling	1953-01-31	The sea	Defence exceedance

			recorded			
4	2000,4th November. The wetest autumn since 1766 caused the highest floods since 1947, though were less extensive in area flooded. Defences on the Aire at Gowdall gave way and flooded land to the south of the river. The Derwent at Stamford Bridge recorded its highest ever levels. Flooding of smaller land drains in Haltemprice and west Hull and south Holderness. Flooding to Beverley & Barmston and Holderness drains (main rivers). Widespread flooding of farmland around Frodingham. Widespread flooding of farmland in the Foulness sub-catchment.	East Yorkshire	Gowdall,Stamford Bridge,Howden,south Holderness,Frodingham,Stamford Bridge	2000-11-04	Main rivers	Defence exceedance
5	2007, 25th June. Major surface water flooding following second intensive rainfall event that month (15th June). Up to 125mm rainfall in one day. Widespread flooding in S & E Yorkshire and Gloucestershire in particular.	East Yorkshire	The whole of the Authority area	2007-06-25	Surface runoff	Natural exceedance
Events of local significance						
6	1373, October. Flooding of Hull from streams coming off the Wolds. Flooding of farmland near Goole due to overtopping of defences of the Trent	East Yorkshire	The western parts of Hull. Land east of Goole	1373-10	Ordinary water courses	Natural exceedance
7	1657, 10th July. A 'great flood' in Langtoft. A stone in a house records a flood depth of 8 feet	East Yorkshire	Langtoft	1657-07-10	Surface runoff	Natural exceedance
8	1697, 20th December. A quick thaw of a heavy snowfall three days earlier caused widespread flooding from the Dutch River between Thorne and Goole. Raised defences were breached and bridges were damaged	East Yorkshire	Goole	1697-12-20	Main rivers	Defence exceedance
9	1790 (midpoint). Increasing frequency of overflowing of fleets (modified natural ordinary watercourses acting as land drains) onto arable land owing to silting up of the Humber and	East Yorkshire	Farmland in south Holderness	1730 to 1850	Ordinary water courses	Natural exceedance

	construction of clows (cloughs) to stop tidal flooding					
10	1846, April. Widespread flooding along the Derwent following a period of heavy rainfall.	East Yorkshire	Derwent valley	1860-04	Main rivers	Natural exceedance
11	1860. A 'great flood' on the Gypsey Race	East Yorkshire	Bridlington?	1860	Main rivers	Natural exceedance
12	1872, December. Low land in Beverley was under water for three months. Large tracts of wheat and turnips destroyed. Similar flooding reported in the Derwent valley	East Yorkshire	Beverley, Little Driffield	1872-10	Main rivers	Natural exceedance
13	1882, December. Widespread flooding along the Derwent following snowmelt	East Yorkshire	Derwent and Rye valleys	1882-12	Main rivers	Natural exceedance
14	1880, 14th September. 2.95" of rain recorded at Wold Newton on the day, with most falling between 7.30 and 9.30 p.m., the consequences being described as disastrous	East Yorkshire	Wold Newton	1880-09-14	Surface runoff	No data
15	1887, January. Rivers and floods appeared in dry chalk valleys, with water unable to penetrate the soil, after a hard December freeze.	East Yorkshire .	Land around Wetwang	1887-01	Surface runoff	Natural exceedance
16	1888, 9th June. A sudden storm flooded Langtoft village centre and created three deep channels in the hillside to the west of the village. Several hundred tons of soil and boulders were brought down the hills and into the village. Water rose to four feet deep in houses within two hours, the stream being 40 feet wide. Destruction of farms and farmland recorded	East Yorkshire	Langtoft	1888-06-09	Surface runoff	Natural exceedance
17	1892, 3rd July. Severe storm over the Wolds caused flash floods in Langtoft, Driffield and Bridlington as water courses overflowed. Four flood waves recorded in one day in Driffield. Waterspouts recorded over the Wolds. River Hull headwaters and Gypsey Race in flood. Severe erosion of hillside topsoil, it being washed into valley floors	East Yorkshire	Langtoft, Driffield, Bridlington, Wetwang, Thixendale	1893-07-03	Surface runoff	Natural exceedance

18	1892, 14th October. Severe floods in Driffield - 2.09" rain (highest ever daily record)	East Yorkshire	Driffield	1892-10	Surface runoff	Natural exceedance
19	1910, 20th May. A thunderstorm between 4 and 5 a.m. generated up to 2 feet of hail. Water ran several feet deep through the town. Several bridges were destroyed. Flood waters up to 6 feet deep in properties. One child drowned. All but 3 houses in Weaverthorpe vilage were submerged in mud	East Yorkshire	Driffield. Weaverthorpe	1910-05-20	Surface runoff	Natural exceedance
20	2004, August 25th.Downpour left homes in East Yorkshire under 2 feet of water. Beverley, Driffield and Nth Froddingham affected. Flooding particularly bad between Driffield and Beverly	East Yorkshire	Driffield, North Froddingham, Beverley	2004-08-10	Surface runoff	Natural exceedance
21	2005, June. 'Record levels' in the Derwent caused widespread flooding along the valley	East Yorkshire	Stamford Bridge	2005-06	Main rivers	Defence exceedance
22	2006, June 13th. Several communities in East Yorkshire suffered flash floods. Up to 2 feet of water on some roads in Market Weighton	East Yorkshire	Market Weighton	2006-06-13	Surface runoff	Natural exceedance
23	2006, July 27th. Flash floods in East Yorkshire after heavy downpours and hail storms. Flooding in main street in Willerby 2 feet deep. Restaurant in Ferriby Rd Hessle flooded.	East Yorkshire	Willerby, Hessle	2006-07-27	Surface runoff	Natural exceedance
24	2006, August 24th. Storm over Wakefield tracked east and caused flooding in Goole and Scunthorpe	East Yorkshire	Goole	2006-08-24	Surface runoff	Natural exceedance
25	2007, July 3rd. High volume pump deployed to pump water from Hull streets. Water waste deep in some parts of the city. Up to 2m of water in some houses in Beverly	East Yorkshire	Beverley, Hull	2007-07-03	Surface runoff	Natural exceedance
26	2007, July 16th. Flood waters had to be cleared from properties in Camerton. Also flooding in Newbegin, Hornsea.	East Yorkshire	Camerton, Hornsea	2007-07-16	Surface runoff	Natural exceedance

Appendix 2

Indicators fact sheets and maps

- **Indicator: Geological Indicators of Flooding (GIF)**

Variable: Geological Indicators of Flooding (Version 6)

Sector: arable/ wild life/ urban

Component: Environmental

Sub-component:

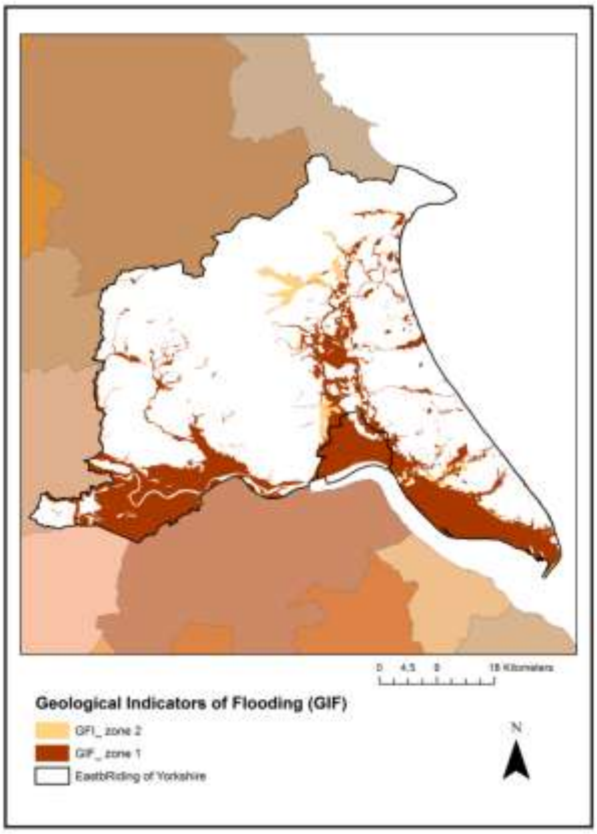
Exposure/Susceptibility

Data source: British Geological Survey (BGS)

Temporal resolution: January 2011

Spatial resolution/ scale: 1:50 000

Data type: vector polygon



Description:

The BGS Geological Indicators of Flooding (GIF) dataset is a digital map based on the BGS Digital Geological Map of Great Britain at the 1:50,000 scale. Current coverage includes England, Wales and Scotland. It characterises superficial deposits on DiGMapGB-50 version 6.18 in terms of their likely susceptibility to flooding, either from coastal inundation or fluvial (inland) water flow. On this basis, the floodplains and coastal plains constituting areas at greatest risk from flooding can be both visualised and defined by superficial deposits as depicted on geological maps. These include deposits such as river alluvium and lacustrine (lake) alluvium (Booth, Wildman 2010).

In summary, GIF includes categorisation of deposits that may be susceptible to: 1) Fluvial Zone 1 & Zone 2: Flooding from rivers where the capacity of the river channel is exceeded and water overflows. This is identified as "fluvial" in the GIF, and is subdivided into higher (zone 1) and lower (zone 2) susceptibility categories; 2) Coastal Zone 1 & Zone 2: Flooding from the sea as a result of high tides and storm surges is identified as “coastal” flooding in the GIF. This is similarly subdivided into higher (zone 1) and lower (zone 2) susceptibility categories (Booth, Wildman 2010).

- **Indicator: Flood zones (FZ)**

Variable: Flood zones 2 & 3

Sector: arable/ wild life/ urban

Component: Environmental

Sub-component: Exposure/Susceptibility

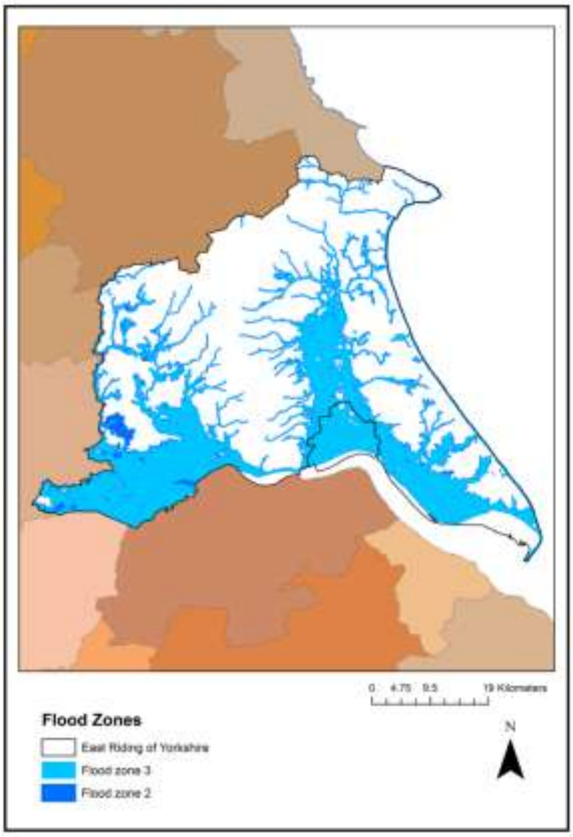
Data source: Environment Agency

Temporal resolution: 2012

Spatial resolution/scale: 1:10 000

Data type: vector polygon

Description:



These are areas, also known as flood plains, which could be affected in the event of flooding from rivers and the sea. For rivers, detailed survey data has been used to provide information about the topography or ground surface, and then combined with information on flows. For coastal areas, survey data and analysed sea level and wave data have been taken. Therefore it is possible to work out the water level at the coast and how the water could flood inland (The Environment Agency 2011). Where detailed mapping is not available, data has been supplemented with national generalised modelling based on a combination of (The Environment Agency 2006):

- ✓ A digital terrain model from Intermap Technologies;
- ✓ Detailed terrain mapping using more detailed LiDAR technology (an airborne mapping technique, which uses a laser to measure the distance between the aircraft and the ground).

Flood Zone 2 shows areas of land with an annual probability of flooding of 0.1% or greater from rivers and the sea, but with an annual probability of flooding of less than 1% from rivers or 0.5% from the sea. Flood Zone 3 shows areas of land with an annual probability of flooding of 1.0% or greater from rivers, and 0.5% or greater from the sea. Flood Zone 2 shows areas of land with an annual probability of flooding of 0.1% or greater from rivers and the sea, but with an annual probability of flooding of less than 1% from rivers or 0.5% from the sea. Flood zone 1 is everywhere in England and Wales not covered by zones 2 or 3(Environment Agency 2009).

- **Indicator: Pollution Incidents (PI)**

Variable: Pollution Incident

Sector: arable/ wild life/ urban

Component: Environmental

Sub-component: Exposure/Susceptibility

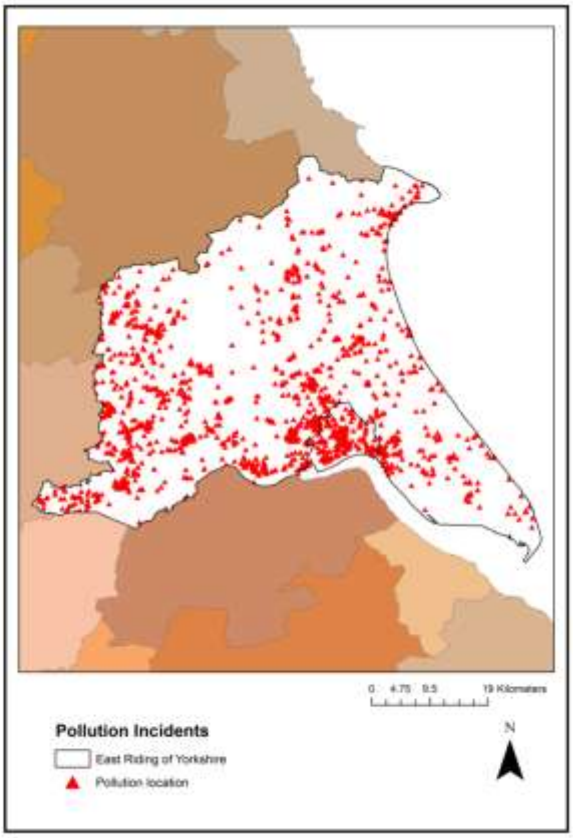
Data source: Environment Agency

Temporal resolution: 2001-2012

Spatial resolution/ scale: 1:10 000

Data type: vector point

Description:



The data is a filtered version of all incidents held on National Incident Recording System (NIRS2). Data supplied includes only substantiated, environmental protection incidents, where the environmental impact level is either category 1 (major) or category 2 (significant), to at least one media (i.e. water, land or air). Data is georeferenced and the pollutant category is included. A pollution incident is defined as 'A specific event, which is being brought to the attention of the Agency, and is within the Agency's areas of responsibility and which may have an environmental and/or operational impact (The Environment Agency 2011).

- **Indicator: Groundwater area (SPZ)**

Variable: Source Protection Zones

Sector: arable/ wild life/ urban

Component: Environmental

Sub-component:

Exposure/Susceptibility

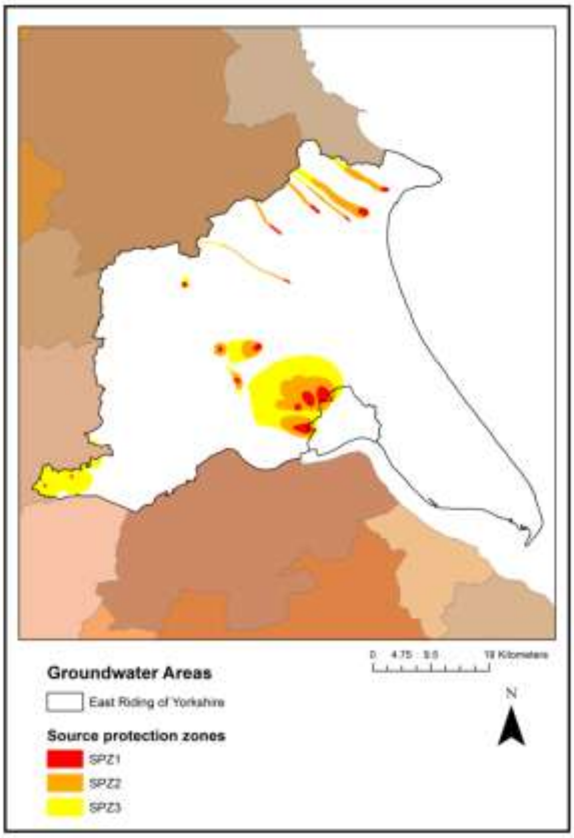
Data source: Environment Agency

Temporal resolution: 2011

Spatial resolution/ scale: 1:50 000

Data type: vector polygon

Description:



Source Protection Zones (SPZs) have been defined for 2000 groundwater sources such as wells, boreholes and springs used for public drinking water supply. These zones show the risk of contamination from any activities that might cause pollution in the area. The closer the activity, the greater the risk. The shape and size of a zone depends on the condition of the ground, how the groundwater is removed, and other environmental factors.

SPZ1 – Inner protection zone: Defined as the 50 day travel time from any point below the water table to the source. This zone has a minimum radius of 50 metres.

SPZ2 – Outer protection zone: Defined by a 400 day travel time from a point below the water table. This zone has a minimum radius of 250 or 500 metres around the source, depending on the size of the abstraction.

SPZ3 – Source catchment protection zone: Defined as the area around a source within which all groundwater recharge is presumed to be discharged at the source. In confined aquifers, the source catchment may be displaced some distance from the source. For heavily exploited aquifers, the final Source Catchment Protection Zone can be defined as the whole aquifer recharge area where the ratio of groundwater abstraction to aquifer recharge (average recharge multiplied by outcrop area) is >0.75 (The Environment Agency 2011).

- **Indicator: Landfill sites (LFS)**

Variable: Authorized landfill sites

Sector: arable/ wild life/ urban

Component: Environmental

Sub-component: Exposure/Susceptibility

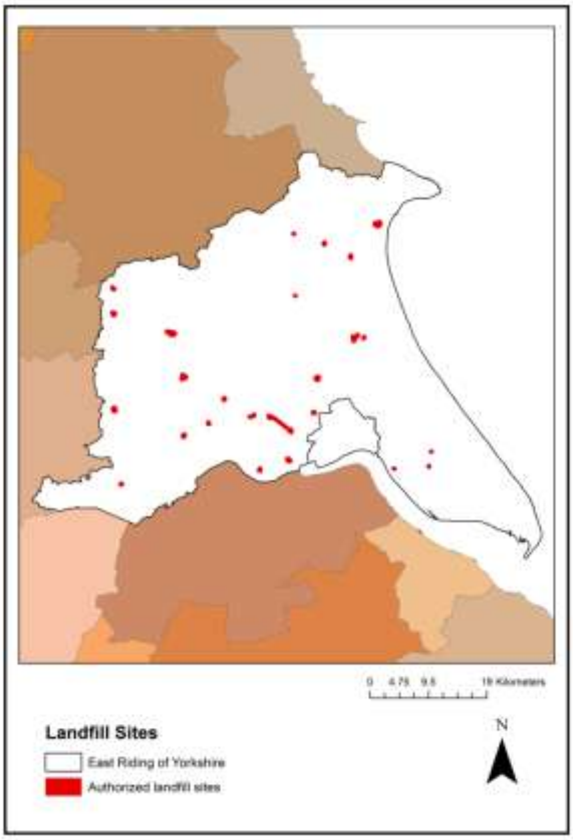
Data source: Environment Agency

Temporal resolution: 1975-2011

Spatial resolution/scale: 1:10 000

Data type: vector polygon

Description:



Landfill sites are where local authorities and industry can take waste to be buried and compacted with other wastes. The Environment Agency licenses and regulates landfill sites to ensure that their impact on the environment is minimised. The map shows the boundaries of each landfill site drawn from the plans. However, the small scale of these maps makes it hard to be 100% accurate. Generally, the boundaries follow field boundaries or roads and in most cases are within five metres of the actual boundary. Where a boundary is not available in electronic format, the site is shown as a dot (The Environment Agency 2011).

- **Indicator: Contaminated Land (CL)**

Variable: Contaminated Land

Sector: arable/ wild life/ urban

Component: Environmental

Sub-component: Exposure/Susceptibility

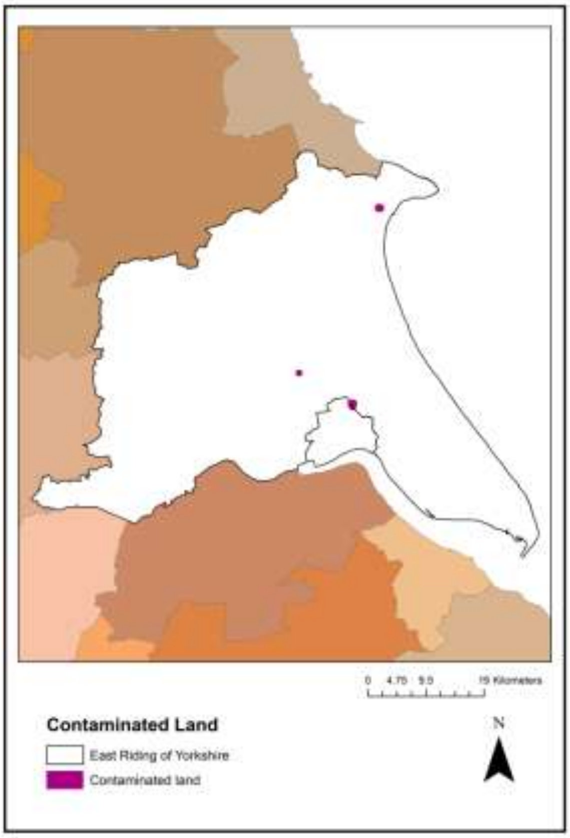
Data source: Environment Agency

Temporal resolution: 2012

Spatial resolution/scale: 1:10 000

Data type: vector polygon

Description:



Defined for non-radioactively contaminated land in section 78A(2) of the Environmental Protection Act 1990 as "any land which appears to the local authority in whose area it is situated to be in such a condition, by reason of substances in, on or under the land, that (a) significant harm is being caused or there is a significant possibility of such harm being caused, or (b) pollution of controlled waters is being, or is likely to be caused." There is increasing pressure to reuse land which is affected by contamination rather than develop greenfield sites such as parks or woodland (The Environment Agency 2011).

- **Indicator: Surface water (SWF)**

Variable: Flood Map from Surface Water (FMfSW)

Sector: arable/ wild life/ urban

Component: Environmental

Sub-component: Exposure/Susceptibility

Data source: Environment Agency

Temporal resolution: 2010

Spatial resolution/scale: 1:10 000

Data type: vector polygon

Description:

The Environment Agency's surface water flood maps give an indication of the broad areas likely to be at risk of surface water flooding. In 2010 the Flood and Water Management Act defined 'surface runoff'. Generally, the type of flooding shown by the

Flood Map for Surface Water (FMfSW) fits with the definition in the Act and shows the flooding that takes place from the 'surface runoff' generated by rainwater (including snow and other precipitation) which: a) is on the surface of the ground (whether or not it is moving), and b) has not yet entered a watercourse, drainage system or public sewer. The FMfSW will pick out natural drainage channels, rivers, low areas in floodplains, and flow paths between buildings. But it will only indicate flooding caused by local rainfall. It does not show flooding that occurs from overflowing watercourses, drainage systems or public sewers caused by catchment-wide rainfall events or river flow. It is therefore very important that users apply local knowledge and in particular the 'locally agreed surface water information' held by the lead local flood authority to assess how suitable the Flood Map for Surface Water is for their needs (The Environment Agency 2011). 30 year FMfSW has 1 in 30 chance of rainfall events occurring in any year. However, users must note that this is the chance of this rainfall, and not of the resulting flood extent occurring. Consequently it only provides a general indication of areas which may be more likely to suffer from surface water flooding in these rainfall probabilities (The Environment Agency 2011).

- **Indicator: Permeability (PRB)**

Variable: Permeability Index (Version 6)

Sector: arable/ wild life

Component: Environmental

Sub-component: Coping Capacity

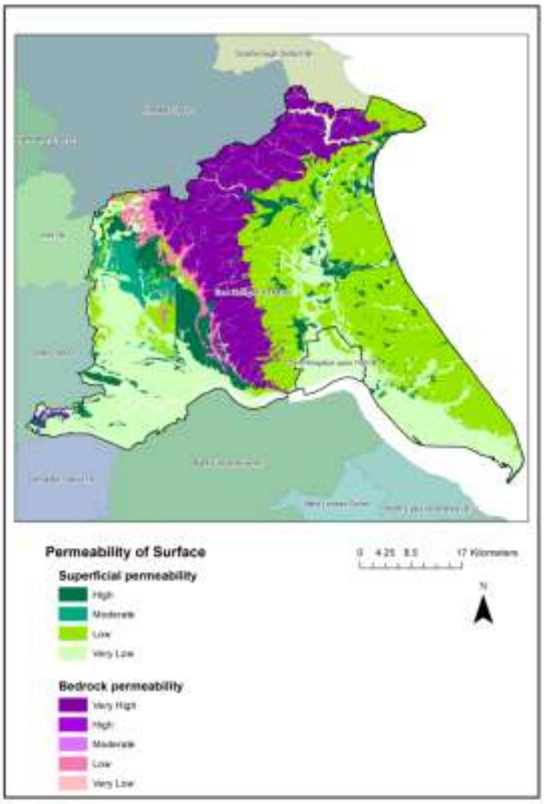
Data source: British Geological Survey (BGS)

Temporal resolution: 2010

Spatial resolution: 1:50 000

Data type: vector polygon

Description:



The Permeability dataset is a derived data product based on an attribution of the 1:50 000 scale BGS digital geological mapping, DiGMapGB-50. It provides a qualitative classification of estimated rates of vertical movement of water from the ground surface through the unsaturated zone, the zone between the land surface and the water table.

The Permeability Index codes have been allocated to every mapped lithology (or combination of lithologies) for each rock unit in DiGMapGB-50. This has been carried out for all four types of deposit shown as separate layers or themes in the DiGMapGB-50 (artificial ground, mass movement deposits, superficial deposits and bedrock) dataset.

- **Indicator: Construction and repair services (CONS)**

Variable: Points of Interest- Construction and repair services

Sector: arable/ wild life/ urban

Component: Physical

Sub-Component: Coping Capacity

Data source: Ordnance Survey

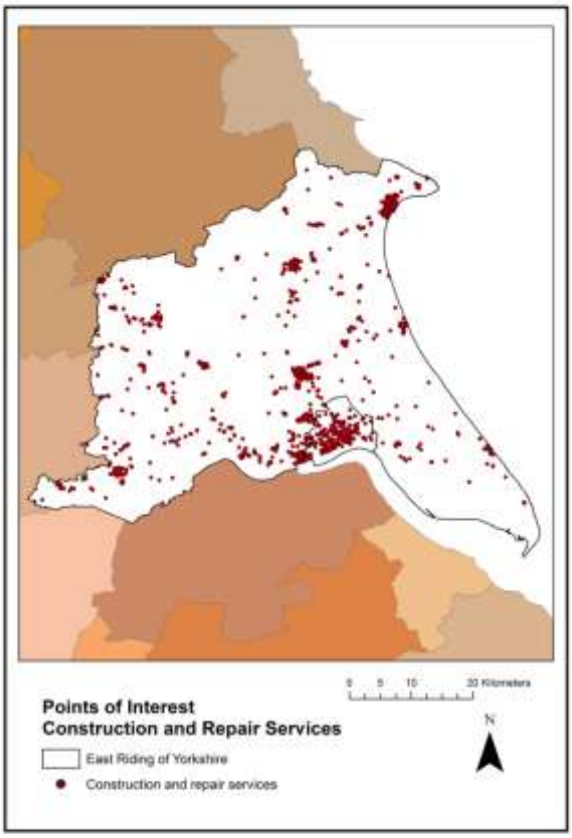
Temporal resolution: 2012

Spatial resolution/ scale: ± 1m

Data type: vector point

Description:

"Points of Interest" (POI) is a dataset containing around four million different geographic features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes: accommodation, eating and drinking, commercial services, attractions, sport and entertainment, education and health, public infrastructure, manufacturing and production, retail, and transport (Ordnance Survey 2013). The "Construction and repair services" class shows places that provide repair and construction services. These services are useful sources of help before, during and after flooding and are therefore counted as coping capacity indicators.



- **Indicator: Central and local government (RESC)**

Variable: Points of Interest- Central and local government

Sector: arable/ wild life/ urban

Component: Physical

Sub-Component: Coping Capacity

Data source: Ordnance Survey

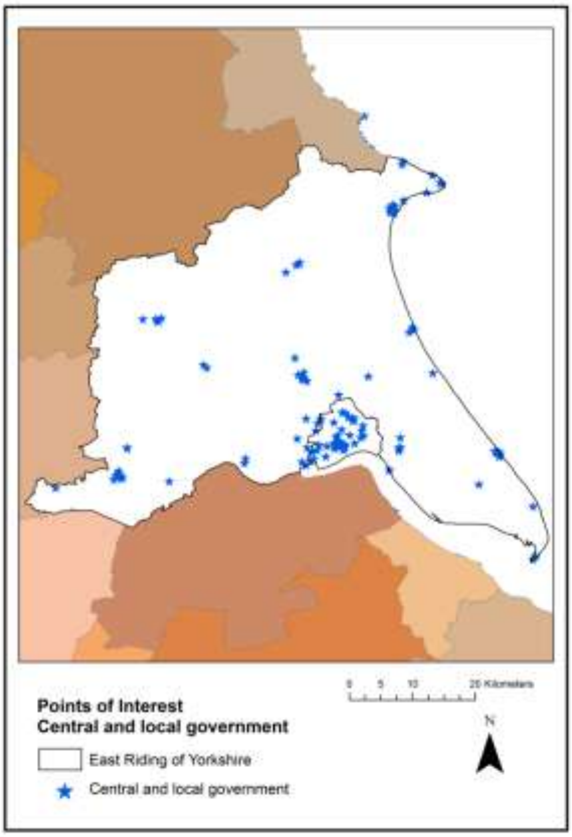
Temporal resolution: 2012

Spatial resolution/ scale: ± 1m

Data type: vector point

Description:

"Points of Interest" (POI) is a dataset containing around four million different geographic features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes: accommodation, eating and drinking, commercial services, attractions, sport and entertainment, education and health, public infrastructure, manufacturing and production, retail, and transport (Ordnance Survey 2013). The "Central and local government" class shows places of government related services such as police stations, armed services, and fire brigade stations. These services are important sources of help before, during and after flooding and therefore are counted as coping capacity indicator.



- **Indicator: Transport-train stations (TRN)**

Variable: Points of Interest- Transport-train stations

Sector: arable/ wild life/ urban

Component: Physical

Sub-Component: Coping Capacity

Data source: Ordnance Survey

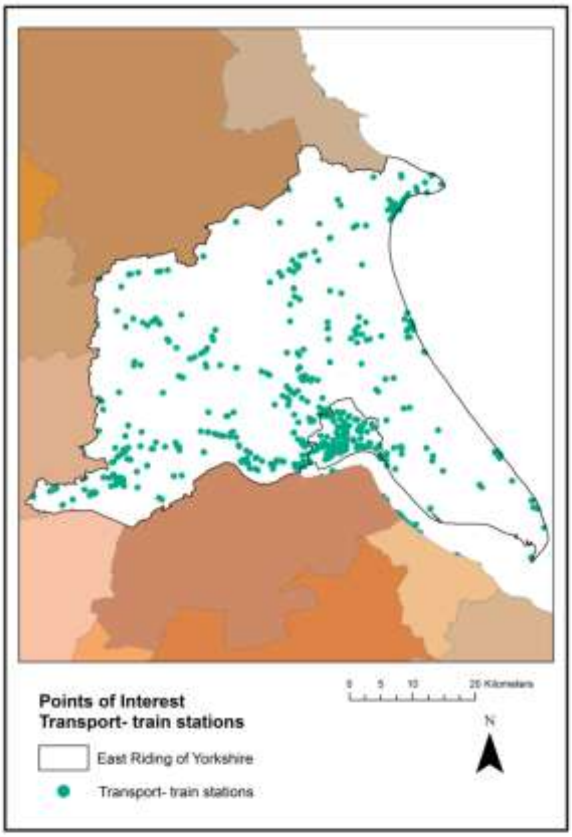
Temporal resolution: 2012

Spatial resolution: ± 1m

Data type: vector point

Description:

"Points of Interest" (POI) is a dataset containing around four million different geographic features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes: accommodation, eating and drinking, commercial services, attractions, sport and entertainment, education and health, public infrastructure, manufacturing and production, retail, and transport (Ordnance Survey 2013). The "Transport-train stations" class shows train stations location. Train stations are useful sources of help before, during and after flooding and are therefore counted as coping capacity indicator.



- **Indicator: Roads (ROAD)**

Variable: Roads network

Sector: arable/ wild life/ urban

Component: Physical

Sub-component: Coping Capacity

Data source: VectorMap District

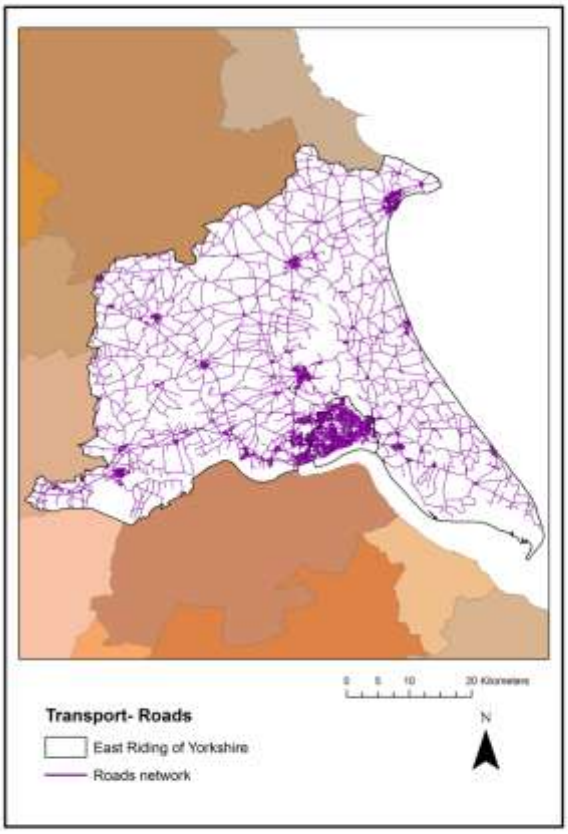
Temporal resolution: 2011

Spatial resolution/ scale: 1:25 000

Data type: vector polyline

Description:

Road alignments are approximate to the road centre lines. Certain types of road have a road name and/or a road number held as attributes of the road alignment. Where a road alignment passes under another road or railway then the alignment is trimmed back either side of the bridge. These features are represented as lines. Road alignments will have one of the following classifications, each of which can be separately identified by the 'Classification' attribute: Motorway, Primary Road, A Road, B Road, Minor



Road, Pedestrianised Street, Local Street, Private Road, Publicly Accessible (Ordnance Survey 2013).

- **Indicator: Household Type (MOHS)**

Variable: Mobile houses

Sector: urban

Component: Physical

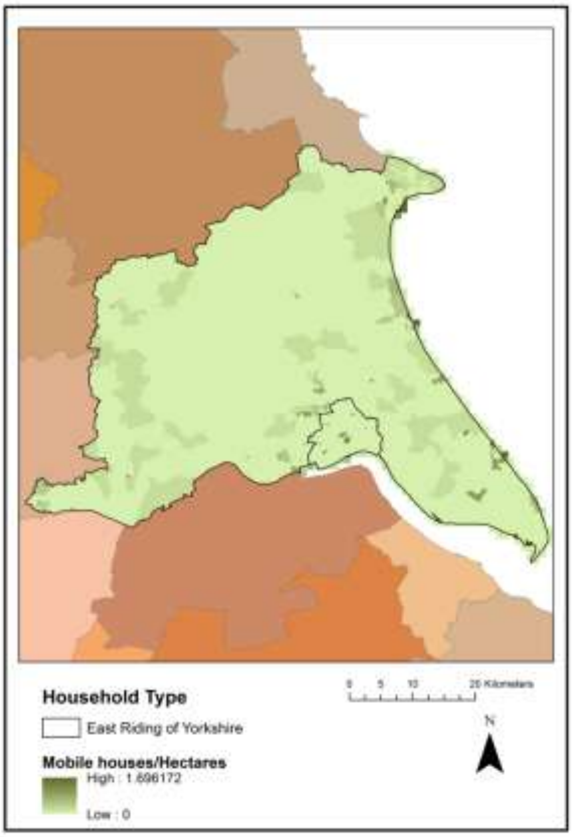
Sub-component: Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:



Casweb is a web interface providing access to aggregated information from the 1971, 1981, 1991 and 2001 UK censuses. The Casweb service of the Census Dissemination Unit (CDU) has been enhanced to provide users with digital boundary data to accompany 2001 census data downloads in a range of standard GIS formats ready for mapping and spatial analysis. Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available; however, the mobile houses from "Household Type" category was used for this indicator (Office for National Statistics 2011a).

- **Indicator: Vehicle (CAR)**

Variable: Number of cars and vans

Sector: urban

Component: Physical

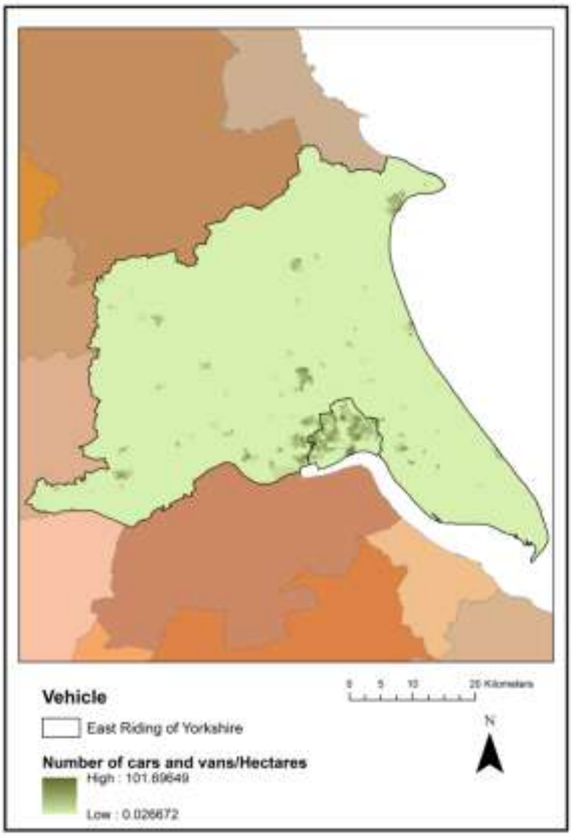
Sub-component: Coping capacity

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

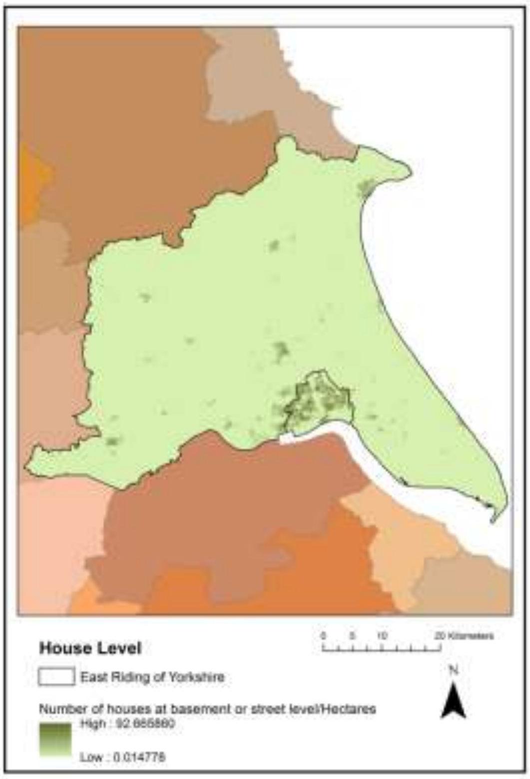
Description:



Casweb is a web interface providing access to aggregated information from the 1971, 1981, 1991 and 2001 UK censuses. The Casweb service of the Census Dissemination Unit (CDU) has been enhanced to provide users with digital boundary data to accompany 2001 census data downloads in a range of standard GIS formats ready for mapping and spatial analysis.

Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. Number of cars and vans in each OA was downloaded and used as the variable of coping capacity of OAs (Office for National Statistics 2011a).

- **Indicator: House Level (LWL)**



Variable: Lowest floor level (at ground or street level)

Sector: urban

Component: Physical

Sub-component: Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:

Casweb is a web interface providing access to aggregated information from the 1971, 1981, 1991 and 2001 UK censuses. The Casweb service of the Census Dissemination Unit (CDU) has been enhanced to provide users with digital boundary data to accompany 2001 census data downloads in a range of standard GIS formats ready for mapping and spatial analysis.

Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. The number of houses at the basement or street level for each OA was used to act as one indicator of household exposure/ susceptibility to flooding (Office for National Statistics 2011a).

- **Indicator: Buildings and assets (BLD)**

Variable: uncertainty map of built-up lands

Sector: urban

Component: Physical

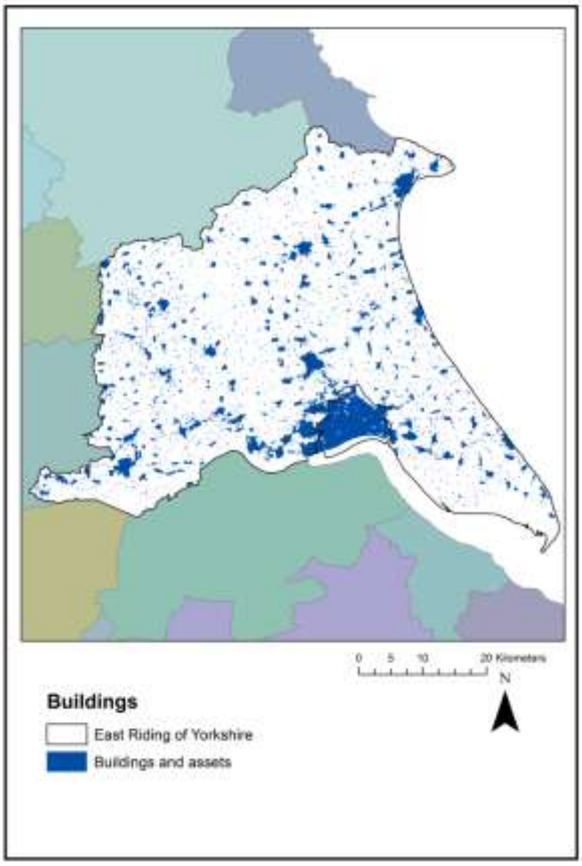
Sub-component: Exposure/susceptibility

Data source: LCM2007, Strategi, Vector Map District, and MasterMap

Temporal resolution: N/A

Data type: 50 km vector grid

Description:



The inconsistency map of the urban sector is used to present the existence of buildings. Four layers of urbanised lands from LCM2007, Strategi, Vector Map District, and MasterMap have been added together to get the final map of buildings' locations within the East Riding of Yorkshire. The resultant map has been used here to map all the possible lands with urbanised/built-up land use. The process is described in more detail in part 6-3.

- **Indicator: Un-employment (UNEP)**

Variable: Ratio of un-employed people

Sector: urban

Component: Economic

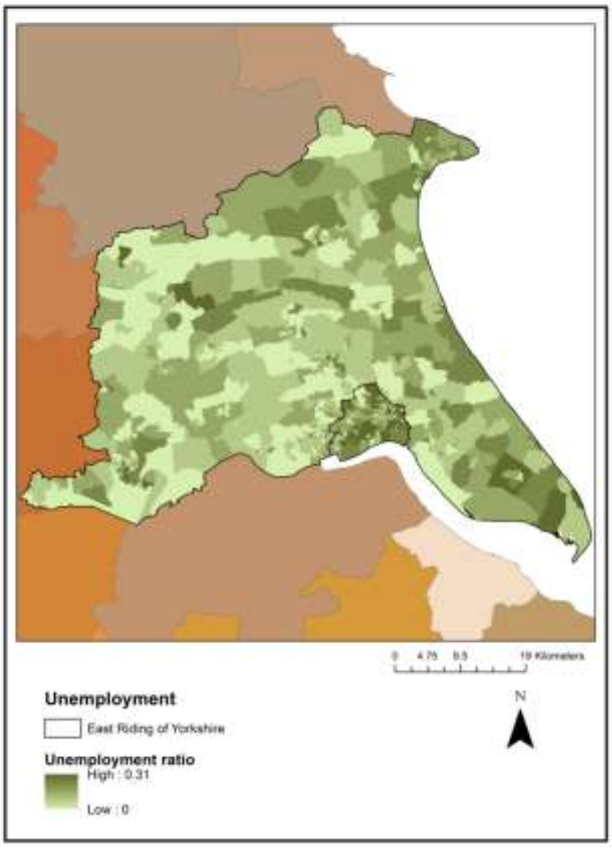
Sub-component: Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:



Casweb is a web interface providing access to aggregated information from the 1971, 1981, 1991 and 2001 UK censuses. The Casweb service of the Census Dissemination Unit (CDU) has been enhanced to provide users with digital boundary data to accompany 2001 census data downloads in a range of standard GIS formats ready for mapping and spatial analysis.

Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. Number of unemployed people divided by the total population presents the desirable indicator of economic exposure/ susceptibility (Office for National Statistics 2011a).

- **Indicator: Communal establishment residents (CER)**

Variable: Ratio of Communal establishment residents

Sector: urban

Component: Economic

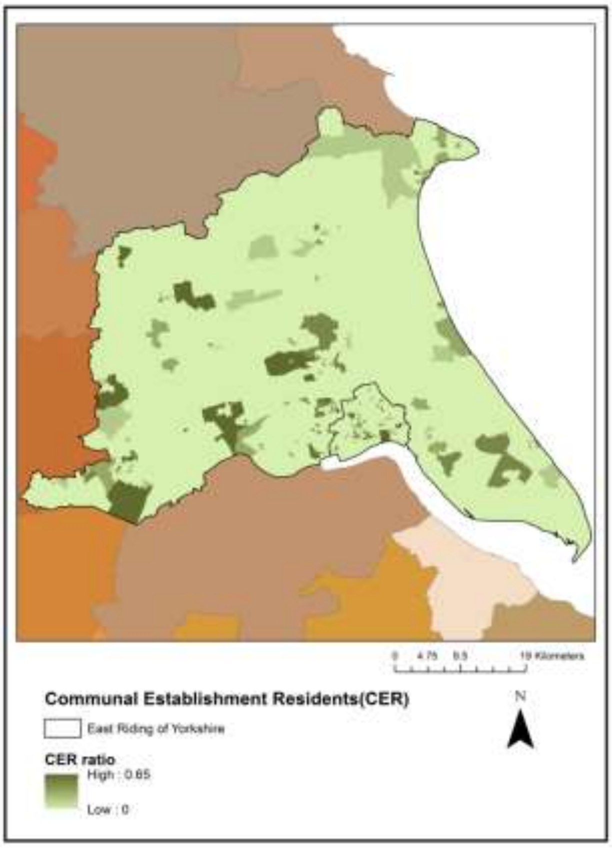
Sub-component: Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:



Casweb is a web interface providing access to aggregated information from the 1971, 1981, 1991 and 2001 UK censuses. The Casweb service of the Census Dissemination Unit (CDU) has been enhanced to provide users with digital boundary data to accompany 2001 census data downloads in a range of standard GIS formats ready for mapping and spatial analysis. Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. The ratio of communal establishment to total population is the variable for this indicator (Office for National Statistics 2011a).

- **Indicator: Tenure (TNUR)**

Variable: Home owners ration

Sector: urban

Component: Economic

Sub-component: Coping capacity

Data source: CASWEB

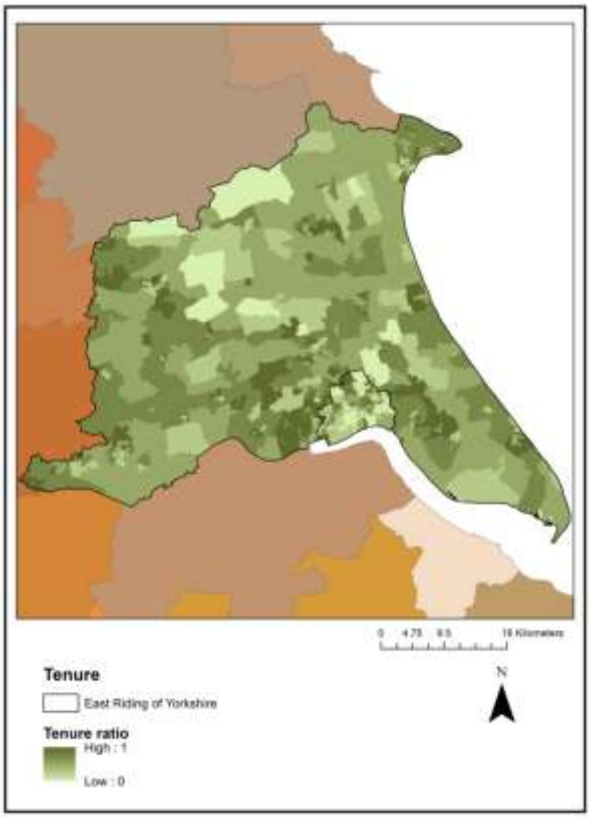
Temporal resolution: 2001

Data type: vector polygon

Description:

Casweb is a web interface providing access to aggregate information from the 1971, 1981, 1991 and 2001 UK Censuses. The Census Dissemination Unit (CDU)'s Casweb service has been enhanced to provide users with digital boundary data to accompany 2001 census data downloads in a range of standard GIS formats ready for mapping and spatial analysis.

Census data has been downloaded at the finest resolution which is Output Areas (OA). There are a great collection of various census data available. The ration of house owners to the total population has been calculated as the variable for "tenure" indicator (Office for National Statistics 2011a).



- **Indicator: Household size (HHSZ)**

Variable: Household size

Sector: urban

Component: Economic

Sub-component: Exposure/susceptibility

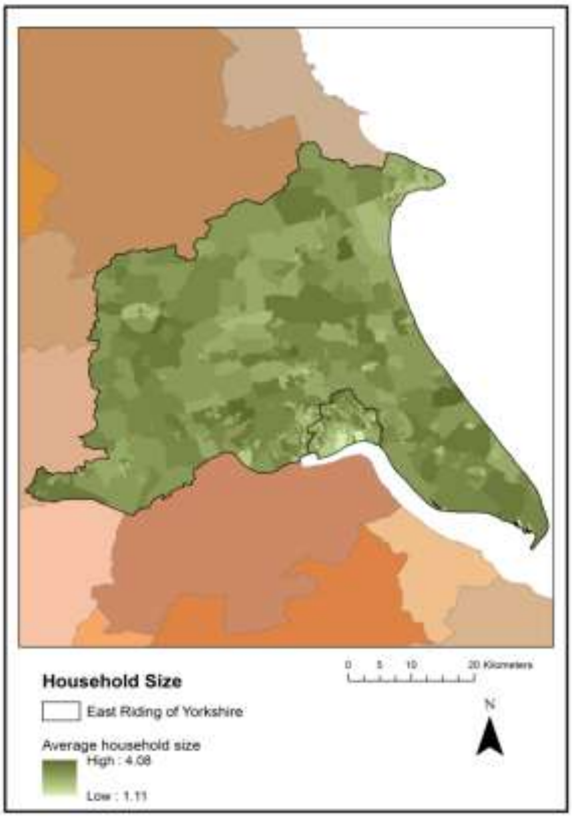
Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:

Casweb is a web interface providing access to aggregated information from the 1971, 1981, 1991 and 2001 UK censuses. The Casweb service of the Census



Dissemination Unit (CDU) has been enhanced to provide users with digital boundary data to accompany 2001 census data downloads in a range of standard GIS formats ready for mapping and spatial analysis.

Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. average household size is the variable that was extracted from the CASWEB website (Office for National Statistics 2011a).

- **Indicator: Commercial services (CMRC)**

Variable: Points of Interest- Commercial services

Sector: urban

Component: Economic

Sub-Component: Exposure/ susceptibility

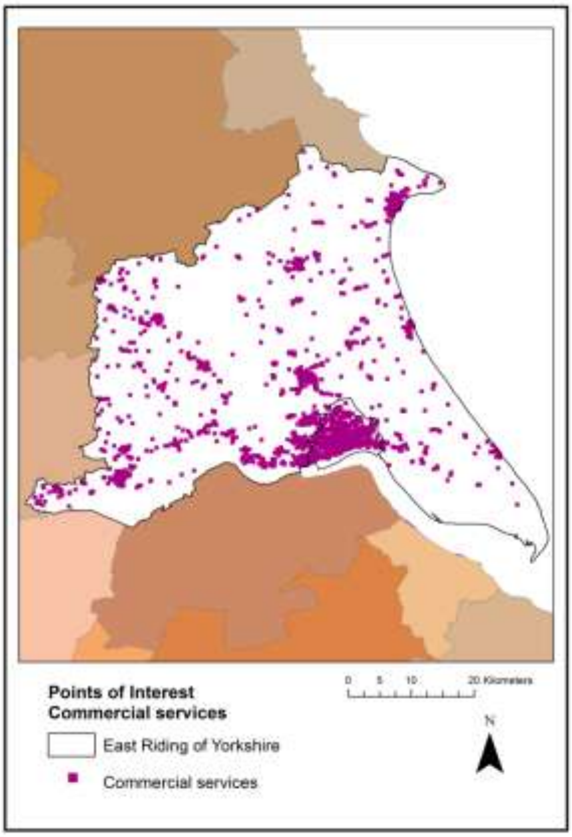
Data source: Ordnance Survey

Temporal resolution: 2012

Spatial resolution/ scale: ± 1m

Data type: vector point

Description:



'Points of Interest' (POI) is a dataset containing around four million different geographic features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes: accommodation, eating and drinking; commercial services; attractions; sport and entertainment; education and health; public infrastructure; manufacturing and production; retail; and transport (Ordnance Survey 2013). The "commercial services" points show the places where there are economically valuable.

- **Indicator: Manufacturing and production (MNU)**

Variable: Points of Interest- Manufacturing and production

Sector: urban

Component: Economic

Sub-Component: Exposure/susceptibility

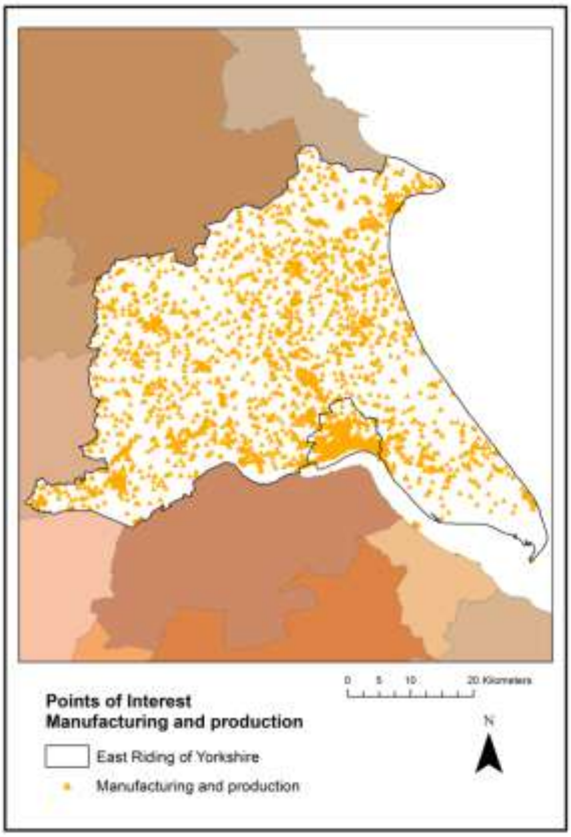
Data source: Ordnance Survey

Temporal resolution: 2012

Spatial resolution/ scale: ± 1m

Data type: vector point

Description:



'Points of Interest' (POI) is a dataset containing around four million different geographic features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes: accommodation, eating and drinking; commercial services; attractions; sport and entertainment; education and health; public infrastructure; manufacturing and production; retail; and transport (Ordnance Survey 2013). The "manufacturing and production" class shows locations where there is economically valuable assets.

- **Indicator: Income (INCM)**

Variable: Average income

Component: Economic

Sub-Component: Coping capacity

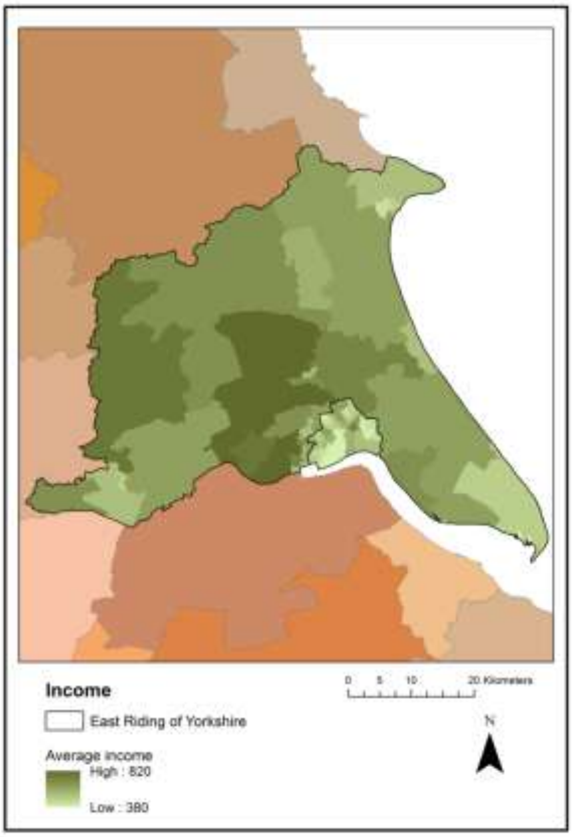
Data source: Office of National Statistics (ONS)

Temporal resolution: 2007/08

Spatial resolution/ scale: Middle Layer Super Output Area (MSOA)

Data type: vector polygon

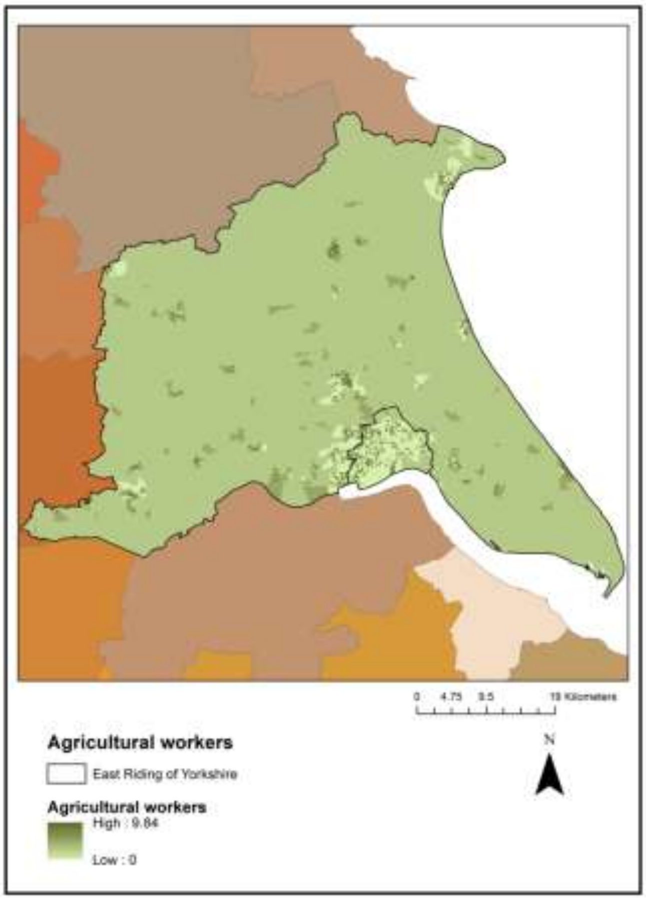
Description:



The Office for National Statistics (ONS) has produced a new set of model-based income estimates for England and Wales. Model-based estimates of average weekly household income on Middle Layer Super Output Area (MSOA) boundaries have been produced for 2007/08. The model-based approach gives estimates that are of a different nature from standard survey estimates because they are dependent upon correctly specifying the relationship between weekly household income and the census/administrative information. The main limitation of estimates for small areas, either those estimated directly from responses to surveys or model-based, is that they are subject to greater variability than those for national or regional estimates. The 2007/08 model-based income estimates for MSOAs are based on the relationship or model between Family Resources Survey (FRS) data describing household income at the household level and the selected covariates at the MSOA level. A model fitting process is used to select from the set of covariates, those with a strong relationship to the survey data. Separate models for England and Wales were investigated and the conclusion was that a single model for each income type was appropriate. In total, four models were produced representing each income type for England and Wales. Total household weekly income (unequivalised) - is the sum of the gross income of every member of the household plus any income from benefits such as Working Families Tax Credit.(Office for National Statistics 2011b)

- **Indicator: Agricultural worker (AGWR)**

Variable: Industry of Employment - Agricultural worker



Sector: arable

Component: Economic

Sub-component: Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:

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Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. The "industry of employment" has been used to extract the number of workers per OA.

- **Indicator: Land productivity (ALC)**

Variable: Agricultural Land Classification

Sector: Arable

Component: Economic

Sub-Component: Exposure/ Susceptibility

Data source: Natural England

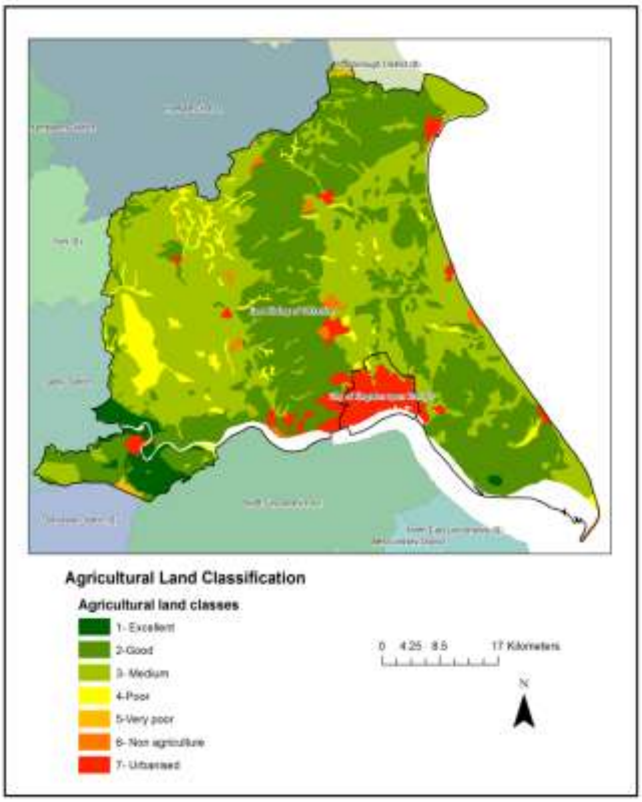
Temporal resolution: 2002

Spatial resolution: 1:250,000

Data type: vector polygon

Description:

Agricultural land classified into five grades. Grade one is best quality and grade five is poorest quality. A number of consistent criteria used for assessment which include climate (temperature, rainfall, aspect, exposure, risk), site (gradient, micro-relief, flood risk) and soil (depth, texture, stoniness).



- **Indicator: Farm locations (FARM)**

Variable: Points of Interest- farm locations

Sector: arable

Component: Economic

Sub-Component: Exposure/susceptibility

Data source: Ordnance Survey

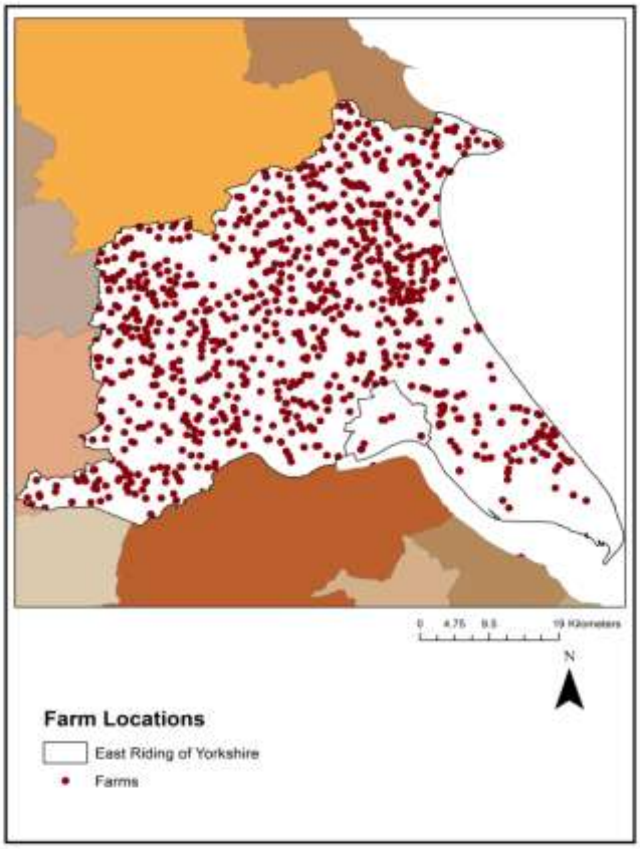
Temporal resolution: 2012

Spatial resolution: ± 1m

Data type: vector point

Description:

'Points of Interest' (POI) is a dataset containing around four million different geographic



features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes: accommodation, eating and drinking; commercial services; attractions; sport and entertainment; education and health; public infrastructure; manufacturing and production; retail; and transport.

- **Indicator: Farm livestock (DFR**)

Variable: livestock report

Sector: arable

Component: Economic

Sub-component: Exposure/susceptibility

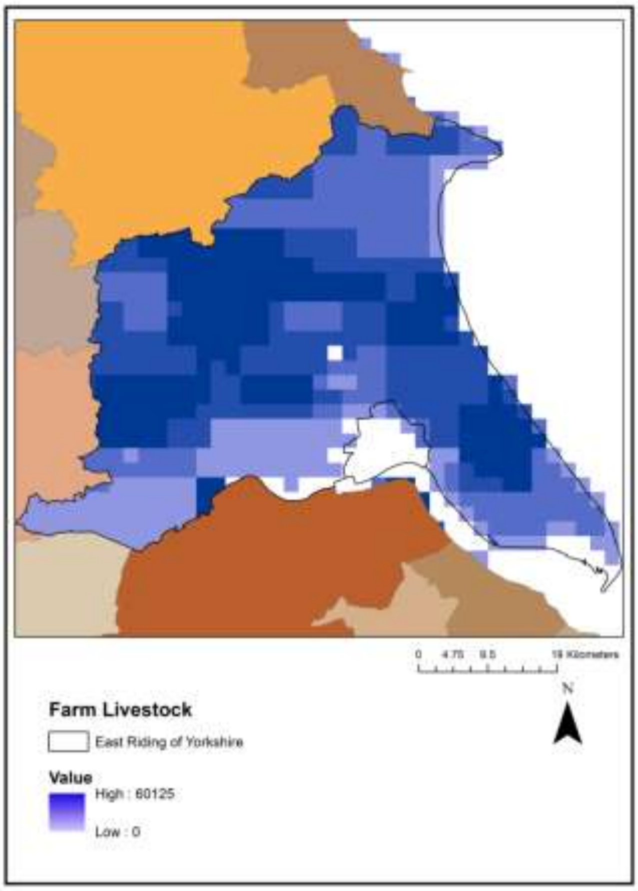
Data source: Defra

Temporal resolution: 2010

Spatial resolution/ scale: 2 km grids

Data type: Vector grid

Description:



Publically available farm production data is accessible through DEFRA. The resolution for this dataset is 2 km which is disaggregated into 1 km grid cells. Livestock report includes sheep, cattle, poultry, horse, goat, deer, and pig. Livestock individuals' production varies among species, however for the purpose of this work, they have been assumed the same and summed up together.

- **Indicator: Forestry workers (FRWR)**

Variable: Number of forestry workers/ OA Hectares

Sector: wildlife

Component: Economic

Sub-component: Exposure/susceptibility

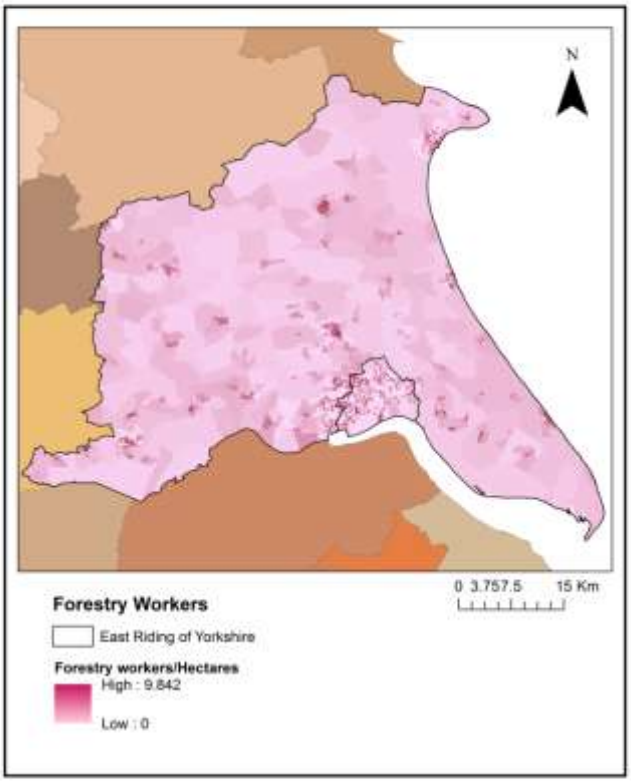
Data source: CASWEB

Temporal resolution: 2001

Spatial resolution/ scale: N/A

Data type: vector polygon

Description:



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Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. However, "Industry of employment - Forestry workers" was used for agriculture category ((Office for National Statistics 2011a).

- **Indicator: Biodiversity action areas (PA)**

Variable: local biodiversity priority areas and Biodiversity opportunity target areas

Sector: wildlife

Component: Economic

Sub-component: Exposure/ susceptibility

Data source: Natural England

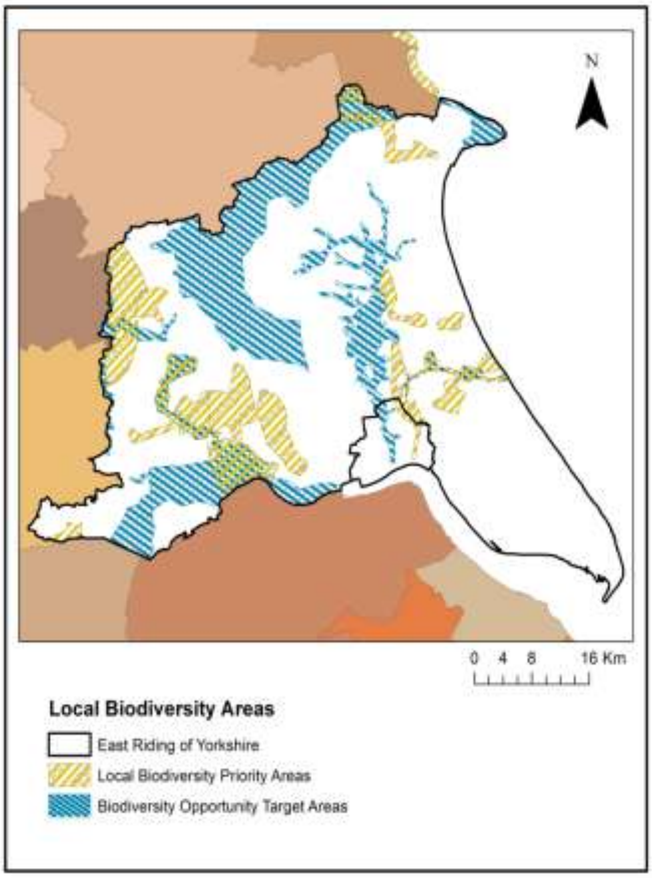
Temporal resolution: 2010 (local biodiversity priority areas) and 2009 (Biodiversity opportunity target areas)

Spatial resolution/ scale: 1:10 000

Data type: vector polygon

Description:

Among the areas of woods and natural habitats, some have been recognised as



The Bio_Ops_Target_Areas are the result of a very large scale consultation process. They are the consolidated results of three projects, one carried out by NGO's (including Wildlife Trusts and RSBP) and two carried out by consultancies (one of which was the Stockholm Institute). It represents the consensus of areas considered to be appropriate for biodiversity improvement. From this the three priority levels that I showed you were derived to inform National, Regional and Local Scale biodiversity improvement projects. Due to changes in policy after the last election, the regional level ceased to exist.

The Local_BiodiversityPriority Areas are those that have been accepted into policy by ERY Council, and will form part of their Local Development Framework. These remain unchanged.

- **Indicator: Natural habitat (FRST)**

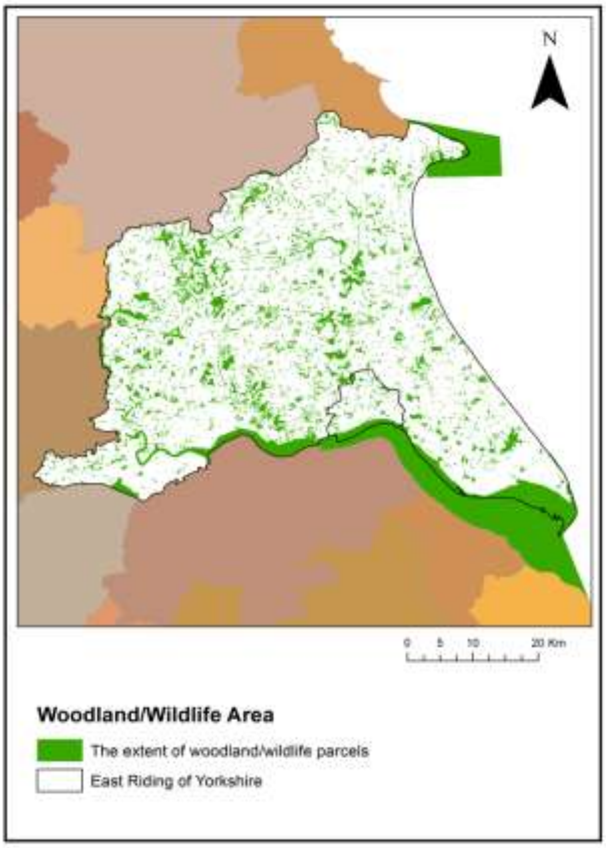
Variable: Inconsistency map compromised of eight datasets

Sector: Wildlife

Component: Economic

Sub-component: Exposure\susceptibility

Data source: LCM2007, Strategi, Vector Map District, MasterMap, forestry commission sub-compartments, National Forest Inventory (VFI), ancient woodland, Natural England protected areas.



Temporal resolution: N/A

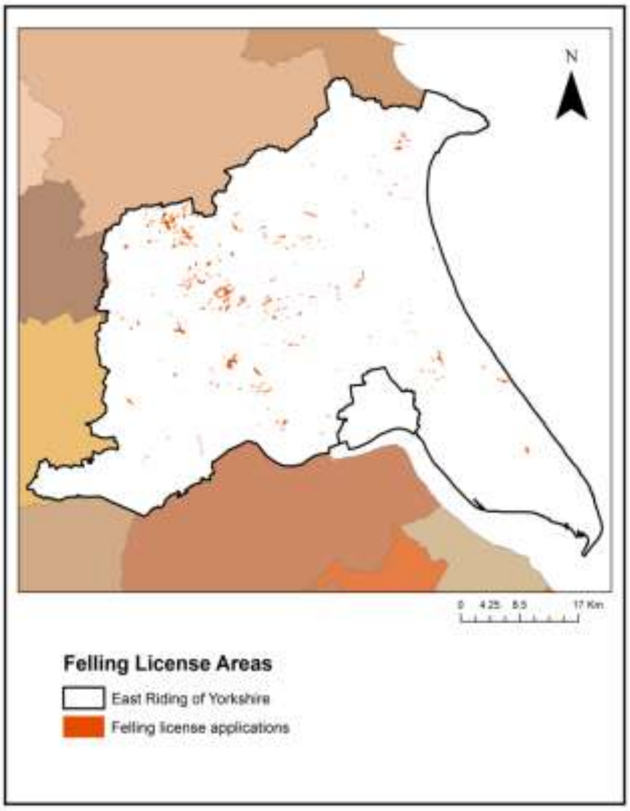
Spatial resolution: 50 m

Data type: Vector grid

Description:

Eight datasets have been used in order to map the extent of all possible parcels associated with woods and natural habitat. This map shows the binary existence of wildlife habitats within a $50 \times 50\ m^2$ grid cell. Although the tempo-spatial resolution of datasets vary, but for the purpose of this work, it is ok to merge them.

- **Indicator: Felling license areas (FLA)**



Variable: Felling license application areas

Sector: Wildlife

Component: Economic

Sub-component: Exposure\susceptibility

Data source: Forestry commission

Temporal resolution: 2012

Spatial resolution: 1:2500

Data type: Vector polygon

Description:

Felling Licence Application (FLA) areas are approved by Forestry Commission England. Anyone wishing to fell trees must ensure that a licence or permission under a grant scheme has been issued by the Forestry Commission before any felling is carried out or that one of the exceptions apply.

- **Indicator: Population (POP)**

Variable: Population density

Sector: Urban

Component: Social

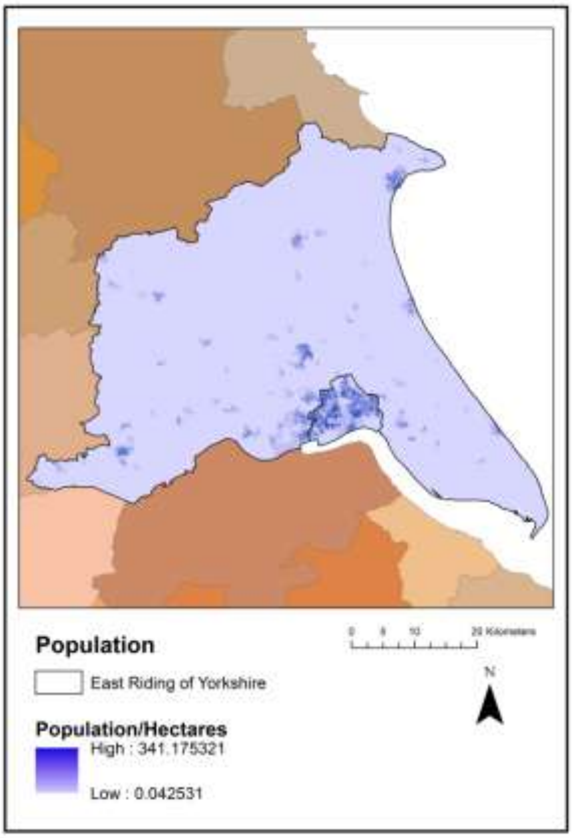
Sub-component: Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:



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Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. Total population of OAs were downloaded and the density of population per OA was used as the variable for this indicator (Office for National Statistics 2011a).

- **Indicator: Age (AGE)**

Variable: Age rate

Sector: Urban

Component: Social

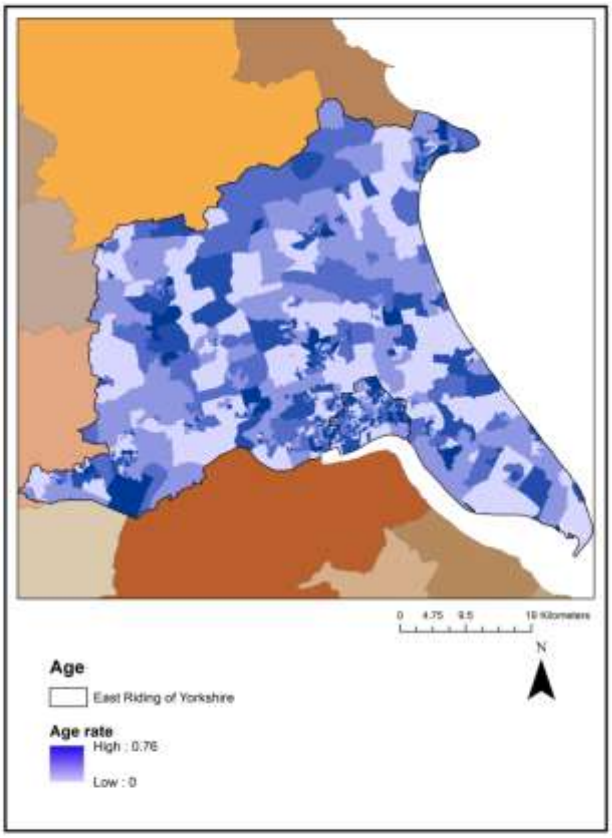
Sub-component: Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:



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Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. Rate of population under 16 and above 74 were calculated regarding to the total population of each OA (Office for National Statistics 2011a).

- **Indicator: General health (GHLT)**

Variable: Population rate in "Not good" health condition

Component: Social

Sub-component: Exposure/susceptibility

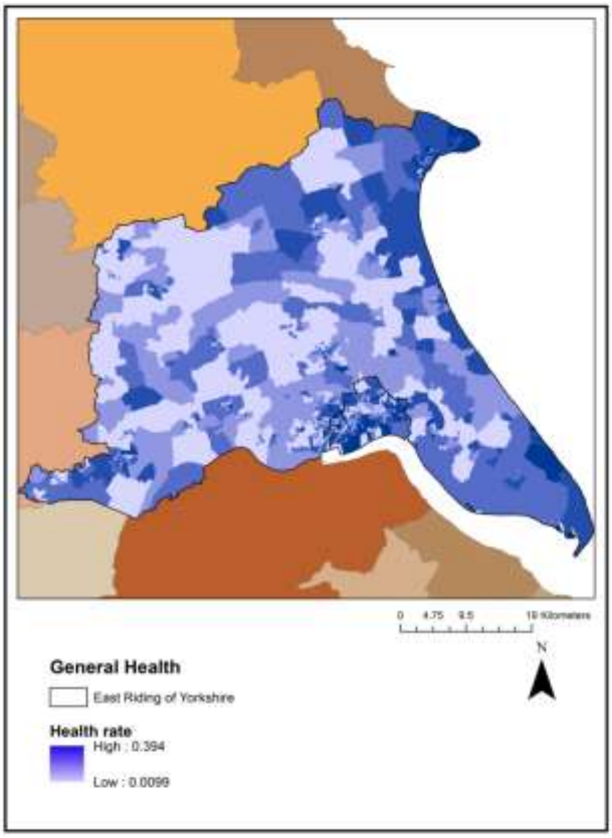
Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:

Casweb is a web interface providing access to aggregated information from the 1971, 1981, 1991 and 2001 UK censuses. The Casweb service of the Census Dissemination Unit (CDU) has been enhanced to provide users with digital boundary data to accompany 2001 census data downloads in a range of standard GIS formats ready for mapping and spatial analysis.



Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available.. Population in "no good" condition were extracted in each OA and the rate has been calculated based on the total population in each OA (Office for National Statistics 2011a).

- **Indicator: Students away from home (STWY)**

Variable: Students away from home

Sector: Urban

Component: Social

Sub-component: Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:

Casweb is a web interface providing access to aggregated information from the 1971, 1981, 1991 and 2001 UK censuses. The Casweb service of the Census Dissemination Unit (CDU) has been enhanced to provide users with digital boundary data to accompany 2001 census data downloads in a range of standard GIS formats ready for mapping and spatial analysis.

Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. Number of students away from home was downloaded for OAs. The rate of values were calculated at OAs based on the total population (Office for National Statistics 2011a).

- **Indicator: Lone parents (LNPR)**

Variable: Lone parents with dependent children ratio

Sector: Urban

Component: Social

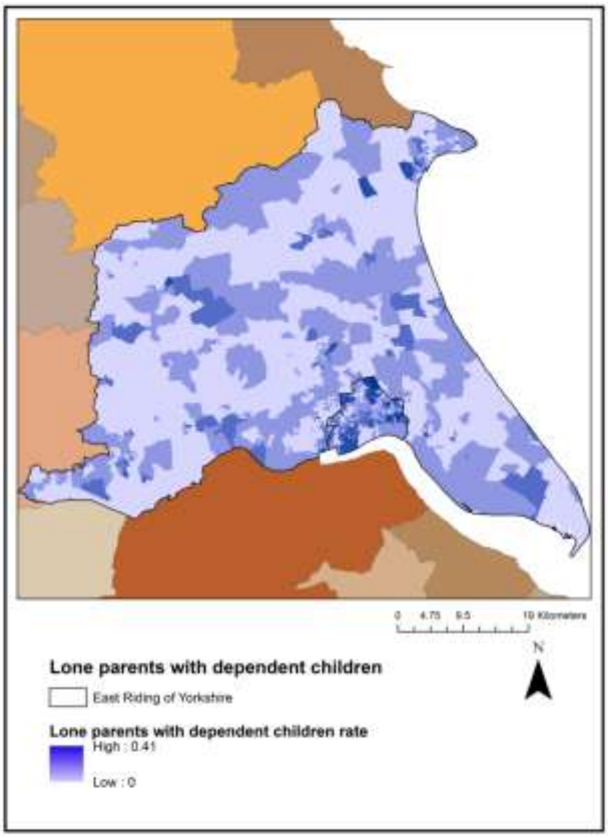
Sub-component: Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:



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Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. Number of lone parents with dependent children were downloaded and the ratio of the values to the total population were calculated as the variable of this indicator (Office for National Statistics 2011a).

- **Indicator: Migration (MGR)**

Variable: Migration rate

Sector: Urban

Component: Social

Sub-component:

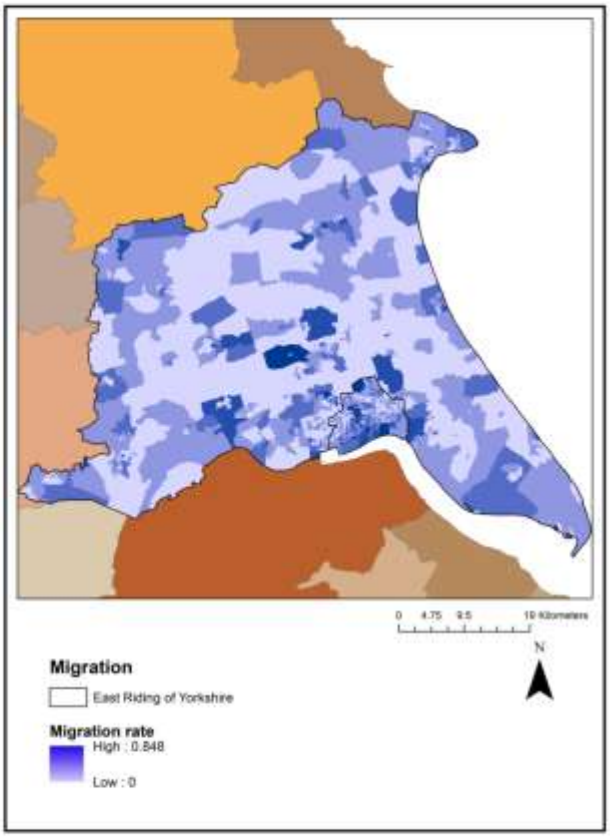
Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:



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Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. Number of migrants per OA were downloaded and the ratio to total population was calculated (Office for National Statistics 2011a).

- **Indicator: Limiting long term illness (LLTI)**

Variable: Limiting long term illness ratio

Sector: Urban

Component: Social

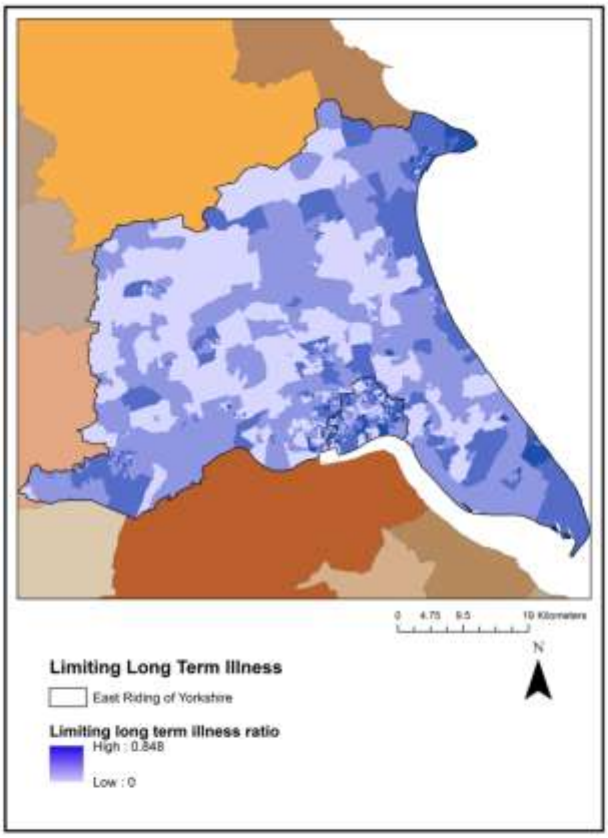
Sub-component: Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:



Casweb is a web interface providing access to aggregated information from the 1971, 1981, 1991 and 2001 UK censuses. The Casweb service of the Census Dissemination Unit (CDU) has been enhanced to provide users with digital boundary data to accompany 2001 census data downloads in a range of standard GIS formats ready for mapping and spatial analysis.

Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. Population with limiting long term illness were downloaded at the OA resolution and the ration of the value to total population were calculated (Office for National Statistics 2011a).

- **Indicator: Qualification (QUAL)**

Variable: Population with "no qualification" rate

Sector: Urban

Component: Social

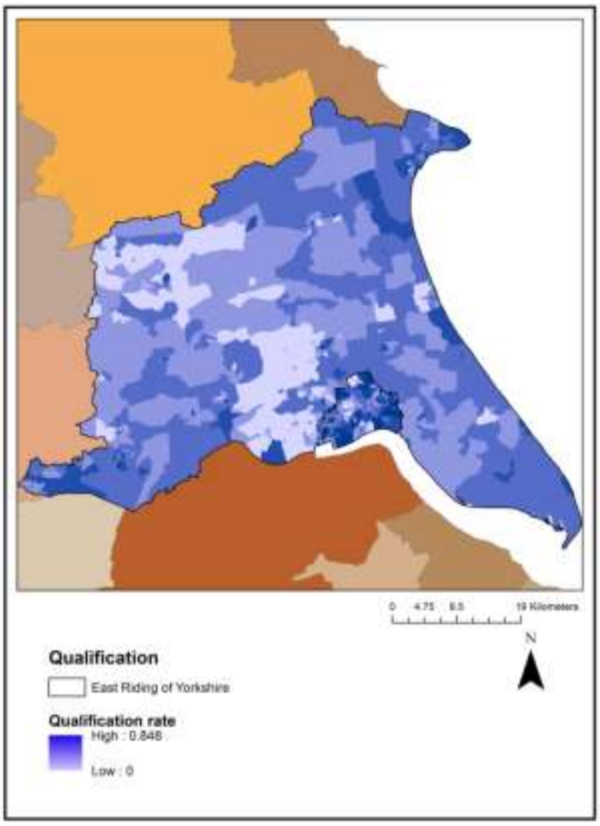
Sub-component: Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:



Casweb is a web interface providing access to aggregated information from the 1971, 1981, 1991 and 2001 UK censuses. The Casweb service of the Census Dissemination Unit (CDU) has been enhanced to provide users with digital boundary data to accompany 2001 census data downloads in a range of standard GIS formats ready for mapping and spatial analysis.

Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. Population with "no-qualification" for each OA were downloaded and its rate has been calculated based on the total population of OAs (Office for National Statistics 2011a).

- **Indicator: Accommodation, eating, drinking services (ACDR)**

Variable: Points of Interest- Accommodation, eating, drinking services

Sector: Urban

Component: Social

Sub-Component: Exposure/susceptibility

Data source: Ordnance Survey

Temporal resolution: 2012

Spatial resolution: ± 1m

Data type: vector point

Description:

Points of Interest (POI) is a dataset containing around 4 million different geographic features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes:

Accommodation, eating and drinking, Commercial services, Attractions, Sport and entertainment, Education and health, Public infrastructure, Manufacturing and production, Retail, Transport (Ordnance Survey 2013). Accommodation, eating, drinking services have been selected as an indicator based on their importance in terms of social exposure/ susceptibility.

- **Indicator: Attractions (ATT)**

Variable: Points of Interest- Attractions

Sector: Urban

Component: Social

Sub-Component: Exposure/susceptibility

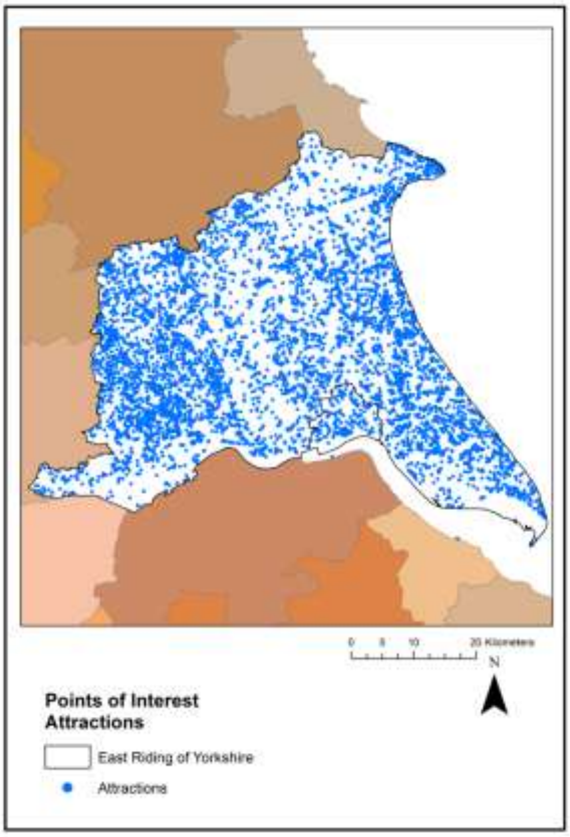
Data source: Ordnance Survey

Temporal resolution: 2012

Spatial resolution: ± 1m

Data type: vector point

Description:



'Points of Interest' (POI) is a dataset containing around four million different geographic features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes: accommodation, eating and drinking; commercial services; attractions; sport and entertainment; education and health; public infrastructure; manufacturing and production; retail; and transport (Ordnance Survey 2013). Attraction locations have been selected as an indicator of social exposure as they hold social importance and hot spot.

- **Indicator: Sports and entertainment services (SPR)**

Variable: Points of Interest- Sports and entertainment services

Sector: Urban

Component: Social

Sub-Component:

Exposure/susceptibility

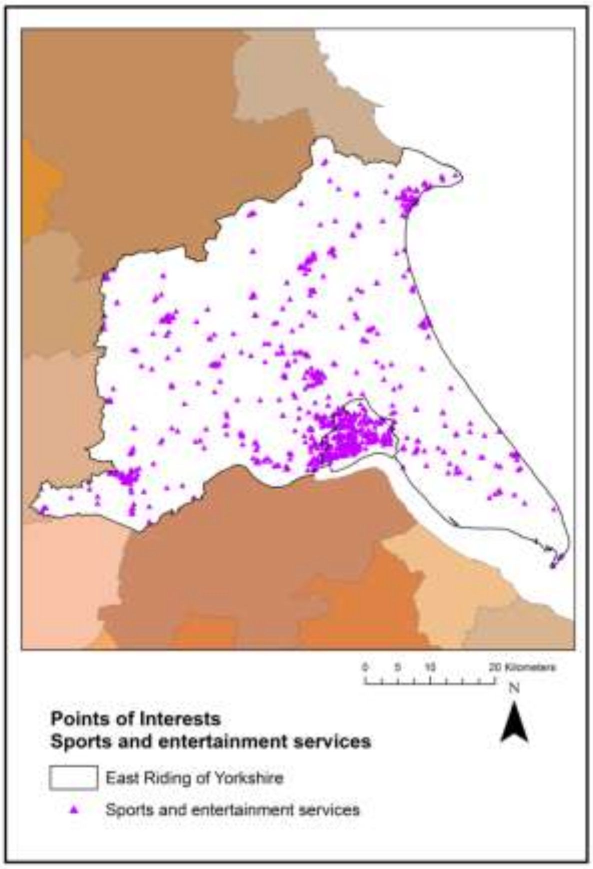
Data source: Ordnance Survey

Temporal resolution: 2012

Spatial resolution: ± 1m

Data type: vector point

Description:



'Points of Interest' (POI) is a dataset containing around four million different geographic features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes: accommodation, eating and drinking; commercial services; attractions; sport and entertainment; education and health; public infrastructure; manufacturing and production; retail; and transport (Ordnance Survey 2013).The location of "Sports and entertainment services" is an indicator of social exposure/ susceptibility as they have social importance in the community and in addition there is higher probability of the crowd to be there.

- **Indicator: Health services (HLTH)**

Variable: Points of Interests- Health services

Sector: Urban

Component: Social

Sub-Component: Coping capacity

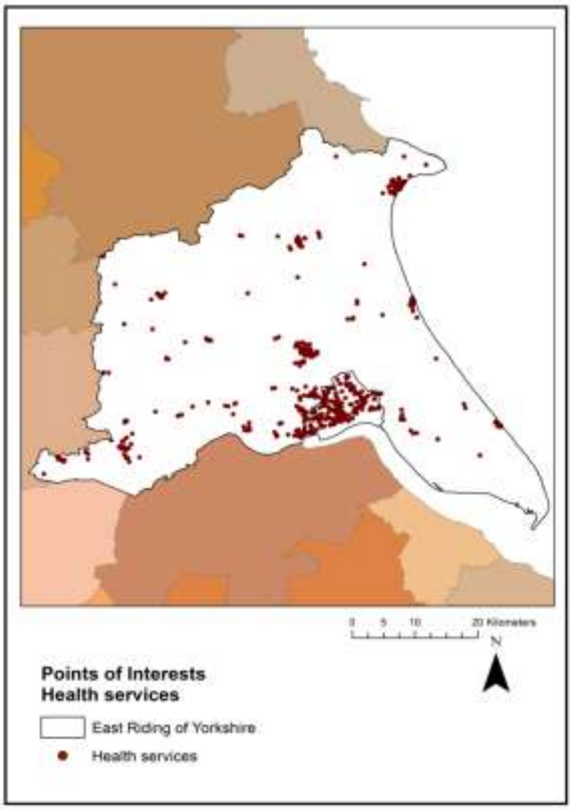
Data source: Ordnance Survey

Temporal resolution: 2012

Spatial resolution: ± 1m

Data type: vector point

Description:



'Points of Interest' (POI) is a dataset containing around four million different geographic features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes: accommodation, eating and drinking; commercial services; attractions; sport and entertainment; education and health; public infrastructure; manufacturing and production; retail; and transport (Ordnance Survey 2013). Health services provide an important source for social coping capacity for the human rescue in the community.

- **Indicator: Infrastructure (INFR)**

Variable: Points of Interests- Infrastructure

Sector: Urban

Component: Social

Sub-Component: Coping capacity

Data source: Ordnance Survey

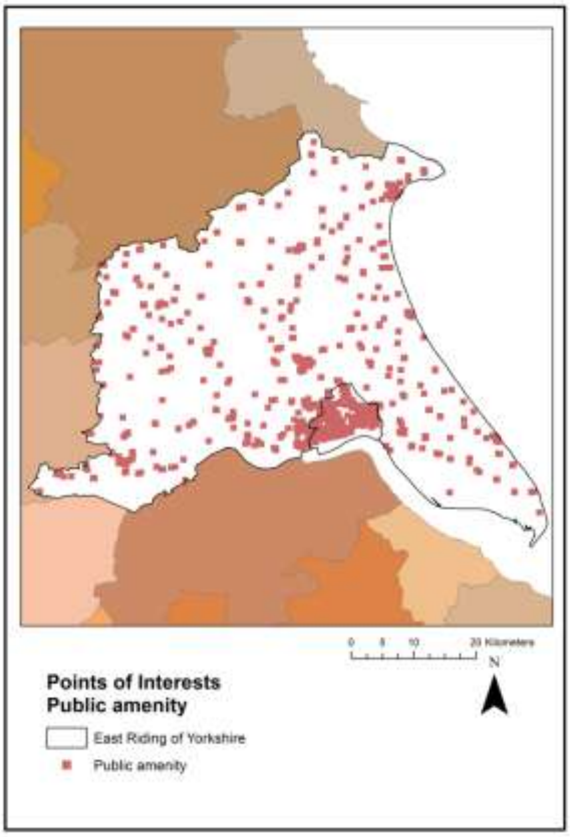
Temporal resolution: 2012

Spatial resolution: ± 1m

Data type: vector point

Description:

'Points of Interest' (POI) is a dataset containing around four million different geographic features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes: accommodation, eating and drinking; commercial services; attractions; sport and entertainment; education and health; public infrastructure; manufacturing and production; retail; and transport (Ordnance Survey 2013). Public infrastructure has been detected as an indicator of social coping capacity. The location of infrastructures such as halls and community centres can play role in terms of emergency management.



- **Indicator: Retails (RTL)**

Variable: Points of Interests- Retails

Sector: Urban

Component: Social

Sub-Component: Exposure/susceptibility

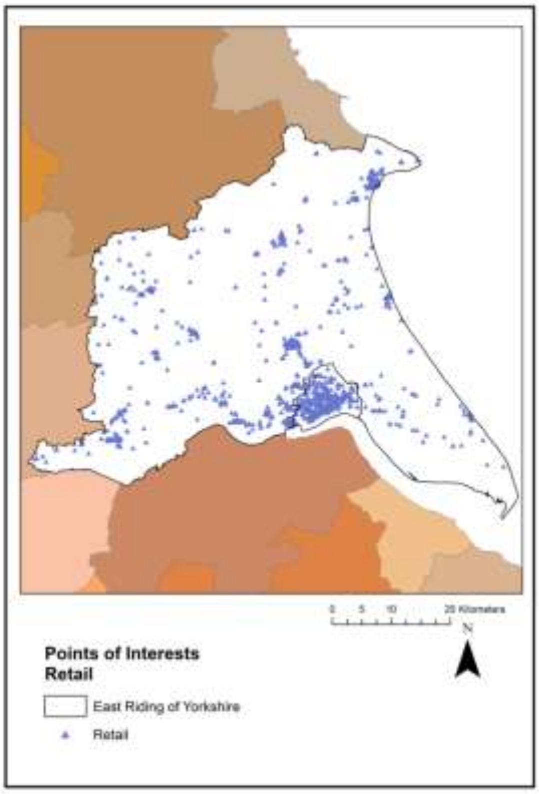
Data source: Ordnance Survey

Temporal resolution: 2012

Spatial resolution: ± 1m

Data type: vector point

Description:



'Points of Interest' (POI) is a dataset containing around four million different geographic features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes: accommodation, eating and drinking; commercial services; attractions; sport and entertainment; education and health; public infrastructure; manufacturing and production; retail; and transport (Ordnance Survey 2013). Location of retail is an indicator of social exposure/susceptibility as they hold social values.

- **Indicator: Schools (SCHL)**

Variable: Points of Interests- Schools

Sector: Urban

Component: Social

Sub-Component: Exposure/susceptibility

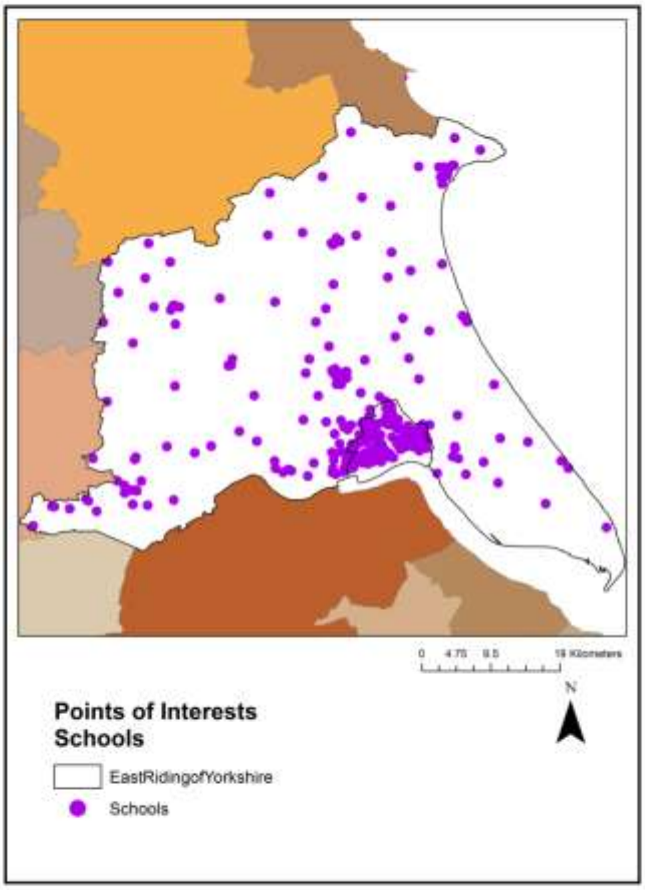
Data source: Ordnance Survey

Temporal resolution: 2012

Spatial resolution: ± 1m

Data type: vector point

Description:



'Points of Interest' (POI) is a dataset containing around four million different geographic features. All features are supplied with location, functional information and addresses where possible. The product covers all of Great Britain. There are nine main classes: accommodation, eating and drinking; commercial services; attractions; sport and entertainment; education and health; public infrastructure; manufacturing and production; retail; and transport (Ordnance Survey 2013). Schools are indicator of social coping capacity as they act as support and amenity places in terms of extreme events.

- **Indicator: Sex (SEX)**

Variable: Female rate

Sector: Urban

Component: Social

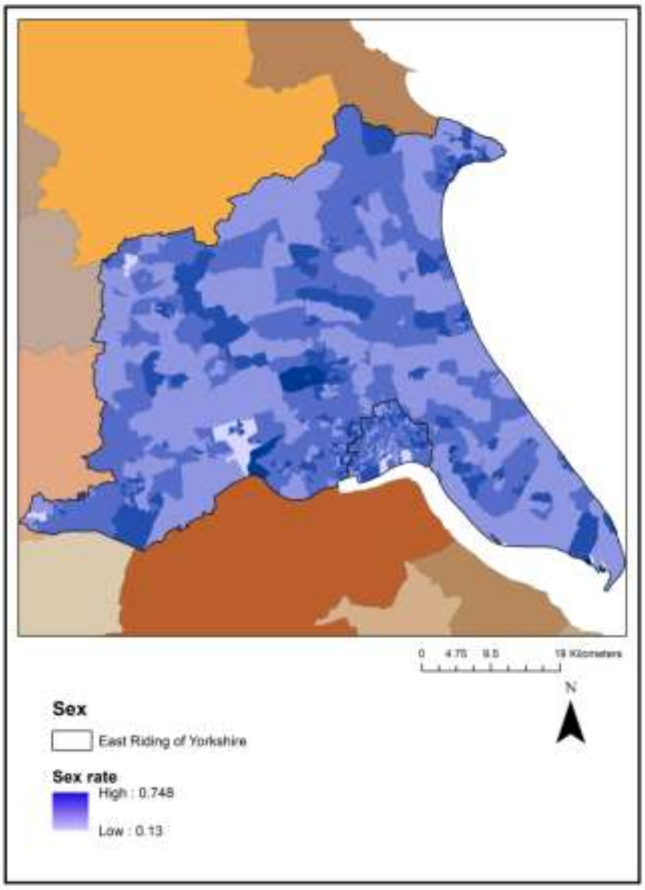
Sub-component: Exposure/susceptibility

Data source: CASWEB

Temporal resolution: 2001

Data type: vector polygon

Description:



Casweb is a web interface providing access to aggregated information from the 1971, 1981, 1991 and 2001 UK censuses. The Casweb service of the Census Dissemination Unit (CDU) has been enhanced to provide users with digital boundary data to accompany 2001 census data downloads in a range of standard GIS formats ready for mapping and spatial analysis.

Census data have been downloaded at the finest resolution, which is output areas (OA). There are many different sets of census data available. Ration of female population to total population was used the variable for this indicator (Office for National Statistics 2011a).

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