A Comprehensive Spatial Assessment of the Environmental Vulnerability in the UK

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A Comprehensive Spatial Assessment of the Environmental Vulnerability in the UK

by

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Specialisation: Environmental Modelling and Management

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Abstract

The environmental vulnerability index (EVI) classified the UK environment as *extremely vulnerable* in 2004. Despite the application of the national-based EVI assessment there is a general consensus within the field of vulnerability science that environmental vulnerability is a rather local occurring issue due to the heterogeneity of the environment and the spatially varying occurring pressures. Therefore, following the alarming EVI result in 2004, an environmental vulnerability index is developed for the UK (EVI_{UK}) to be applied on sub-national levels. The aim is to define the stresses and pressures for the UK specifically, evaluating the environmental vulnerability and using the results to direct planning policies. The EVI method was adapted from current literature and especially with adjusted indicators explicitly representing stresses occurring in the UK. 51 indicators were identified, grouped into eight sub-indicators, populated with GIS data and then aggregated linearly for county-level, producing results between 0 and 1, low to high vulnerability respectively. The spatially distributed environmental vulnerability of the UK is low to moderate with a mean EVI_{UK} of 0.35. The sub-indicators show more diverse results and indicate higher vulnerabilities for individual counties. The lowest EVI_{UK} score has Derbyshire and the highest Hampshire with 0.32 and 0.44 respectively. For these two counties the assessment was also conducted on borough-level, showing similar results as the county-level evaluation. Furthermore, with the help of a stepwise backward regression analysis the most dominant indicators were determined on both application levels. Standing out are the indicators *nature reserves* and *land cover diversity*. In the context of sub-indicators *land use and energy* and *climate* seem to be causing the environmental vulnerability dominantly. These results relate to both county and borough-level assessment. Following a Monte Carlo Simulation applied to the dominating indicators, the uncertainty of the model can be considered as small with a standard deviation of 0.0076. In addition to that a sensitivity analysis resulting from the Monte Carlo Simulation produces robust results. When comparing the results, the county-level assessment suggests to produce more reliable results and also related to policy competences the county can be identified as the appropriate implementation level for the EVI_{UK}.

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Abbreviations

CVI	Coastal Vulnerability Index
Defra	Department for Environment Food & Rural Affairs
Derby	Derbyshire County
EPI	Environmental Performance Index
ESI	Environmental Sustainability Index
EVI	Environmental Vulnerability Index
EVI_{UK}	Environmental Vulnerability Index for the UK
EVI_{UKc}	Environmental Vulnerability Index for the UK, county-level assessment
EVI_{UKb}	Environmental Vulnerability Index for the UK, borough-level assessment
GIS	Geographic Information Science
Hamp	Hampshire County
NCCVA	National Climate Change Vulnerability Assessment
UK	United Kingdom
RS	Remote Sensing
SDI	Sustainable Development Indicators
SoE	State of the Environment
SOPAC	Secretariat of the Pacific Community

1. Introduction

Extremely vulnerable that is the conclusion of an environmental vulnerability assessment of the United Kingdom (UK). In 2004 a global assessment on environmental vulnerability was applied to a total of 235 countries, classifying the countries' environmental vulnerability to future shocks (Kaly, Pratt, & Mitchell, 2004) (Fig. 1). The evaluation for the UK concluded with the highest vulnerability class, as being *extremely vulnerable*. This result indicates that the UK environment is under pressure and future shocks are likely to deteriorate the environment (Kaly et al., 2004; Natural England, 2009). However, the natural environment is highly important for human life, due the resources it provides and the services it fulfils (Costanza et al., 1997). In everyday life people interact with the environment while using and profiting from its resources and services (Natural England, 2009). Furthermore, human welfare depends on the health of the environment (Villa & McLeod, 2002). All our used and processed products can be traced back to natural resources; hence our economy is highly relying on those (Natural England, 2009, 2011b). Additionally to this, as one of its services, the environment acts as a pollution filter and absorber, which allows us to generate a certain amount of pollution without causing major harm (South Pacific Applied Geoscience Commission, 2013a).

As a matter of fact the natural environment is exposed to human impacts and natural hazards on a daily basis (Filser et al., 2008). Occurring natural hazards are for example volcanoes, earthquakes, storms, flooding, droughts and landslides (Park, 2001). Impacts of human nature are for instance pollution and the use of land. Another set of stresses are related to negative climate change variability, which affect the systems' vulnerability with their character, magnitude and rate of occurrence (Hinkel, 2011; McCarthy, Canziani, Leary, Dokken, & White, 2001; Patt, Schröter, de la Vega-Leinert, & Klein, 2009). The environment has to cope with these stresses and luckily each environment can manage and adapt to pressures up to a certain degree. This is expressed as the environments' vulnerability, which is characterised mainly by the stress that is exerted on a system, its sensitivity and its capacity to adapt to the pressure (Adger, 2006; Turner, Kasperson, et al., 2003). It is important to know a country's environmental vulnerability since a high degree of environmental degradation can result directly in loss of diversity, the deterioration of the quality and functions of the environment and indirectly in damage of the social and economic system (Kaly et al., 2004; Natural England, 2011b; Pratt, Kaly, & Mitchell, 2004). However, when applying sustainable development strategies, the vulnerability can be reduced and a country can work towards a healthy environment, a good quality of life and economic security (Natural England, 2009). Vulnerability research in general supports the development of adaptation and mitigation strategies (Patt et al., 2009). Investing into a healthy environment also secures economic prosperity in the long run and postponing the investments now, will increase the costs that need to be paid due to environmental resource degradation at a later time (Natural England, 2011b). In order to design effective development strategies, the environments' vulnerability needs to be known (Pratt et al., 2004; South Pacific Applied Geoscience Commission, 2013a). The main bodies having an influence on sustainability strategies are politicians, stakeholders and local governments, hence environmental vulnerability assessments should be addressed to them (OECD, 2008). Tools and assessment strategies should be directly addressed and designed to be used by and to inform policy-makers, so that they can benefit from the obtained results (Hinkel, 2011; Patt et al., 2009; Schröter, Polsky, & Patt, 2004).

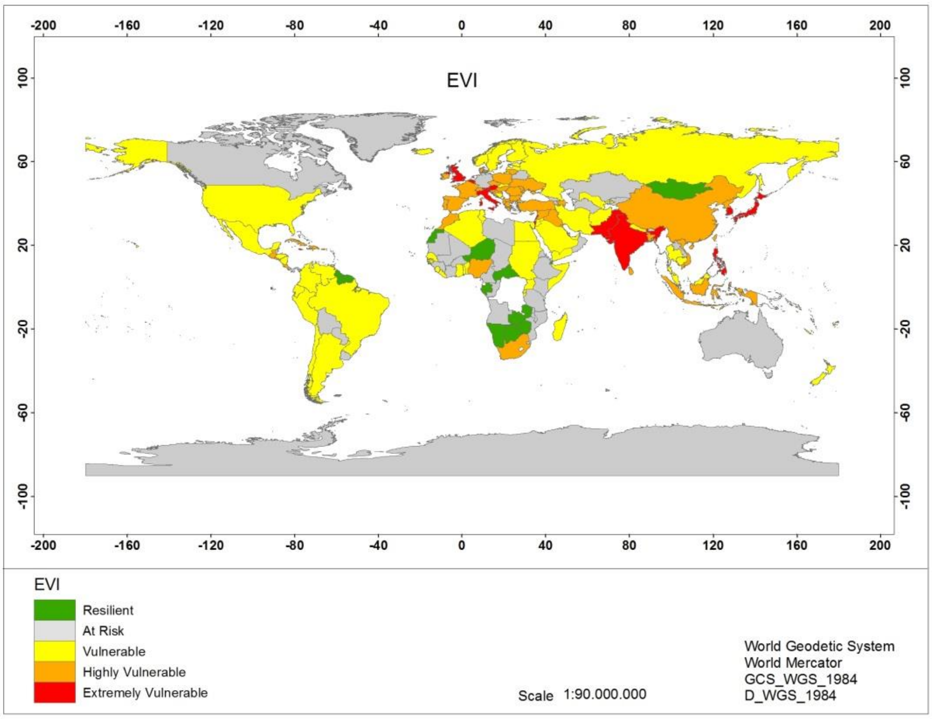

Figure 1: EVI 2004 Results.

There is definite evidence that the natural environment is important and its degradation will have long-lasting effects not only for the environment itself but also the society and economy. When looking at the United Kingdom (UK) one has to notice that the environmental vulnerability has not been assessed yet (Holman & Naess, 2009). The only significant evaluation is the aforementioned Environmental Vulnerability Index (EVI) from 2004 which indicates that the UK is *extremely vulnerable* to future shocks, resulting from both natural hazards and human impacts (Kaly et al., 2004). However, this is an overall assessment at country level having the disadvantage of not being detailed enough as it fails to locate most vulnerable areas (Skondras et al., 2011). The choice of a national-scale was justified with the assumption that major decisions concerning the environment are implemented at national level (Kaly et al., 2004). Scientists however argue, that environmental vulnerability varies locally and therefore a local-based assessment delivers more appropriate results. This also applies when looking at global-scale created hazards that cause the vulnerability (Turner, Kasperson, et al., 2003). A local-based vulnerability assessment has the advantage of reflecting regional heterogeneity within an environment. Considering that the UK covers a total area of about 242,000 km^2, some regional variation may be expected (The World Bank Group, 2014). In addition to that, the UK is an island and therefore owns both coastal and inland areas. When looking at the indicators used by the EVI, some, for example Fishing Effort (35), Spills (41) and Coastal Settlements (48), mainly apply to coastal areas and relatively little to inland areas and others *vice versa*. Based on these observations one can assume that the vulnerability differs among areas depending on the intensity of specific indicators. An examination of the UK's vulnerability on local level may reveal a more detailed result highlighting distinct areas that are extremely and others that are less vulnerable (Sietz, 2014; Turner, Kasperson, et al., 2003; van Vuuren, Lucas, & Hilderink, 2007). These results can help targeting environmental sustainable developments more strategically on local level, thus resulting in more effective implications of reduction policies (Sietz, 2014)**.** The absence of localised vulnerability knowledge is inconvenient when considering that policies, planning strategies and mitigation and adaptation strategies are needed in order to reduce the environmental vulnerability. A more localised study is therefore required. Supporting this is also the fact that there are several regulatory bodies for the environment in the UK. The national agencies like Natural England and the Department for Environment, Food and Rural Affairs (Defra) act on national level, advise the government and provide guidance documents. However, local authorities have the statutory power to implement nature conservation means in the end (UK Environmental

Law Association, 2014). That environmental protection is not only addressed by national governmental bodies but also by regional and local authorities ensures a natural environment quality representing local particularities (Natural England, 2008). Final decisions are therefore not made on national but on local level. As argued above, this leads to better targeted environmental protective policies. Following this the current research problem is that the UK environment was classified as *extremely vulnerable* but there is not sufficient information indicating which areas on a sub-national scale are most vulnerable. Additionally to this the main hazards causing the environmental vulnerability are also still unrecognised. As long as this is unknown, suitable adaptation and mitigation strategies, directed at reducing the environmental vulnerability, cannot be designed and implemented.

2. Literature Review

2.1 Concept of Vulnerability

The concept of vulnerability is considered a widespread and complex topic. In order to assess it properly the scientific community agrees that a conceptual framework is essential to guide the assessment process, account for transparency and assures the inclusion of all important components. Villa & McLeod (2002) propose a three-step-system for environmental vulnerability assessments: model of vulnerability, model of the system and mathematical model. The model of vulnerability will be defined in this section of the study and aims to determine the main components and their interrelations of environmental vulnerability. The second step, the model of the system, is part of the index development (section 5.1) and presents the indicators chosen for this particular application. Likewise, is the mathematical model part of the index development (section 5.6). It illustrates how the indicator information will be aggregated in order to present the environmental vulnerability (Villa & McLeod, 2002).

Vulnerability research generally focuses on social-ecological systems underlining that human actions and the natural system are linked and influence each other (Adger, 2006). Due to the coupled human-environment system, a full vulnerability assessment involves complex factors, processes and feedbacks, often combining numerous disciplines (Schröter et al., 2004; Turner, Matson, et al., 2003). An example of the complexity of vulnerability is given by (Lummen & Yamada, 2014). Part of vulnerability is its multidimensionality, physical, social, economic, environment, institutional and human factors, its dynamic aspect in relation to temporal change, its scale dependency and site specification that need to be taken into consideration (Lummen & Yamada, 2014). In addition to its own complexity, recent literature integrates vulnerability in the framework of risk assessment (Jörn Birkmann, Kienberger, & Alexander, 2014; Du & Lin, 2012; Queste & Lauwe, 2006). Du & Lin (2012) even argue that vulnerability is the key issue in understanding disaster risk, as it describes the elements at risk.
The currently most accepted concept of vulnerability and risk is described in a simple equation:

$$R = E * H * V$$

Where R is Risk, E is exposure, H is hazard and V is vulnerability. This equation can be found in numerous publications (Birkmann, 2007; Du & Lin, 2012; Lummen & Yamada, 2014; Papathoma-Köhle, Neuhäuser, Ratzinger, Wenzel, & Dominey-Howes, 2007; Villa &

McLeod, 2002). In this context Du & Lin (2012) define risk, or more precisely risk assessment, as the combined output of hazard analysis and vulnerability assessment, while taking into account a systems' exposure. Following this the hazard analysis determines the probability of occurring hazards whereas the vulnerability assessment concentrates on the human or natural factor that cause the receptors' vulnerability (Du & Lin, 2012). Further the term exposure defines the degree to which a system is exposed to pressures (Kazmierczak & Cavan, 2011). Similarly to the risk equation addresses Crichton (2009) the topic but associates the four elements with one another in a 'risk triangle'. Risk is the area of the acute angled triangle and exposure, hazard and vulnerability represent one side each. The increase or decrease of one component affects the risk. With the triangle Crichton (2009) adds the spatial component to the system, indicating that for risk to be realised the receptor and hazard need to coincide spatially (Kazmierczak & Cavan, 2011). Furthermore, this triangle representation implies that no risk exists if one if its' sides is missing (Crichton, 2009).

Next to the overall context and interrelations of vulnerability, it is also important to identify what the different terms signify. Vulnerability is not a stand-alone term; it has to be seen in context of two questions: Who or what is vulnerable (*responder*)? To what is that system vulnerable to (*stressor*) (Adger, Brooks, Bentham, Agnew, & Eriksen, 2004; Villa & McLeod, 2002)? When it comes to a proper definition of vulnerability one can find various within the literature. Although the definitions differ from one another they cover the same main components of vulnerability: hazard (harm), exposure, sensitivity, adaptive capacity and recovery. Turner, Kasperson, et al. (2003) state that 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 a stress/stressor' (Turner, Kasperson, et al., 2003). Adger (2006) adds the absence of adaptive capacity to the definition. Similarly to this defines (Holman & Naess, 2009) vulnerability as a function of exposure, sensitivity and adaptive capacity. The term exposure describes the value and proximity to a hazard event (Crichton, 2009). Whereas Smit & Wandel (2006) refer to exposure as an almost inseparable property of a system together with sensitivity, indicating the likelihood of the system experiencing harm. Further components of vulnerability are resilience and adaptive capacity. Resilience indicates a systems' ability to absorb changes resulting from hazards (Holling, 1973). Several scientists define resilience and vulnerability as each other's inverse (Barnett, Lambert, & Fry, 2008; Kaly et al., 2004). Similarly to resilience looks the adaptive capacity at the systems' capacity to manage stress. The adaptive capacity however, defines the capacity of the system to adjust to changes (McCarthy et al., 2001). Following this, a hazard represents the event or cause for loss and harm of a system and besides that defines the frequency and severity of a harmful event (Crichton, 2009). In other definitions the terms harm, stressor or pressure are used but refer to the same mechanism as hazards. Lastly, when looking at risk on its own, it is defined as the 'likelihood of incurring harm, or the probability that some type of injury or loss would result from the hazard event' (Cutter, Emrich, Webb, & Morath, 2009; Lummen & Yamada, 2014). It is commonly described as in expected losses in a given area, at a given point in time, due to a hazard (De Lange, Sala, Vighi, & Faber, 2010).

It is noticeable, that the concept of vulnerability incorporates divergent elements. For the purpose of this study the vulnerability function by (Holman & Naess, 2009) is implemented focusing on exposure, sensitivity and adaptive capacity in the context of vulnerability, hence. In addition to the above stated, defines Bohle (2001) two different sides of vulnerability. He distinguishes between an external and an internal side. While the external side refers to the exposure to pressures exerting stress externally on the system the internal side describes the inability to cope of the system (Bohle, 2001). Therefore, the external side represents exposure and the internal side the sensitivity and adaptive capacity part of the vulnerability equation. Overall all the elements and different facets underline the vulnerabilities' complexity (Barnett et al., 2008; Turner, Matson, et al., 2003; Villa & McLeod, 2002).

2.2 Vulnerability Assessment

From a general point of view every vulnerability assessment has the purpose of informing decision makers on the state of the environment (Aubrecht, Özceylan, Steinnocher, & Freire, 2013; Hinkel, 2011; Kienberger, Blaschke, & Zaidi, 2013; Schröter et al., 2004). This shows that the main implication area of vulnerability is politics and planning. Hinkel (2011) underlines the applicability of vulnerability assessments to policies, as it defines six aims of an assessment. The targets go from identifying mitigation means, particularly vulnerable people, regions or sectors, raising awareness of climate change, assigning resources for adaptation policies, monitoring policy performance to conducting scientific research. Recognisably do five out of six aims are directed towards policies.

In the field of vulnerability research one can observe the emphasis of multiple pressures and multiple pathways of vulnerability (Adger, 2006). The term vulnerability is very broad in its definition, which

consequently makes it applicable to various systems, different spatial and also temporal scales. Resulting from this almost universal applicability, many methodologies have been developed, each addressing a different system or scale (Hinkel, 2011). The variety of methodology includes participatory, simulation-model-based and indicator-based approaches (Hinkel, 2011). In order to make vulnerability assessments, despite their numerous methodologies, more comparable, the tendency leads to the development of metrics that are independent of time and location to their greatest extent (Alwang, Siegel, & Jørgensen, 2001).
When now combining the emphasis of multiple stressor analysis, the preferred application of metrics and the complex system of vulnerability, one realises that a vulnerability assessment requires a significant representation of parameters to develop an appropriate image of a systems' processes and outcomes (Adger, 2006). Therefore, the execution of vulnerability assessments is considered to be challenging (Turner, Matson, et al., 2003). Consequently, the vulnerability assessments to date are less advanced compared to risk and hazard analyses, despite their strong connection and interrelation between each other (Du & Lin, 2012).
For this reason Schröter et al. (2004) established five criteria summarising important features of vulnerability studies. First of all the included knowledge should be varied and flexible. Secondly, the scale needs to be addressed and possible nesting be acknowledged. Moreover the multiple global drivers and their interactions always need to be included. Another point is to allow for differential adaptive capacity. Lastly, the information used should be historic and prospective (Schröter et al., 2004). While having these criteria in mind Zabeo et al. (2011) described the general steps of a vulnerability assessment in short. The four steps integrate the identification of scale-dependent receptors, the identification of attributes that approximate the receptors' vulnerability, the assignment of values to the attributes with the help of spatial analysis and finally the aggregation of attribute values for the overall vulnerability estimation (Zabeo et al., 2011).

There is a plethora of vulnerability assessments in the literature, considering different receptors, stressors and study areas. One way of categorising and creating an overview can be done with the vulnerability cube developed by (Kienberger et al., 2013). The three axes of the vulnerability cube represent each one dimension of the assessment classification. The three dimensions are: space, time and level. The space dimension embodies the scale of the vulnerability, for example individual, household, municipality, the temporal vulnerability identifies the event or process and the level stands for organisational level that the vulnerability occurs in (Kienberger et al., 2013). This is a first categorisation of assessments. In addition to that the evaluation can be distinguished by the different receptors and stressors it address and the methodology that is applied.

The most common method for vulnerability assessments is the indicator-based approach. In 2004 Schröter et al. (2004) developed a general guideline for vulnerability assessments that address the effect of global change. In this guideline they also apply indicators. Indicators are common for vulnerability studies as they help to simplify a complex issue and allow to aggregate different information (Farell & Hart, 1998). In this context Schröter et al. (2004) point out that the indicators have to be place-based describing the exposure to drivers, the sensitivity and adaptive capacity of the human-environment system. This is applicable to all studies, independent of its scale, time, or application level. A good example for this is the assessment of regional level vulnerability within the EU to various weather hazards by Lung, Lavalle, Hiederer, Dosio, & Bouwer (2013). Besides the climatic data representing the weather hazards, they determined the exposure and sensitivity input data for three impact indicators, heat, flood and fire, like population density (Lung et al., 2013). A similar approach is followed by Papathoma-Köhle et al. (2007) as they identify most vulnerable communities to landslides in Baden-Württemberg, Germany. In order to populate their indicators Papathoma-Köhle et al. (2007) used GIS layers with the corresponding information. Likewise, analysed Taubenböck, Roth, & Dech (2006) the vulnerability of Istanbul to earthquake. The vulnerability indicators were populated with the help of remote sensing imagery and GIS layers. In 2010 a paper for ecological vulnerability reviewed the different methods on how the indicators in an vulnerability assessment can be populated data and aggregated (De Lange et al., 2010). They came up with four possibilities: 1. scoring of the indicators based on expert judgement; 2. Use of GIS layers; 3. Model Calculations; 4. Multi-criteria analysis tools (De Lange et al., 2010).
Alternatively to the indicator-based vulnerability assessment Huang, Liu, Ma, & Su (2012) applied a data envelopment analysis-based model. The problem that Huang et al. (2012) see with indicators assessments is that the selection of indicators and the applied weights cause arguments and are biased or even arbitrary. The DEA is a mathematical programming theory that extracts information from observations. For one decision-making unit not the overall trend as in a regression analysis is calculated but the efficient frontier of the input-output data. What is left out in this study is the cause-effect part. The mechanisms of vulnerability are considered as a black box

but therefore the focus is on reflecting the vulnerability but not its indicators. Accordingly the indicator-based approach and a DEA-model do not exclude but maybe even supplement each other (Huang et al., 2012).

2.3 UK Vulnerability Assessment

Vulnerability assessments were conducted in the UK already. Holman & Naess (2009) give a short summary of the kind of assessments made in the past and which implementation areas they mainly covered. Up to the date of the study, regional scoping studies and regional and national modelling studies were applied. The regional scoping studies can be classified into four groups. First of all sub-regional vulnerability studies were executed. They mainly focus on flood-prone areas, the subsidence of clay-rich soils or to the urban heat island effect of cities. Next to this, attention was given to sectoral vulnerability. Aspects like transport and energy infrastructure, winter sports, manufacturing and insurance industry were assessed. Furthermore, also vulnerable social groups or workers were identified within social vulnerability studies. Lastly, industries that were ill-informed or ill-prepared for flooding were assessed (Holman & Naess, 2009). Within the category of modelling studies, climate change impact and response studies were executed primarily. Based on this Holman & Naess (2009) generalise that there is an emphasis of climate change and socioeconomic scenarios within the vulnerability assessments in the UK.

Supporting this, the only vulnerability assessments in the UK that could be found either addresses the issue of floods or climate change. As climate change is a pressing topic Natural England (2011a) published an extensive report on the national vulnerability towards climate change. It covers indicators for adaptive capacity, habitat sensitivity and climate exposure defining the national vulnerability (Natural England, 2011a). An example for a vulnerability assessment for flooding is given by Kazmierczak & Cavan (2011). They examine the vulnerability of people within Manchester towards floods. The physical environment and the land use pattern present the peoples' exposure to floods, 26 indicators depict the vulnerability and hazard component, as in the presence and spatial distribution of surface water flooding (Kazmierczak & Cavan, 2011).

2.4 Natural Environment

When talking about the environment one refers to 'the whole sum of the surrounding external conditions within which an organism, a community or an object exists' (Monkhouse & Small, 1978). The natural environment more precisely refers to the non-cultural and non-social environment, excluding the built-up and urbanised areas (Kaly et al., 2004; Monkhouse & Small, 1978). A healthy environment fulfils certain services and provides resources that are essential for human life. Examples are clean air, clean water and productive soils for the food production (Natural England, 2009). The services provided by the environment assure the wellbeing of humans and is the basis of the economy (Defra, 2012, 2013c). The importance of a healthy environment is recognised internationally and therefore also addressed in EU directives in order to protect and enhance the natural resources (Defra, 2012). This protection and special attention is needed because the natural environment is very vulnerable to external hazards and pressures (Defra, 2012). As aforementioned, the hazards and pressures have both natural and anthropogenic origins (Filser et al., 2008). The degradation of the natural environment has not only effects on the nature itself but also on political, social and economic structures (Natural England, 2011b; Pratt et al., 2004). This underlines the importance of the natural environment and that protection strategies are necessary. Otherwise the economic prosperity of an area will decline and it will be more difficult and moreover more expensive to restore the natural environment to a healthy state (Natural England, 2009). Implementing climate change and environmental vulnerability reduction policies might even be a pro-growth schemes (Natural England, 2009). The environmental threat addressed in this study is environmental vulnerability. Predominantly it is spoken of in the context of climate change, as climate related hazard events, like floods or storms, have an immediate effect on the state of the environment and additionally the incremental change of climate on long terms too (Defra, 2012). In this study the environmental vulnerability is not only defined by climate change but by additional pressures as well.

2.5 Environmental Vulnerability Assessments

Predominantly vulnerability assessments are addressed to humans; they represent the responders who are vulnerable to stressors. This is often expressed in losses related to human welfare, for example damage to property, economic loss, damage to livelihoods, morbidity or mortality (Barnett et al., 2008; Huang et al., 2012; King, 2001; Papathoma-Köhle et al., 2007; Taubenböck et al., 2006). Putting the environment into focus as the affected system experiencing the damage has not been done extensively in the field of vulnerability assessments. Environmental vulnerability is broadly defined as in the risk of the natural environment to experience damage (Kaly et al., 2004). The responding system is the environment in this case (Vogel, 2001). One can only find a small selection of studies for environmental vulnerability, regardless whether the origin is of natural or human hazards. Similarly as to the methods described in section 2.2, Abbasov & Smakhtin (2012) developed an indicator-based assessment putting scores on the environmental vulnerability of small streams. The indicators are individually assessed and a scoring system based on the scientific knowledge applied, before all indicators were summed up for an overall environmental vulnerability score of the streams (Abbasov & Smakhtin, 2012). Likewise Wang et al. (2008) developed an environmental vulnerability index for the Tibetan plateau. The data population of the indicators is based on remote sensing imagery, GIS and then an analytical hierarchy process model defines the weights of the indicators (Wang et al., 2008). The analytical hierarchy process model is also used by Chang & Chao (2012) in their assessment of basins' environmental vulnerability to natural hazards. Furthermore, they applied a multiple criteria analysis for the vulnerability index. A slightly different approach was followed by Tran, O'Neill, & Smith (2010). They assessed the environmental vulnerability of the mid-Atlantic region with a multivariate analysis. The focus is on spatial patterns. One part of the multivariate analysis looks at the occurrence of stressors, determining the distance from vulnerable watersheds and clustering analysis of vulnerable watersheds (Tran et al., 2010). Also Zhang, Wang, Li, & Xu (2014) applied an index in order to assess the environmental vulnerability of Jilin province of China. As an adjustment however, they developed an improved entropy weight model. So far the studies always only refer to one study area and are very site specific. A comparison between studies or in that sense between environmental vulnerabilities is not possible.

The only application filling this gap is the Environmental Vulnerability Index (EVI), an index developed by the Secretariat of the Pacific Community (SOPAC). The EVI focuses on the environment and is designed to be applied on county level, estimating a countries' environmental vulnerability to future shocks (Kaly et al., 2004). It only assesses the natural environment, excluding human systems like built-up areas (Villa & McLeod, 2002). The aim of the development was to create an assessment methodology that is globally applicable and allows comparing countries with one another. Their selected assessment is the application of an index as a fast, standardised and comparable assessment method (South Pacific Applied Geoscience Commission, 2013b). The EVI does not focus on a single hazards but on multiple possibly occurring ones that interact within the complex system (Kouakou et al., 2013). In total 50 indicators were identified for the EVI that represent the different human impacts and natural hazards, exerting stress on the environment. The general definition of vulnerability was interpreted into slightly different terms. The EVI is mainly described by indicators related to hazards, resistance and damage, aiming to include the whole grasp of the vulnerability issue (Kaly et al., 2004). In addition to that, seven sub-groups were formed: climate change, biodiversity, water, agriculture & fisheries, human health aspects, desertification and exposure to natural disasters. These issue groups have assigned indicators so that sub-indicator scores can be calculated. This breaks down the environmental vulnerability matter into comprehensible groups (Kaly et al., 2004). GIS, remote sensing and survey data was used to populate the indicators (Kaly et al., 2004). The result of the aggregation is an EVI score for each country, calculated by the indicator values, specifying a countries' vulnerability (Pratt et al., 2004). Despite its global application the EVI was criticised by several sources. The main disadvantage pointed out about the EVI is that it is unable to locate most vulnerable areas on regional or local level (Barnett et al., 2008; Skondras et al., 2011). In addition to this Villa & McLeod (2002) claims that the methodology of the EVI, more precisely the weighting and scaling process, is biased and hence not representative. Furthermore they criticised that certain indicators were only populated with proxy data (Villa & McLeod, 2002). Another assessment of the EVI stated, that the indicators chosen are not applicable to every country in the world (Skondras et al., 2011). An example are volcanoes (7) and earthquakes, as natural hazards only occurring in certain areas of the world or for instance sanitation (44) as an indicator only suitable for mainly developing countries (Skondras et al., 2011).

2.6 Environmental Vulnerability Assessment UK

The literature search for environmental vulnerability assessments in the UK revealed that there has not been one conducted yet (Holman & Naess, 2009). This does not mean that the environment and its importance is not addressed in the UK, but a specific vulnerability assessment is not existent yet. Up to know, mainly national institutions have published reports and studies about the state of the natural environment or the national ecosystem (Natural England, 2008; Watson Steve et al., 2011). Defra (2008) even issued a pocket guide on sustainability development indicators. The only environmental vulnerability study for the UK, is the Environmental Vulnerability Index (EVI) which was applied to 235 countries in 2004 including the UK, as stated here before (Kaly et al., 2004). Within that assessment the UK environment was classified as *extremely vulnerable*, the highest vulnerability class (Kaly et al., 2004). Further results of the assessment summaries that the indicators causing the environmental vulnerability in the UK the most are: environmental openness (18), industry (41), mining (43), biotechnology (34), pesticides (33), SO_2 emissions (38) and vehicles (45) (SOPAC, 2005). Except environmental openness all indicators are human induced pressures. In contrast to that are most of the resilient indicating variables of nature origins like for example earthquakes (8), volcanoes (7), relief (14) and slides (10). Also some human related pressures were considered as low and hence not causing any vulnerability: terrestrial reserves (29), land cover loss (26), fishing effort (36) and conflicts (50) (SOPAC, 2005).

2.7 Scale

Scale is a crucial topic. The term 'scale' has two different meanings. On the one hand it is the extent of the assessment, as in area size, and on the other hand the amount of detail or granularity (Joao, 2000). In vulnerability assessments both definitions are important. The main question is always which spatial scale is the appropriate one for the assessment scope as vulnerability is strongly connected to a place (Kienberger et al., 2013). This is particularly difficult as hazards causing vulnerability occur at various scales (McLaughlin & Cooper, 2010). On one side this leads to overlapping and interacting of issues appearing on different scales (Adger et al., 2004; Wickham et al., 1999). On the other side the change of scale can also mean that new variables are included and others become insignificant. A reason for this is that with the change of scale, from local to regional or global, environment will be characterised always differently (Basso et al., 2000). This theory is supported by observations that national scale trends not automatically represent regional or even local trends (Desjeux et al., 2015). Multi-scale and purpose-tailored environmental vulnerability assessments are therefore necessary. The scale influences the elements that contribute to environments' vulnerability, the data type and availability and even the utility of an index-assessment (McLaughlin & Cooper, 2010). Although the different levels or scales vary from one another, their vulnerability studies can still benefit from each other (Fekete, Damm, & Birkmann, 2010). The contextualisation of a vulnerability assessment is therefore a challenge (Birkmann, 2007).

When it comes to vulnerability studies they have been applied to all possible scales: national, regional and local. Despite the existing national assessments Adger et al. (2004) argue that the national scale is an inappropriate assessment level for vulnerability, as vulnerability is context specific and particularly spatially differentiated. Van Vuuren et al. (2007) strengthen this argument when saying that 'vulnerability requires the sub-national level'. The environment of a country is generally very heterogeneous and therefore requires a lower assessment scale in order to account these heterogeneities (Zhao et al., 2015). In the assessment of environmental vulnerability of Greece based on the EVI Skondras et al. (2011) point out that not being able to locate most vulnerable areas is the biggest weakness of the EVI.

As stressors occur on all spatial scales and they have to be evaluated in each assessment scope again, it seems more appropriate to choose the assessment scale based on the application scale. The application background of a vulnerability study is to identify vulnerable areas, so that decision-makers can implement policies reducing the vulnerability. Based on the appropriate policy-scale the assessment scale can be chosen (Kienberger et al., 2013). Generally the strategies for preventing and reducing impacts are outlined in regional, national and even super-national frameworks (Tavares & Pinto dos Santos, 2013). For the reduction of vulnerability Sietz (2014) however, says local implementations are more effective than global or regional ones. There are several studies that claim the local administration level is the best fitting level (Tavares & Pinto dos Santos, 2013). Though, national scale assessments applied globally allow identifying regions and countries with high vulnerabilities and comparing countries with one another, local assessments highlight vulnerabilities more place-specific (Birkmann, 2006). The reduction of vulnerabilities as in implementation of mitigation and adaptation strategies requires such a place-specific localisation. The planning responsibility of local councils is the crucial aspect for this (Tavares & Pinto dos Santos, 2013). Next to the planning authority of local councils they are also responsible for targeted public information campaigns and raising awareness within the population to make reduction strategies more effective (Queste & Lauwe, 2006). Taking into account these reasons and a study conducted by Fekete et al. (2010), the county-level appears to be the most appropriate application level for an environmental vulnerability study in the UK.

The county-level assessment is very applicable as it is a local administration authority and in addition to that is reasonably homogeneous in size, political processes are organised from the county councils, federal statistic data is available and they fall into the category of NUTS3, which allows the comparison to other European countries. Overall is the county-level for policy-makers and planners involved in vulnerability strategies very convenient as they have to decide about administrative units (Fekete et al., 2010).

As vulnerability, and especially environmental vulnerability, is a spatially defined issue, thus one can also think to assess it from a more spatial point of view. Vulnerability studies can also be conducted on a grid-base. An argument for this is that natural environments do not particularly coincide with administrative boundaries (McLaughlin & Cooper, 2010). Additionally, scientific calculations, preciseness and spatial relations are better attended to in a grid-based study (Fekete et al., 2010). However, then the problem arises on how to include census data that is only available on borough or county-level and also the resulting vulnerability issues are not as comprehensible for policy-makers (Fekete et al., 2010). This incomprehensibility possibly leads to the council refraining from taking action. Since this defeats the whole purpose of the assessment, a county-level based study is still the most appropriate.

2.8 Index

An index is a widely used tool for giving justified information and statements about a system, that is generally not directly measurable (Dobbie & Dail, 2013). Hence, an index is commonly applied for assessing vulnerability issues in general and also suggests being an appropriate tool for evaluating environmental vulnerability (Huang et al., 2012). An index itself determines trends and points out issues (OECD, 2008). For this reason indices on international level are used to measure and highlight differences between countries (Queste & Lauwe, 2006). More precisely, an index helps that the state of a complex system can be measured, simplified and communicated (Farell & Hart, 1998; Hinkel, 2011; OECD, 2008). Another advantage of using indices and indicators is the possibility to conduct temporal and spatial comparing environmental vulnerability assessments (Hinkel, 2011; OECD, 2008). The use of indicators, which get aggregated to one index, assists in making a theoretical concept operational. In addition to that indicators contribute to a transparent, robust and relatively objective tool, which again simplifies communicating the application and results firstly to decision-makers and secondly to the public (Adger et al., 2004; OECD, 2008).

Especially a nested structure, with the application of sub-indicators, increases the understanding (OECD, 2008). When it comes to vulnerability studies an index is the tool delivering most important information for policy-makers (Queste & Lauwe, 2006).

2.9 Geo-Information Science and Remote Sensing

A thorough environmental vulnerability assessment requires the inclusion of an extensive amount of spatial data. The use of Geographic Information System (GIS) and remotely sensed (RS) data present tools capable of handling the spatial data needed and in addition to that provide the functions to derive supplementary and helpful information from it (Wang et al., 2008). Besides that, a GIS simplifies the integration process of the various data (Basso et al., 2000). The conventional output of a GIS is a map, with the benefit of managing multiple layers for tailored integration combinations, depending on different application purposes (Wang et al., 2008). Furthermore, the illustration of issues as a map helps the user of this information to understand it and emphasises the full extent of the problem more adequately than a descriptive text (Wang et al., 2008). Up to now, GIS and RS have not been applied widely for regional environmental vulnerability assessments despite their usefulness, effectiveness and ability to display spatial distribution of characteristics (Wang et al., 2008). Back in 1999 Wickham et al. (1999) even acknowledged that an integrated environmental assessment is only achievable due to the GIS, remote sensing and landscape ecology and hence giving GIS and remote sensing big credit.

3. Research Objectives and Questions

Following the research problem and the identified gap in the field of environmental vulnerability, the overall objective of this study is to determine the environmental vulnerability of the UK on sub-national level and to identify the main pressures causing it.
In order to assess this objective, four sub-objectives have been formulated together with research questions that answer these sub-objectives.

To start off with this study, the conceptual model developed in section 2.1 of the literature review has to be specified to the UK case. Generally occurring pressure and hazard groups have been defined already, but following this the relevant pressures and hazards for the UK natural environment have to be identified in order to finalise the conceptual model. This is particularly important as these pressures will feed into the index assessing the UK environmental vulnerability (EVI_{UK}). Hence, the first sub-objective is to identify the main pressures occurring in the UK in order to finalise the conceptual environmental vulnerability framework. The research questions that need to be answered to reach this objective are: Which are the main pressures acting on the UK natural environment? Which EVI indicators can be used in the EVI_{UK} index as well? Which indicator/s from the EVI is/are not applicable to the UK? Which additional indicators help describing the environmental vulnerability in the UK?

Succeeding the finalised conceptual framework, all information are provided to actually assess the environmental vulnerability. Therefore the second sub-objective is to create an index determining the environmental vulnerability, which can be applied to sub-national levels. The chosen sub-national levels are county and borough-level. The index development process is described in the literature. Despite this, decisions still have to be made on which normalisation, weighting and aggregation method are most appropriate for the UK index. Another research question is which aggregation unit is most fitting for the index. Is a grid-based approach or an aggregation based on administrative units more appropriate?

After having developed and applied the EVI_{UK} it is of interest if there are certain indicators that cause the main proportion of identified environmental vulnerability. And if yes, which indicators are these. Attention should be given to dominant indicators, as they might narrow down the most important threats. This can be especially helpful for targeting mitigation and adaptation policies for environmental vulnerability. Another aspect of dominant indicators is to assess whether the main hazards for the environment are the same or different on county and borough-level. Therefore, the third sub-objective is to identify the main pressures causing the environmental vulnerability in the UK. Supporting research questions are: Which indicators are the main pressures causing a high environmental vulnerability on county-level? Which indicators are the main pressures causing a high environmental vulnerability on borough-level? Are the indicators causing the environmental vulnerability the same on county and borough-level?

After having developed the EVI_{UK} and assessed its results, it is important to look at its implication possibilities. The general idea of composite indicators is to be developed for and used by policy makers. The main aim is to provide the policy-makers and stakeholders with a valid tool, which they can apply and base their policies and planning programmes on. Hence, the last sub-objective is to demonstrate the most appropriate implementation level of an environmental vulnerability index assessment. The main helping research questions are: What is the main planning procedure and policy structure in the UK? Based on the results obtained, which assessment level seems to be most suitable for an environmental vulnerability assessment? How can policy makers benefit from the EVI_{UK}?

4. Study Area

The study area selected for this research is the United Kingdom. The whole UK covers a total area of about 242,000 km^2 (The World Bank Group, 2014) and is situated in the north-west of Europe. As in island it is surrounded by the North Atlantic Ocean and the North Sea. The UK is located roughly between 50°N and 61°N as well as -8°W and 2°W.

Before starting the assessment it is important to get to know the UK's characteristics, especially those relevant for the natural environment. Generally one can observe a rather cool, moist and mainly maritime influenced climate in the UK (Brown, 1992). The average annual temperatures are mild and extremes are rather moderate. Despite these steady conditions the weather can vary between different times and locations in the country widely. A reason for this is the closeness to the track of the Atlantic depressions, which interfere with the weather patterns, diverging from the predominant south westerly and polar maritime air flow (Brown, 1992). Throughout the UK one can observe reasonable variations within climate patterns as the high grounds in the north and west block the air masses, causing windward and leeward weather variations. Based on its position the UK experiences mild winters and high average annual temperatures. Reasons for this are the North Atlantic Drift and that the surrounding oceans store and release to heat more evenly throughout the year (Brown, 1992). This results in average annual temperatures of 11.5°C in the south and 7.5°C in the north of the UK. The meteorological data applied later in this study show that the average maximum temperature is 10.6°C and the minimum temperature 4.7°C averaged over the whole country. In terms of precipitation one can distinguish patterns clearly. First of all the south has less precipitation than the north, predominantly the uplands in Scotland but also in Wales and the Lake District (Brown, 1992). Another difference can be observed between north east and south west. The north east is wetter as it is influenced by the mountains, unstable maritime air and frontal systems (Brown, 1992). The last important climate factor is the wind presenting further differences within the UK. The prevailing winds are from south and west and on average have a wind force of five. In addition to the regional wind variations one can also differentiate between seasons. This is particularly obvious when looking at the occurrence and distribution of gales. The strongest and most frequent gales occur in coastal areas on the west coast. In contrast to that the inland and east coast areas are spared by strong winds mainly (Brown, 1992). Another relevant aspect of the natural environment is the soil dispersion. In England and Wales mainly brown and gley soils occur. Each soil covers about 40-45% of

the areas units. Less common are lithomorphic, podzols and peat soils. Scotland has a more balanced distribution of soils as brown, podzols, gley and peat soils all comprise about 20% each. Alone lithomorphic soils cover only 10% (Brown, 1992). Land use and land cover information show that more than three quarters of the UK area is agriculturally used indicating that the areas are mainly covered by crops, grass or lie in fallow. The missing fourths includes forests, woodlands and urban areas. In addition to that the main habitats are grasslands, woodlands and peatlands. These broad classes are further subdivided indicating the state of the habitat as in acidic, neutral, semi-natural or plantation. In total 155 habitats were distinguished (Joint Nature Conservation Committee, 2014).
The UK has about 63,000,000 inhabitants in total. The majority lives in England and only 5.3, 3.1 and 1.8 million people in Scotland, Wales and Northern Ireland respectively. Overall the population increased by 7% since 2001 and this mainly in Northern Ireland, Scotland and East England (Office for National Statistics, 2012).

The UK was chosen as the study area for several reasons. First of all it is a country that was included in the EVI assessment in 2004 and was classified as *extremely vulnerable*. This categorisation, in contrast to *resilient* or *at risk*, already points out that environmental vulnerability is an issue in the UK and hence critical to further investigate. Additionally to this, is the UK a diverse country: mountains and lowland areas, inland and coastal areas and varying climate conditions throughout the country. These divergent characteristics display the diversity of areas in the UK. As described in the introduction and literature review (section 1 and 2) this assessment is based on the assumption that vulnerabilities vary locally due to the not conform pressures occurring. Following the description of the UK there are spatially varying conditions that most likely have an influence on the environmental vulnerability. A second argument speaking for the UK is that a country was needed that has a hierarchical structure of administrative units. As the main objective is to determine the environmental vulnerability on sub-national scales this was a vital condition. The UK holds a multi-level administrative system including regions, counties, districts and boroughs, hence providing choices for sub-national scales and assuring that the scientific question can be answered. Besides the above mentioned reasons for picking the UK as a study area, it was also essential that for the country chosen, secondary data is available freely and easily accessible. For the EVI 2004 analysis 96% of the data needed was already available for the UK. In addition to that there are numerous governmental departments dedicated to one aspect of life and services in the UK that one can assume that these collect and provide data. Based on these two observations and assumptions it is very likely to find sufficient data for the assessment. At last, but not unimportantly, reason for choosing the UK as a study area is that the UK itself declared to engage in climate change reduction and environmental protection strategies. Despite this, the subject of environmental vulnerability is new to the UK and not yet addressed and therefore represents gap. As the incentive for environmental protection actions is already there one can assume that in the case of positive findings related to environmental vulnerability, these have a chance to be implemented. Also, the UK is a developed country with a stable government facing no imminent threats like war or other conflicts. Hence, the UK has the capacity to address environmental issues in contrast to conflict-troubled countries. Combining all these arguments the UK presented itself as a valid study area for the planned comprehensible environmental vulnerability study on sub-national levels.

This study was initially designed to be conducted for the whole UK. However, data-constraints for Northern Ireland, Scotland and Wales had the consequence that only England was addressed in the end (Fig. 2).

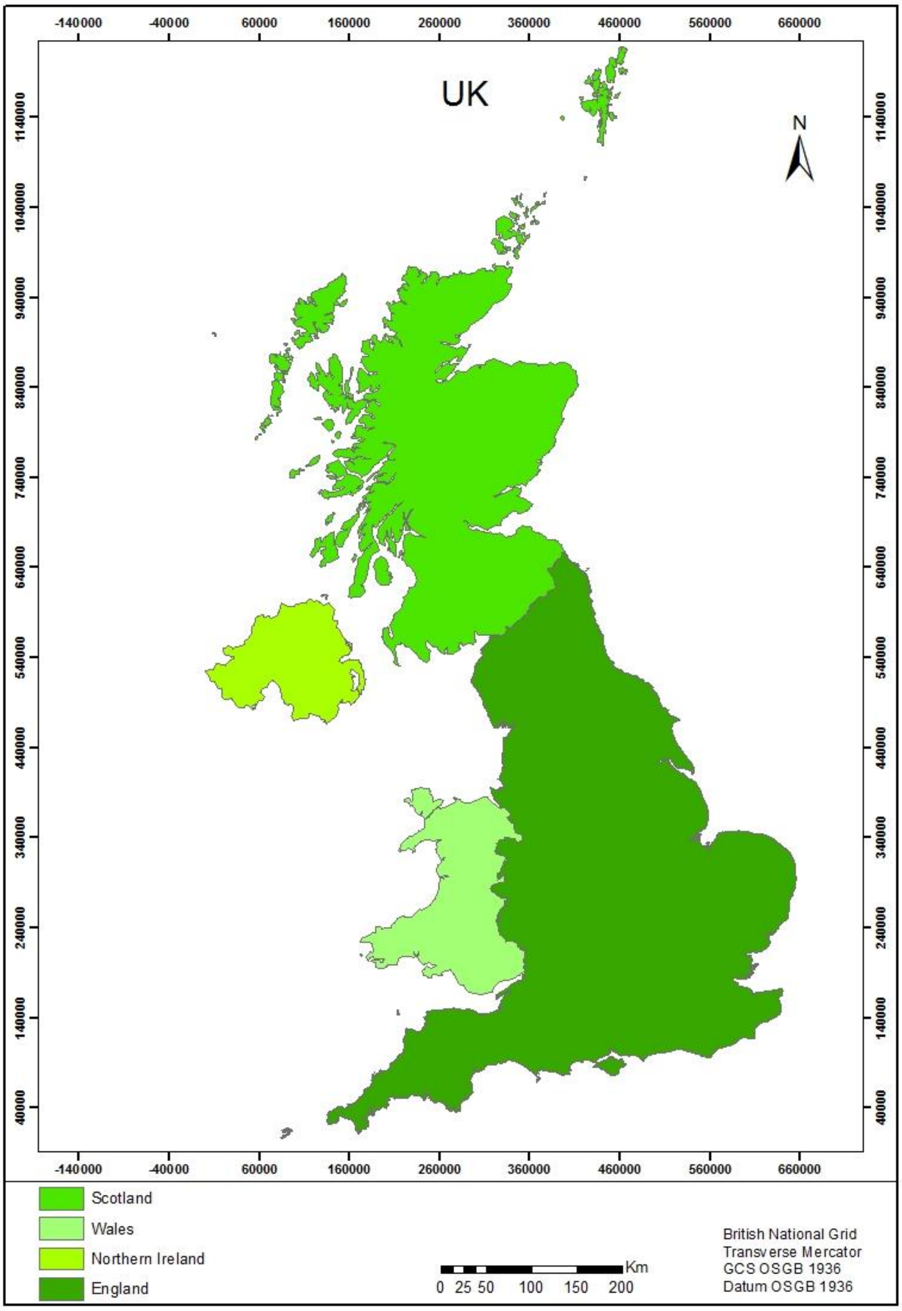

Figure 2: UK territories.

5. Methodology

The development of an index assessing the environmental vulnerability on sub-national level requires several steps. The OECD handbook in constructing composite indicators lays out elaborated guidelines (OECD, 2008) (Fig. 3).

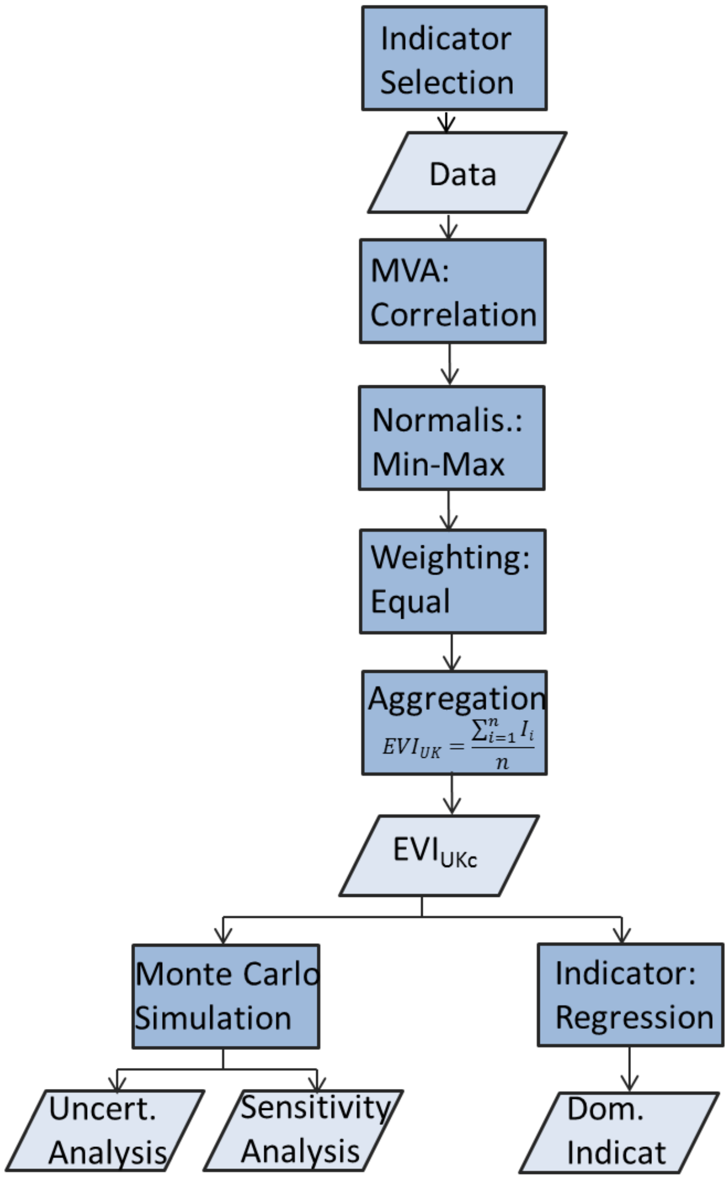

Figure 3: Flowchart of the methodology based on OECD (2003).

5.1 Selecting Indicators

The first step is to identify the indicators describing the system and issue under assessment. Based on the conceptual model that was developed in section 2.1, the system is the UK natural environment and the issue is the vulnerability of the environment. Hence, all main pressures and hazards causing damage or stress to the UK natural environment need to be identified. The indicators chosen for this assessment have to have both scientific relevance and also for policy-makers (McLaughlin & Cooper, 2010). In order to avoid subjectivity the selection of indicators is based on previous indices and scientific literature (OECD, 2008).
The EVI, as the only current index assessing the environmental vulnerability, can be taken as a starting point. Besides that there are several other indices that define relevant aspects for the UK natural environment. Comparably to the EVI an environmental sustainability index (ESI) or the succeeding environmental performance index (EPI) are available (Hsu et al., 2014; World Economic Forum, 2002). The main idea of the ESI and EPI is the same as for the EVI. With the help of twenty indicators an environments' sustainability state is defined in the ESI. Furthermore the Coastal Vulnerability Index adds important aspects to the list of pressures and risks (U.S. Geological Survey, 2013). The island characteristics of the UK with its long coastline need to be taken into account in the vulnerability assessment. Certain characteristics specifically indicating the vulnerability of the coast are required.
The range of indicators stated by these indices creates a long list of generic pressures. However, so far the relevance for the UK of each indicator was neglected. With the help of several UK publications and general scientific literature, it was decided whether to include or exclude an indicator for the EVI_{UK}. The main publications looked at are a report about the State of the Natural Environment (Natural England, 2008), a pocket guide published by Defra for sustainable development (Defra, 2008) and the National Climate Change Vulnerability Assessment of the UK (Natural England, 2011a). These reports define pressures and important characteristics of the UK environment and therefore give justification of which of the indicators stated before to include or exclude in an environmental vulnerability index specifically developed for the UK. Although most of these indices and reports describe vulnerabilities and pressures towards the human system some indicators used also present threats to the environment and are therefore applicable to this study. The final composite indicator consists of 51 indicators, grouped together to eight sub-indicators.
Table 1 shows all selected indicators and the sub-indicator groups with their justification of inclusion. In the appendix table 15 shows

the indicators from EVI, ESI, EPI and CVI, which were excluded for this study, also with a justification.

Table 1: Indicator Selection for the EVI_{UK}.

Sub-Indicator	Indicator	Justification/Source
Climate	Wind	EVI, SoE
	Precipitation Max	EVI, SoE, NCCVA
	Precipitation Min	EVI, SoE, NCCVA
	Temperature Max	EVI, SoE, NCCVA
	Temperature Min	EVI, SoE, NCCVA
	Phenology	SoE
	Sea Surface Temp.	EVI
	Sea Level	CVI, SoE
	Tide	CVI
Biodiversity	Relief	EVI, NCCVA
	Lowlands	EVI, NCCVA
	Coast length	CVI
	Soil Diversity	NCCVA
	Invasive Species	SoE
	Diseases	SoE
	Endangered Species	EVI
	Birds	SDI
Natural Hazards	Slides	EVI
	Storms	EVI, SoE
	Floods	SDI
Agriculture	Fertilisers	SoE, EVI, ESI
	Land Degradation	SoE, EVI
	Drainage	SoE, SDI
	Intensive Farming	EVI
Population	Population Density	EVI, ESI, SoE
	Population Change	EVI, ESI
	Tourists	EVI
	Vehicles	EVI, ESI
Fishery	Fishing stocks	EVI, ESI, SoE, SDI
	Fishing Efforts	EVI, ESI, EPI, SoE, SDI
Pollution & Waste	River Water Quality	SDI, ESI
	Pesticides	EVI, ESI, EPI, SoE
	Air Quality	ESI, EPI
	Carbon Emissions	EPI, SDI
	Waste	EVI, ESI, SDI
	Waste Recycling	EVI, ESI, SDI
	Electricity	EVI
	Med. and Chemicals	SoE
Land Use &	Infrastructure	EVI, SoE, SDI

Energy		
	Fossil Fuels	SoE
	Biofuels	SoE
	Excavation	EVI, SoE
	Groundwater	SoE
	Trophic level	EVI
	Ecological Network	NCCVA
	Land Cover Diversity	NCCVA
	Land Cover	EVI, ESI, EPI, SDI
	Land Cover Change	EVI, ESI
	Coastal Settlements	EVI
	Marine Reserves	EVI, EPI
	Nature Reserves	EVI, ESI, EPI, NCCVA,SDI

5.2 Data

Following the selection of indicators for the EVI_{UK}, these have to be populated with variables (OECD, 2008). The first assessment level is the county-level. In order to assure coverage of the whole UK the districts have to be included in the county-level assessments. District councils represent the same administrative unit as counties but are mainly applied for cities. The different characteristics of counties and districts are discussed in section 6.1.2.
The whole assessment is based on the quality of the variables. They either contribute to the strength of the composite indicator or its weakness. The selection criteria for a variable include its relevance, analytical soundness, timeliness and accessibility (OECD, 2008). The main formats of the data-sets are GIS layers and census data. A requirement for census data was that it can be aggregated to county-level first and later to borough-level. When fitting-data was unavailable the indicators were populated alternatively with proxies (OECD, 2008).
The initial aim was to assess the whole UK but finding data for Wales, Scotland and Northern Ireland was difficult and hence due to time constraints excluded from the assessment. The focus is on England. An overview of the selected datasets for the single indicators and hence also the indicators definition can be found in the appendix (Tab. 16).

As defined before, the EVI_{UK} assessment will be based on aggregating the information to county and borough-level. Therefore, the lowest data resolution needed to be of equal size or preferably higher resolution than that. As each indicator-set will be aggregated to the administrative unit, it is insignificant that the data-sets contain different resolutions. The final output maps is based on the counties or boroughs only.

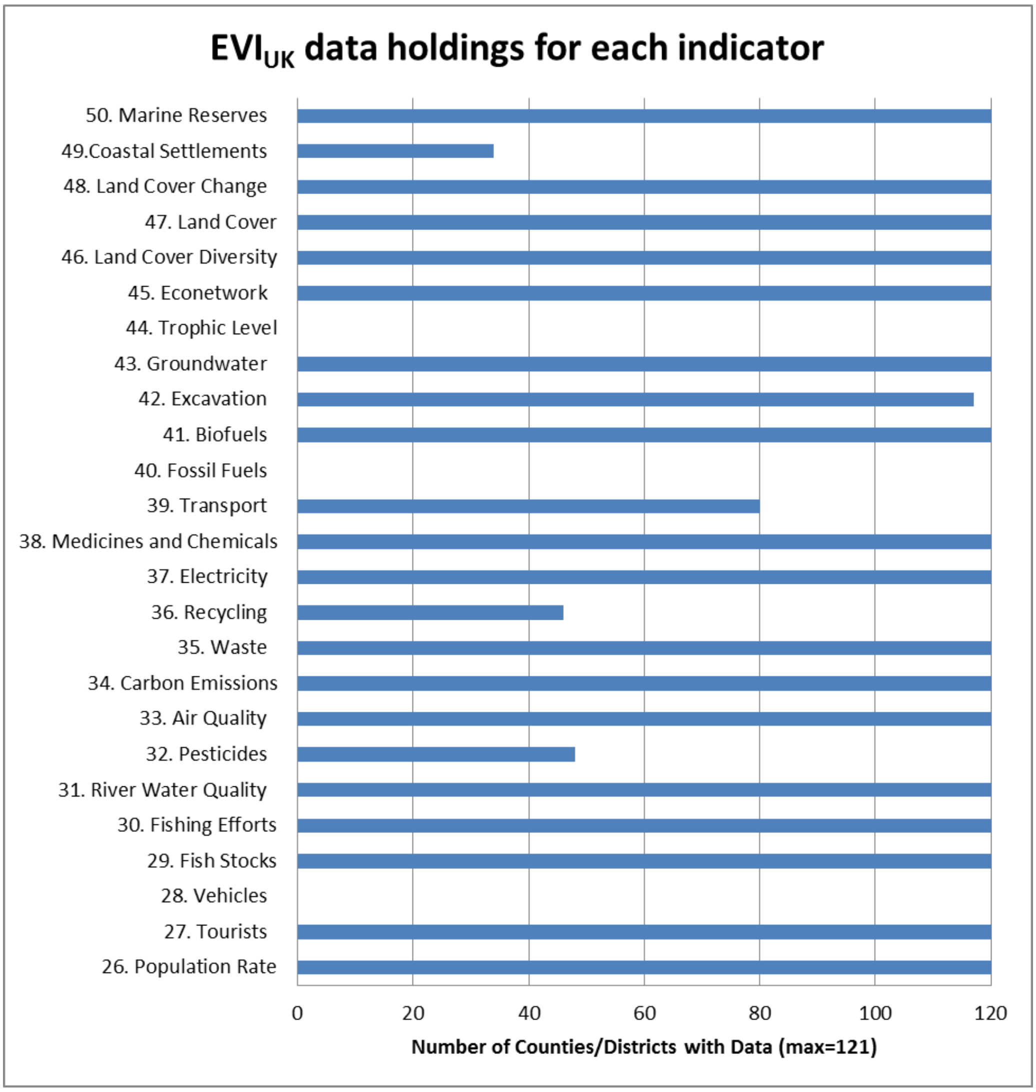

Figure 4: EVI_{UK} data holdings for each indicator.

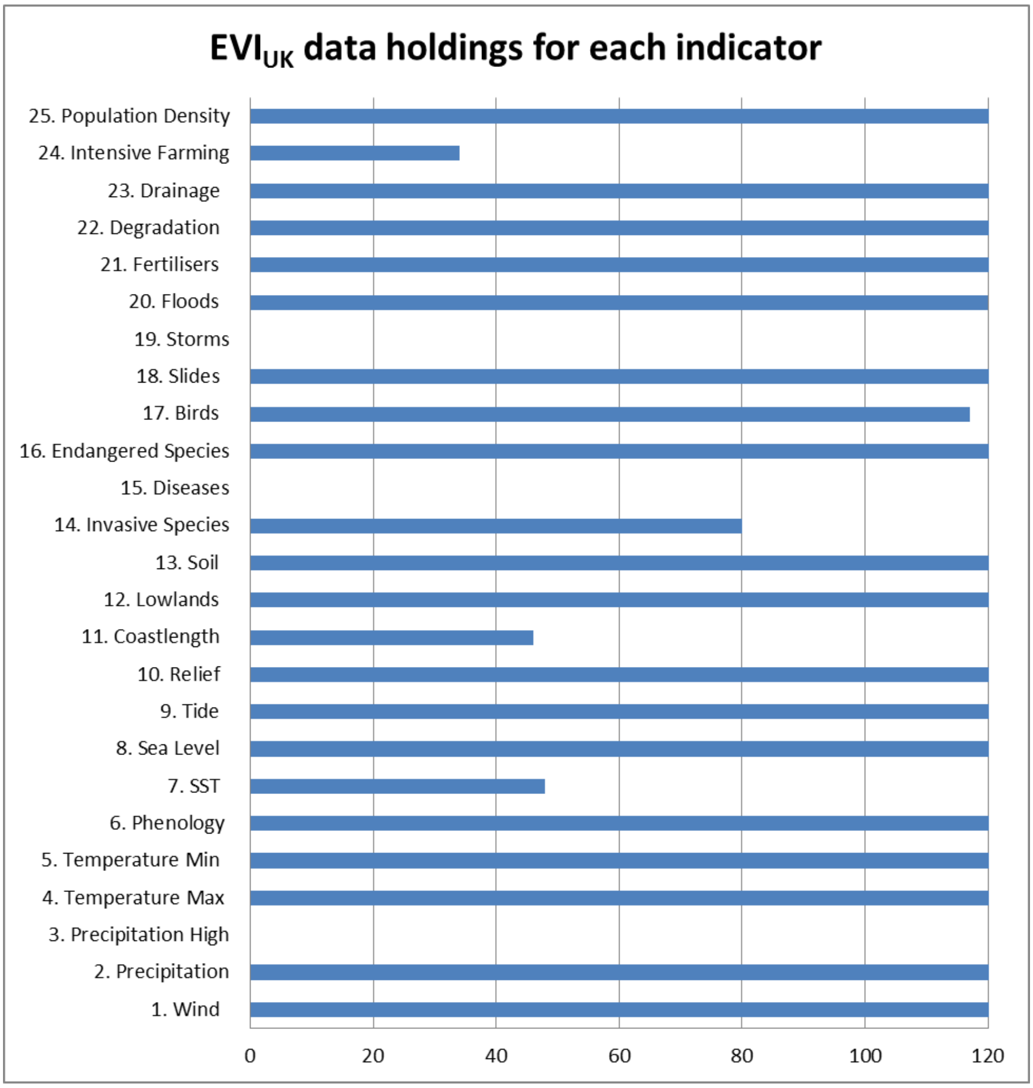

Figure 5: EVI$_{UK}$ data holdings for each indicator 2.

There are six indicators for which no appropriate data sets could be found (for example diseases, storms, medicines and chemicals). Despite these missing indicators more than 80% of the indicators can be populated with data which is the threshold applied for the EVI assessment (Kaly et al., 2004). The majority of indicators are available for the assessment per county/district figure 4 and 5.
Another angle to look at data coverage is to explore how many data-sets are available for each county, district and borough. An average of 39 indicators, populated with data, can be applied to the counties

and districts. Only three counties hold all 45 indicators for the assessment. Likewise, only five counties have less than 35 indicators available.

For the second part of the study the aggregation was conducted on borough-level for two counties. Numerous data-sets from the county-level assessment were also fitting for the next sub-national level assessment. Nevertheless, for about four indicators more suitable data-sets had to be identified and implemented. An overview of the chance in variables is in table 2.

Another aspect of this step within the framework of the development of a composite indicator is the data-processing part. No data-set was in the correct format so that it could have been included in the composite indicator. The focus in the data-processing step is to convert the data-sets into the correct projection (GCS_OSGB_1936), create polygons that than can be spatially joined to the county, district and borough-level before calculating the desired statistic. In Figure 6 an example of processing steps for the indicator sea surface temperature is shown. The other 44 indicators were prepared similarly.

Table 2: Indicating data-sets for borough-level assessment.

Indicator	Data Source
Intensive Farming	No data-set available
Biofuels	No data-set available
Tourists	Hampshire County Council Statistics per Borough
Vehicles	Department for Transport per Borough

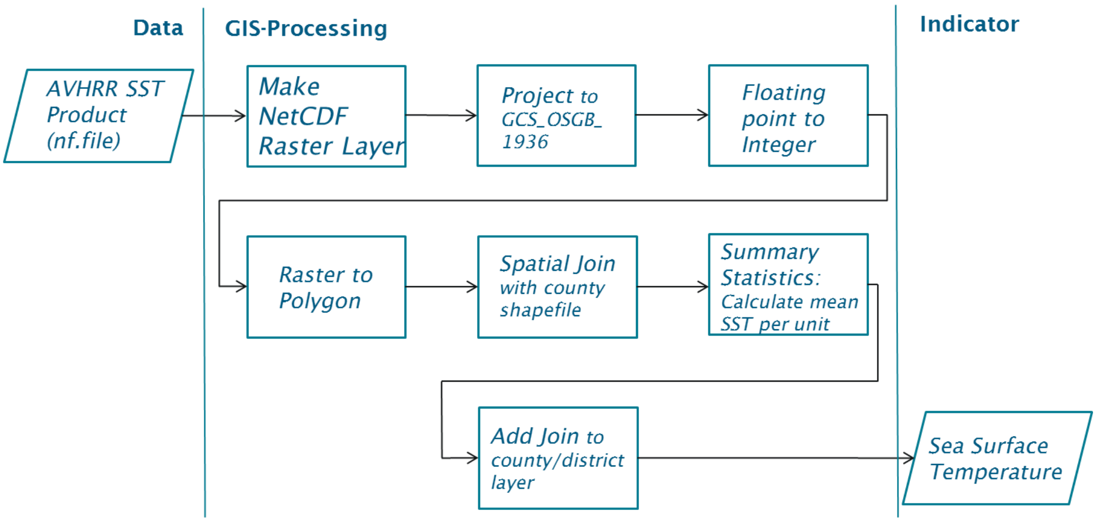

Figure 6: Data-processing example of sea-surface temperature.

5.3 Multivariate Analysis

Preceding the construction of a composite indicator the nature of the variables needs to be analysed carefully (OECD, 2008). In order to assess the data-set structure, a correlation matrix with all variables was calculated and the corresponding p-Values derived from regression analysis. The matrix was calculated based on the z-score standardised data (section 5.4). A correlation matrix helps to determine relationships between the variables as the result indicates how suitable the data-set is for the assessment (McLaughlin & Cooper, 2010; OECD, 2008; Singh, Murty, Gupta, & Dikshit, 2009; Walford, 2011). A close correlation between two variables can suggest an overweight in the index. This implies the removal of one indicator with its data-set in order to avoid the index being overwhelmed and misleading decision-makers (Carey, 1998; OECD, 2008; Rencher, 2002).
Based on the Cohen (1988) classification with Pearson's Correlation threshold of $R > 0.5$ the results of the correlation matrix show several highly correlated variables (Cohen, 1988). As highly correlated variables make the interpretation of results and especially the assessment of effects of individual variables very difficult, the variables cannot be included in the composite indicator like this (Vickers & Rees, 2007). A first step was to substitute correlated variables with proxies. This reduced the number of correlated variables. Nonetheless, several correlations remained. A pairwise regression analysis of the correlated variables confirmed that the

correlations are statistically significant. Voas & Williamson (2001) point out that despite the negative effects of correlated variables, they still have predictive and also meaningful descriptive powers which justifies the inclusion. They even suggest that highly correlated variables have the advantage of being precise predictors (Vickers & Rees, 2007; Voas & Williamson, 2001). As the inclusion of correlated variables is a controversial topic the correlations were assessed further. From 60 remaining correlations 39 can be explained as naturally occurring correlations with literature (Appendix Tab. 17). The remaining correlations seem to be arbitrary as no connection can be drawn between the variables.

Despite the correlations, no indicator was excluded from the list of EVI_{UK} indicators: firstly because its general inclusion was justified in section 5.1, secondly certain correlations occur naturally and can be explained by literature and thirdly because no obvious relation between variables can be drawn, also as the data comes from diverse sources. Besides that also other studies support the inclusion of correlated indicators (Vickers & Rees, 2007; Voas & Williamson, 2001). Furthermore, when evaluating the EVI assessment from 2004, one notices that 82 correlations can be detected which did not lead to any changes in the EVI study but remained within the index calculation. Those indicators that are part of both EVI and EVI_{UK} assessment and show correlations actually correlate in both assessments.

5.4 Normalisation

Normalisation of the data is required since the measurement units of the individual indicators vary and otherwise cannot be aggregated to one composite indicator (OECD, 2008).

There are various normalisation techniques described in the literature. Either one of them has their advantages and disadvantages. For example ranking is inappropriate for this study as a normalisation technique is needed that normalises equalises the units of the different variables. Likewise it is not helpful to look at percentages of change in relation to a consecutive year since no temporal assessment is conducted. Moreover, there is no reference point for the different variables which also eliminates certain techniques (OECD, 2008). Based on this selection the widely applied Min-Max normalisation was applied (OECD, 2008; Suarez-Alvarez, Pham, Prostov, & Prostov, 2012). Since the input data for the assessment is derived from several data sources they contain a variety of units. The Min-Max method is independent of input units and transforms data linearly into a range from 0-1 (Jain, Nandakumar, & Ross, 2005; Suarez-Alvarez et al., 2012). This normalisation allows the data to be combined and enables and easy comparison and analysis. Furthermore, the combination of categorical and continuous variables is possible (Suarez-Alvarez et al., 2012). Additionally to this, a 0-1 scale is easily comprehensible which is beneficial in the context that policy-makers and stakeholders, non-experts in the field of environment and vulnerability, are the targets for this study.

The Min-Max Normalisation is calculated:

$$I_{qc}^{t} = \frac{x_{qc}^{t} - min_c(x_q^t)}{max_c(x_q^t) - min_c(x_q^t)}$$

Where each indicator x_{qc}^{t} for a generic country c and time t is transformed to I_{qc}^{t} , where $min_c(x_q^t)$ and $max_c(x_q^t)$ are the minimum and maximum value of x_{qc}^{t} across all countries c and time t. In this way, the normalised indicators I_{qc} have values ranging between 0 and 1 (OECD, 2008).

Noted has to be that the normalisation had to be reversed for a small number of indicators. Reason for this is that it is assumed that a normalised score of 1 correlates to high environmental vulnerability. During the normalisation process the value 1 is assigned to the highest variable value. For most of the indicators the highest variable value also represents the highest vulnerability. However, for a few indicators this is not appropriate. For *nature reserves* for example a high percentage of protected nature areas decreases the environmental vulnerability. Therefore the normalisation had to be reversed (OECD, 2008; World Economic Forum, 2002).

Skondras et al. (2011) point out another advantage of the min-max normalisation, as the scale applied by the EVI is not sensitive enough to observe change when comparing assessments over years. This is due to the normalisation of the data into seven classes. Not putting the data into classes but just normalising it to the same range with the same units avoids this drawback.

A different normalisation technique was applied for the multivariate analysis. With the z-score standardisation the data will be transformed to have a mean of zero and a variance of one (Suarez-Alvarez et al., 2012). The output of the different data has matching scores in a common domain (Jain et al., 2005). When applying the z-score standardisation one can analyse the data set in relation to one another. A convenient application is to determine the best and the worst, the highest and the lowest. One is not looking at quantitative differences but relational differences (Jain et al., 2005; Suarez-Alvarez et al., 2012). As the overall aim was to quantify the environmental vulnerability the z-score standardisation was not fitting but helped identifying correlations (section 5.3).

The z-score standardisation formula is:

$$I_{qc}^{t} = \frac{x_{qc}^{t} - x_{qc=c-}^{t}}{\sigma_{qc=c-}^{t}}$$

Where for each individual indicator x_{qc}^{t} , the average across country $x_{qc=c-}^{t}$ and the standard deviation across countries $x_{qc=c-}^{t}$ are calculated, with c- as the average across countries (OECD, 2008).

Both normalisation techniques help to assess the environmental vulnerability and to justify further investigation on borough-level.

5.5 Weighting

The overall aim of this study is to assess the vulnerability of the environment to a variety of pressures. Currently there is no scientific agreement to apply differential weights to an environmental assessment since there are no information related to the causal relationships between indicators evaluating the environmental vulnerability available yet (OECD, 2008; World Economic Forum, 2002). Hence, no pressure can be considered to cause a higher or smaller vulnerability to the environment than the other pressures. Another option in order to apply a weighting scheme is to consult experts or stakeholders (Giannetti, Bonilla, Silva, & Almeida, 2009; OECD, 2008). A stakeholder consultation is beyond the scope of this study, though. On top of that Giannetti et al. (2009) even specifies that expert knowledge is often very subjective, inaccurate and vague which can lead to misinterpretation of the results. Resulting from this an equal-weighting scheme is applied. Besides the already mentioned benefits there are two more advantages with equal-weights; firstly equal-weights support the assumption that numerous small pressures acting together in an area can cause the same environmental vulnerability as one strong pressure and secondly equal-weights are preferred when a high degree of correlation between the variables exist. Differential weights would possibly increase their effect otherwise (OECD, 2008).

5.6 Aggregation

After the preceding steps a linear aggregation of the indicators followed. The linear aggregation method is useful when the variables are normalised to identical units (section 5.4) (OECD, 2008). Furthermore, it brings advantages as it is a straight forward method which is easy comprehensible and hence is reasonably transparent (Abbasov & Smakhtin, 2012; Hsu et al., 2014). This is particularly important since the EVI_{UK} is developed for policy makers and stakeholders and therefore a high level of transparency is advisable. Kaly et al. (2004) additionally point out that there is no scientific proof yet that a more advanced aggregation model produces more fitting results. In order to be able to interpret the results even more clearly the sum of the indicators will be divided by the number of indicators used, resulting in standardised values between 0-1.

The EVI_{UK} is calculated:

$$\mathrm{EVIuk} = \frac{\sum_{i=1}^{n} I_i}{n}$$

Where *I* stands for the indicators and *n* specifies the number of indicators available.

6. Results and Discussion

6.1 EVI_{UK} County-level Assessment

6.1.1 Results

The EVI_{UK} results on county-level range from 0.269 to 0.447 on a scale from 0 to 1, low vulnerability to high vulnerability respectively. The mean result is 0.351 and the standard deviation is 0.035 which indicates only small variations between the counties and districts in England. Furthermore, the results imply that the vulnerability of the environment in England is overall low, with few exceptions as moderate (Fig. 7). Overall one can recognise that the environment in the south of England is more vulnerable than the north, indicating a minor trend. A result ranking can be found in the table 18 in the appendix.

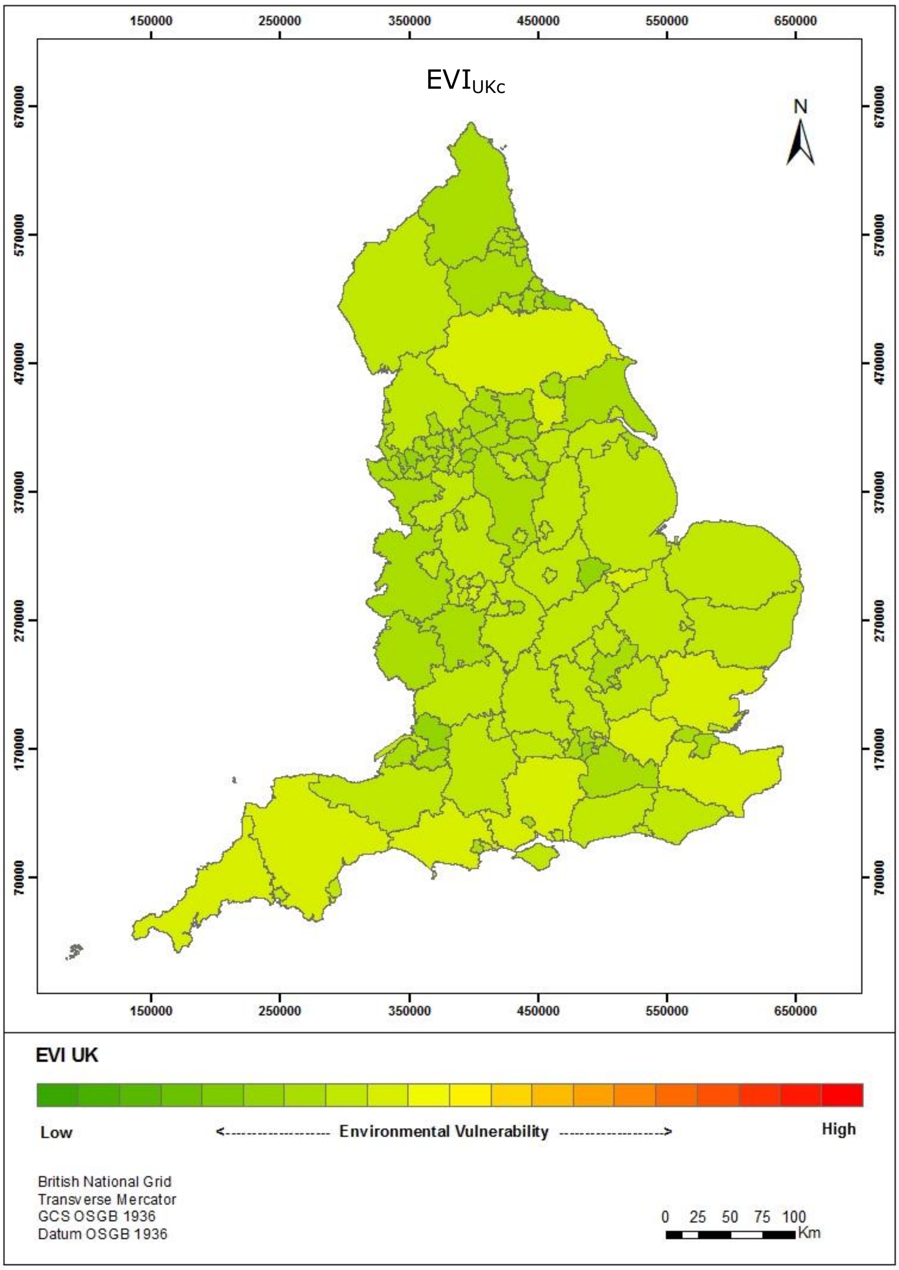

Figure 7: EVI_{UKc} Result.

Table 3: Comparison of EVI_{UK} and Sub-Indicator Results.

Sub-Indicator	Min EVI_{UK}	Mean EVI_{UK}	Max EVI_{UK}	Standard Deviation
EVI_{UK}	0.269	0.351	0.447	0.035
Climate	0.229	0.460	0.705	0.078
Biodiversity	0.120	0.352	0.554	0.073
Natural Hazards	0	0.079	0.508	0.087
Agriculture	0.0002	0.267	0.735	0.213
Fishery	0	0.085	1	0.155
Population	0.072	0.307	0.751	0.167
Pollution & Waste	0.061	0.226	0.686	0.109
Land Use & Energy	0.301	0.472	0.660	0.062

The results of the sub-indicators differ, however. When calculating the EVI_{UK} only based on the indicators associated to the sub-indicators the result ranges and variations increase for certain sub-indicators (Tab. 3). All of the eight sub-indicators reach a maximum of > 0.50, indicating that the environmental vulnerability in certain counties or districts is moderate to high. However, the general tendency, the mean EVI_{UK}, for all sub-indicators displays a low to moderate vulnerability, equivalent to the overall EVI_{UK}. The maps of the sub-indicators are in the appendix (Appendix Fig. 16-23).
The sub-indicators natural hazards and population do not show clear trends in their environmental vulnerability. In contrast to this does the sub-indicator fishery show a clear contrast between inland and coastal counties as expected, since the fishing sector is mainly present in coastal counties. A different kind of divergence in results is displayed by agriculture and land use and energy. Both sub-indicators demonstrate that middle England counties and districts have the highest environmental vulnerability. The remaining sub-indicators, climate and pollution and waste, show a north-south disparity. For both sub-indicators the south of England is more vulnerable than the north. A similar result is depicted by biodiversity only that both north and south are more vulnerable and middle England displayed as resilient. The combined effects of biodiversity, climate and pollution

and waste can explain the overall trend of the south being more vulnerable than the north.

6.1.2 Urban vs. rural administrative Units

The main sub-national administrative units are counties and districts in England. In order to assess the whole of England they have to be combined in this analysis. Yet, the different characteristics of counties and districts have to be taken into consideration when evaluating the results. In the overall assessment we are looking at 121 administrative units with 43 being counties and 78 districts (Tab. 4).
Districts are mainly cities and urban areas compared to the areal extensive counties. This can be particularly seen at the area covered by districts and counties. The areal extent of districts ranges from 33 km^2 to 1166 km^2. In contrast to that counties' area vary between 351 km^2 and 8053 km^2. The size of about 17 counties and districts is similar but other than that there is a strict division in the sense that districts are small and counties are big.
Another striking difference between counties and districts, also related to the unit area, is the population density. Apart from Greater London Authority with about 5280 inhabitants/km^2, districts have the highest population densities ranging from 4800 inhabitants/km^2 in Luton District to 532 inhabitants/km^2 in Redcar and Cleveland. Only a few districts have a smaller population density than this. The population density in English counties is generally lower. It varies from 695 inhabitants/km^2 in Hertfordshire to about 62 inhabitants/km^2 in Northumberland. The population density statistics suggest that districts are mainly urban and counties mainly rural territories. This can be confirmed when looking at the urban area percentage within districts and counties. From 43 counties in England only 1 county (Greater London Authority) has an urban area extent of more than 20% of its county area. The percentage of urban area in relation to the county area in the other counties is smaller than 20%. Contrary to this only 15 districts of 78 have an urban area extent of less than 20% of the overall area. All other districts hold a higher percentage of urban area.
When looking at the percentage covered by forest in counties and districts the division is not as clear. Both counties and districts contain from almost no forest area (0.2% in Cambridgeshire) to 46% of forest area in Maidenhead and Windsor (Exception: Bracknell Forest with 82%). Noticeable is however that according to the data 19 districts have no forest area at all.

Table 4: Comparison of County and District Characteristics.

	Area (km^2)	Population Density (inhabitants/km_2)	Urban Area (%)
Counties	400 - 8000	60 – 700	< 20
Districts	< 1100	500 – 4800	> 20

Overall these spatial statistics display a clear differentiation between counties and districts. Counties are bigger, less populated and less urbanised whereas districts are smaller, highly populated and more urbanised. Hence, one can assume that the pressures that dominantly act on the environment differ between counties and districts. Thus, the policies and programmes applied conserving the environment and lower environmental vulnerability in districts and counties probably also diverge.

6.1.3 Selection *best* and *worst* county

In a second assessment step the implementation of the EVI_{UK} on borough-level, for a comparison of sub-national levels, is followed. The area with the highest and with the lowest environmental vulnerability is chosen for this. Succeeding the results obtained in section 6.1.2 districts and counties differ from one another and consequently a comparison of results between the two would be more complex. Because of this the selection of the *best* and *worst* environmental vulnerability area in England is only based on the county results. The *best* county, so the least vulnerable one, is South Gloucestershire with an EVI_{UK} score of 0.30. The *worst* county, so the most vulnerable one, is Hampshire with a score of 0.44. However, with this selection one problem arises. The county South Gloucestershire is a unitary authority and hence just has one administrative unit. There are no lower administration levels, in the form of boroughs. Therefore, this county is not suitable for the selection. A further selection was required and resulted in Derbyshire as the *best* county (Tab. 5 and Fig. 8). In the appendix is a ranking table for all EVI_{UKc} results (Tab. 18).

Table 5: Selection overview of *best* and *worst* county.

	County	EVI_{UK} score	Boroughs
best	Derbyshire	0.32	8
worst	Hampshire	0.44	11

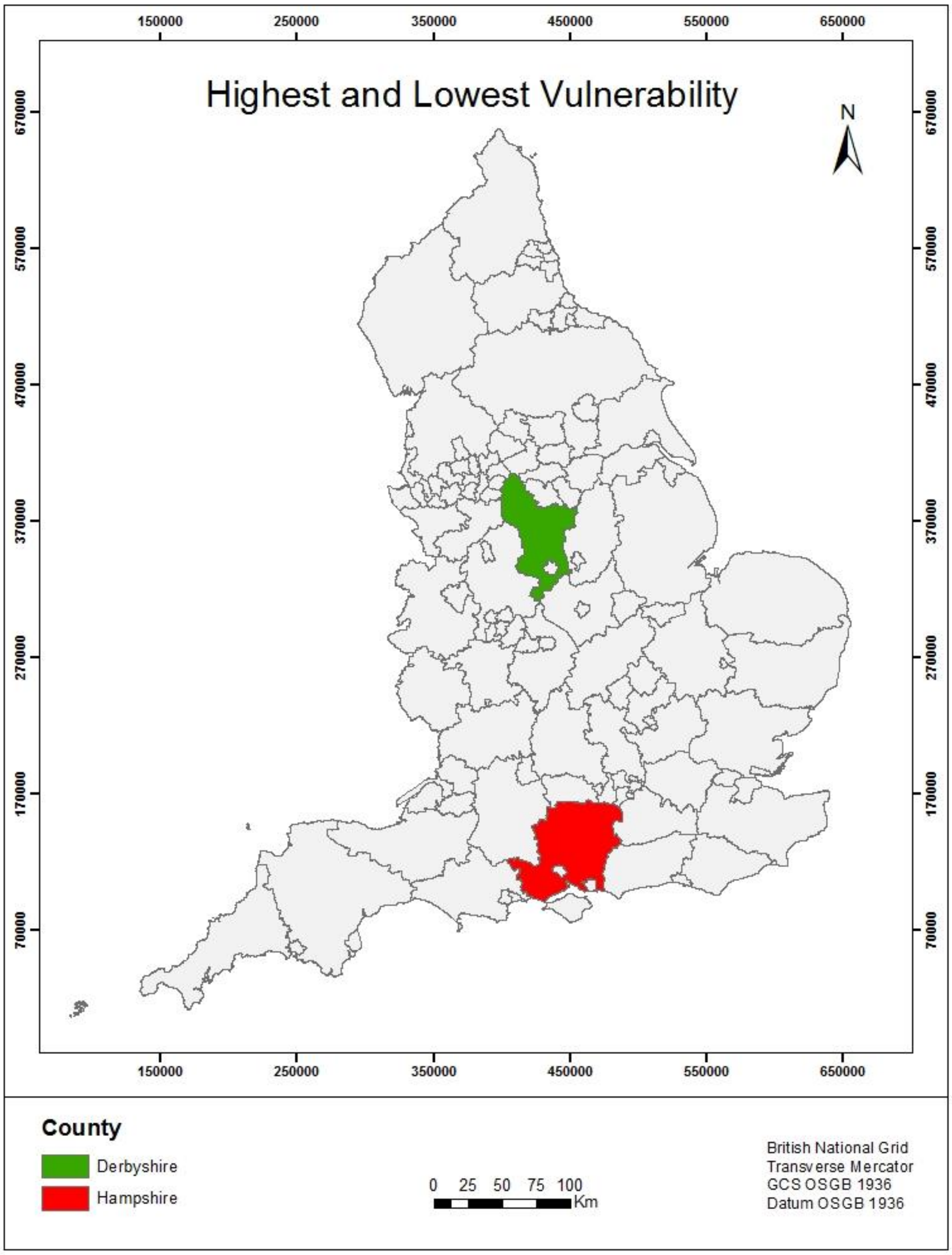

Figure 8: Location of the *best* and the *worst* county.

6.2 EVI_{UK} Borough-level Assessment

6.2.1 Hampshire

The EVI_{UK} results for the boroughs in Hampshire range from 0.33 to 0.47. The mean result is 0.42 and the standard deviation of the results is 0.04, which indicates a small variation between the boroughs of Hampshire. Furthermore, the results imply that the environment in Hampshire is overall up to moderate vulnerable (Fig. 9). Compared to the overall England result, the environment in the Hampshire boroughs is slightly more vulnerable. This supports the fact that it was selected as the *worst* county.

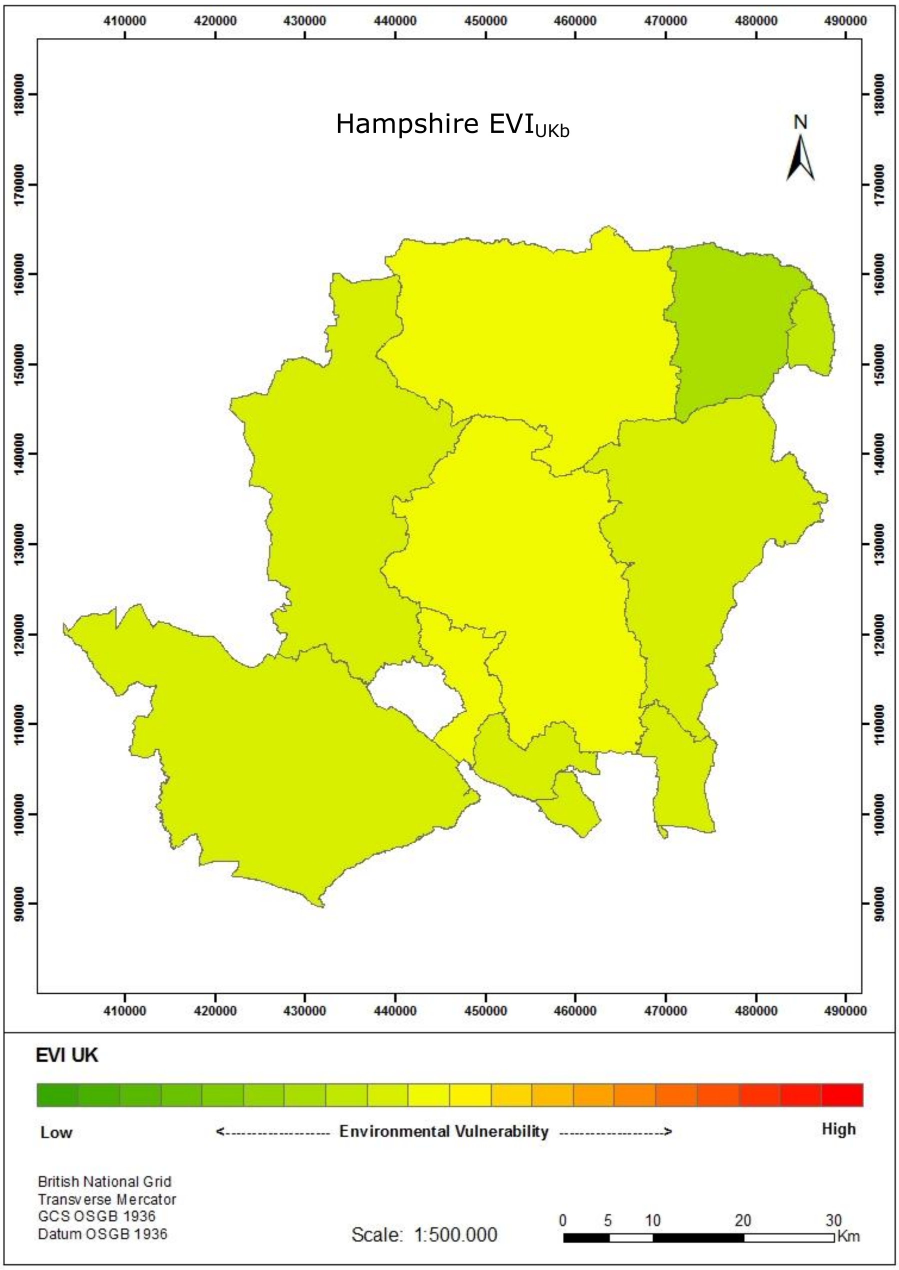

Figure 9: Hampshire EVI_{UKb} results.

Table 6: Comparison of Hampshire EVI_{UK} and sub-indicator results.

Sub-Indicator	Min EVI_{UK}	Mean EVI_{UK}	Max EVI_{UK}	Standard Deviation
EVI_{UK}	0.33	0.42	0.47	0.04
Climate	0.144	0.34	0.593	0.137
Biodiversity	0.09	0.351	0.641	0.163
Natural Hazards	0.011	0.20	0.869	0.282
Agriculture	0.021	0.409	0.936	0.303
Fishery	0	0.43	1	0.348
Population	0.018	0.435	0.825	0.262
Pollution + Waste	0.042	0.423	0.617	0.161
Land Use + Energy	0.358	0.537	0.712	0.108

Similar as in the county-level assessment the sub-indicators for Hampshire also differ from the EVI_{UK} results (Tab. 6). Once again all sub-indicators have a maximum EVI_{UK} score of > 0.50. Natural Hazards, agriculture and population even exceed 0.80. This indicates that the individual sub-indicators point out higher environmental vulnerabilities for certain pressure groups. The general results, mean EVI_{UK}, range around 0.40 therefore indicating a moderate environmental vulnerability throughout the sub-indicators. The maps of the sub-indicators are in the appendix (Appendix Fig. 24-31).

In the borough-level assessment of Hampshire spatial differentiation in environmental vulnerability can be identified. In the overall EVI_{UK} assessment for Hampshire all the boroughs reach a similar moderate environmental vulnerability. Only Hart has a little lower vulnerability. In the sub-indicators the spatial variations are more pronounced. The sub-indicators climate and pollution, comparably to the county-level assessment, show a north-south difference. The south is more vulnerable than the north. Likewise, does the natural hazards sub-indicator show this trend. However, only two boroughs can be considered vulnerable and the rest as resilient. The biggest spatial differentiation is depicted by agriculture. Boroughs are classified as resilient as well as highly vulnerable. The remaining sub-indicators display spatial dissimilarities but with no obvious trend.

6.2.2 Derbyshire

The EVI_{UK} result for the boroughs in Derbyshire range from 0.35 to 0.505. The mean result is 0.43 and the standard deviation of the results is 0.058, which indicates a small variation between the boroughs of Derbyshire. Furthermore the results imply that the environment in Derbyshire is overall up to moderate vulnerable (Fig. 10). Compared to the overall England result, the environment in the Derbyshire boroughs is more vulnerable. This is contradictory to the fact that Derbyshire was selected as the *best* county. The EVI_{UK} score of 0.32 for Derbyshire is even outside of the result range obtained on borough-level.

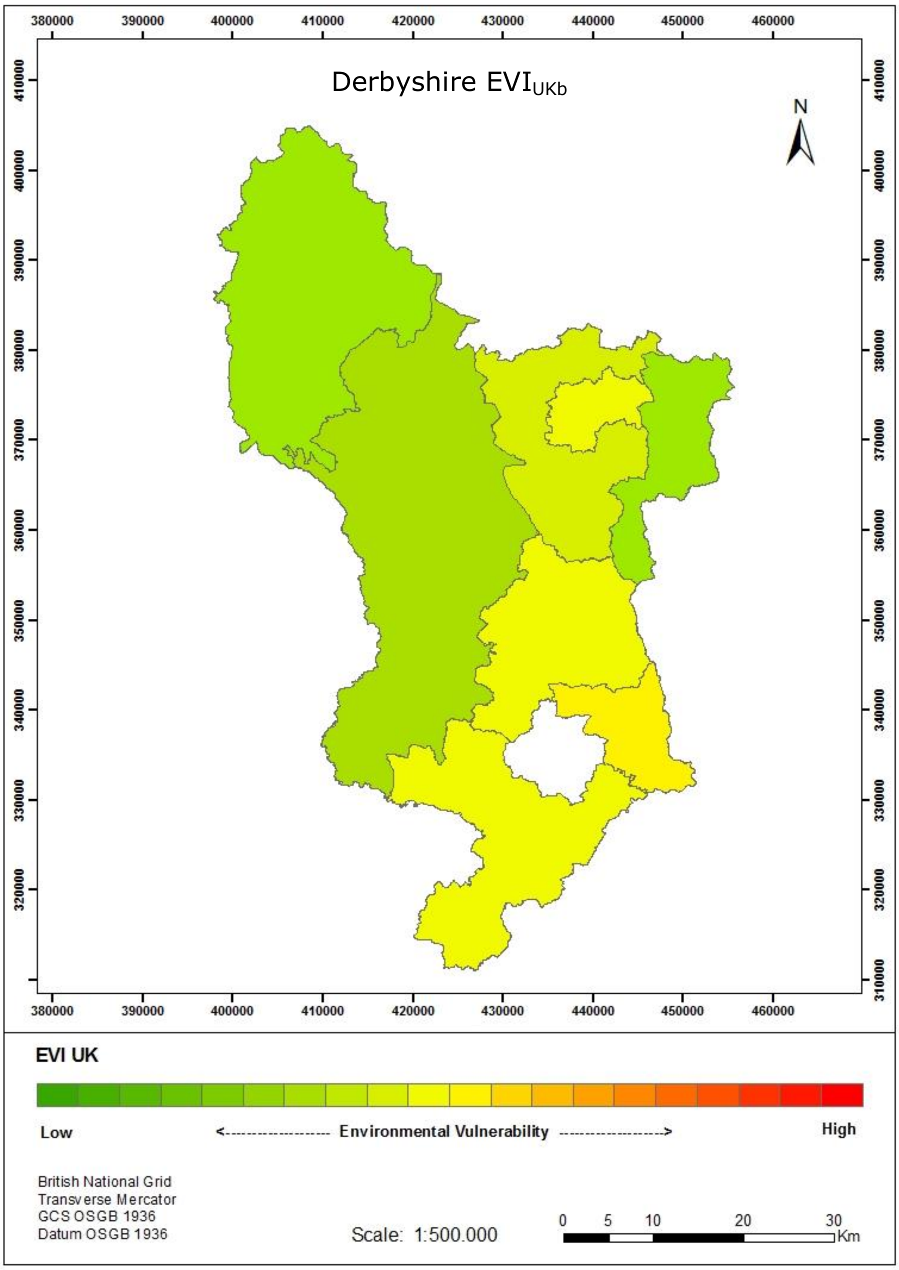

Figure 10: Derbyshire EVI_{UKb} result.

Table 7: Comparison of Derbyshire EVI_{UK} and sub-indicator results.

Sub-Indicator	Min EVI_{UK}	Mean EVI_{UK}	Max EVI_{UK}	Standard Deviation
EVI_{UK}	0.347	0.43	0.505	0.058
Climate	0.407	0.50	0.640	0.074
Biodiversity	0.134	0.38	0.55	0.158
Natural Hazards	0.002	0.313	0.605	0.223
Agriculture	0.045	0.347	0.596	0.195
Fishery	0	0.125	1	0.354
Population	0.181	0.43	0.624	0.147
Pollution + Waste	0.215	0.49	0.757	0.193
Land Use + Energy	0.273	0.465	0.733	0.165

Similar as in the county-level assessment the sub-indicators for Derbyshire also differ from the EVI_{UK} results (Tab. 7). All eight sub-indicators have a maximum EVI_{UK} score of > 0.50. This indicates that the individual sub-indicators point out higher environmental vulnerabilities for certain pressure groups and some counties and districts experience a very high environmental vulnerability. The mean result however, points out medium vulnerabilities. The maps of the sub-indicators are in the appendix (Appendix Fig. 32-39).

The overall trend in environmental vulnerability in Derbyshire is that the south of the county is more vulnerable than the north. One can observe a gradual increase in environmental vulnerability from north to south. The sub-indicator natural hazards splits the county into two. The western boroughs have a low vulnerability and the eastern boroughs a moderate vulnerability. A similar distinct trend can be recognised for land use and energy, pollution and waster and population. All three sub-indicators display a higher vulnerability in the south and a lower on in the north. This can once again explain that the overall environmental vulnerability in Derbyshire is lower in the north and higher in the south.

6.3 Discussion County- and Borough-level Assessment

The low county-level environmental vulnerability is an unexpected result as the EVI global assessment classified the UK as *extremely vulnerable*, the highest vulnerability class (Kaly et al., 2004). Hence, a generally higher environmental vulnerability, at least in parts of England, was anticipated. An explanatory comparison to the EVI global assessment is drawn in section 6.5. In contrast to that the sub-indicators derive a more elaborated environmental vulnerability image. More clearly are spatial differences in environmental vulnerability depicted and suggest that certain indicators mainly cause the vulnerability. This implies that the indicators in the overall aggregation counterbalance each other. A similar result was presented by (Skondras et al., 2011). They explain that the individual indicators have an unintentional weight which comes out more clearly in the sub-indicators as fewer indicators are aggregated and therefore the compensability between indicators is lower (Dobbie & Dail, 2013; Hudrliková, 2013). The conclusion of Skondras et al. (2011) is that sub-indicators more appropriately describe the environmental vulnerability compared to the overall score. Adger et al. (2004) and Saisana, Saltelli, & Tarantola (2005) agree to this. At this point it has to be stated that the results for the fishery sub-indicator should be taken out of the assessment. The reason for this is that only one indicator of fishery could be populated with data. Hence, there is just one indicator, which data was stressed between 0 and 1 in the min-max normalisation. The normalisation artificially pretends that there is a county, district or borough with no vulnerability and one with complete vulnerability for fishery. See more in section 6.5.

The borough-level assessments partly differ from the county-level assessment. The overall EVI_{UKb} result for Hampshire on the borough-level agrees with the county-level assessment. With an EVI_{UKb} range from 0.33 to 0.47 the county-level result of 0.44 falls into that extent. The range of results is similar. The sub-indicator results however, suggest very high environmental vulnerabilities in some of the boroughs of Hampshire. This did not come out in the county-level assessment. The borough-level assessment results for Derbyshire vary to the county-level assessment more. The EVI_{UKb} result range for the boroughs from 0.35 to 0.51 does not include the EVI_{UKc} county-level result of 0.32, which underlines that the overall environmental vulnerability of Derbyshire on borough-level is identified as more vulnerable. Also the sub-indicator results for Derbyshire are higher than on county-level and indicate higher environmental vulnerabilities. Nevertheless, the sub-indicator results of Derbyshire are lower than of Hampshire, which is consistent with the assumption that Derbyshire is the *best* and Hampshire the *worst* county in England.

Based on these results an extrapolation for the whole area of England can be predicted. If the EVI_{UKb} assessment was conducted for all boroughs in England the average EVI_{UKb} would be higher than the average resulting from the county-level assessment. A more diverse and extreme result would be obtained when looking at the sub-indicators for all boroughs. Any conclusion drawn from this hypothetical assessment would regard the environmental vulnerability of England as considerably higher than from the county-level assessment. As the EVI_{UKb} range from the Derbyshire boroughs differs from the overall Derbyshire county-level assessment it cannot be said for sure that Derbyshire would be identified as the *best* county after an England-wide borough-level assessment. Hence, it seems more appropriate to talk about *less vulnerable* for Derbyshire and *more vulnerable* for Hampshire. This, however, has strictly to be seen as an assumption. Especially because Holman & Naess (2009) point out that local level assessments have little predictive capacities.

In a similar study conducted by Schmidtlein, Deutsch, Piegorsch, & Cutter (2008) the results show that highly vulnerable aggregation units like counties, in a multi-level assessment, are made up of lower units that also indicate higher and moderate vulnerabilities for the smaller aggregation units. This is conform with the Hampshire findings but contradictory to the Derbyshire results. Both borough-level assessments reveal spatial variations in environmental vulnerability, ranging from low or no vulnerability up to high vulnerability in some boroughs. As Hampshire is the *more vulnerable* county it is fitting but not for Derbyshire the *less vulnerable* county regarding the study from (Schmidtlein et al., 2008).

Interesting with these results is only, based on the little literature found, that the identified vulnerability becomes higher (more vulnerable) with increasing scale. In an assessment related to coastal vulnerability McLaughlin & Cooper (2010) observed that the vulnerability became lower with increasing scale. This contradictory result cannot be explained and analysed in the scope of the thesis. However, it is important to know that there are studies with different results published.

This second assessment proves once again that sub-national assessments give out more detailed results and suggests once again that sub-indicators are better tools for spatial environmental vulnerability approximations (Adger et al., 2004; Desjeux et al., 2015; Saisana et al., 2005; Skondras et al., 2011). That the same indicators produce different results on varying scales has been observed and stated in the literature before (Desjeux et al., 2015; Kienberger et al., 2013; McLaughlin & Cooper, 2010). Furthermore, the assessments seemed to succeed in eliminating one disadvantage of the EVI. Both assessments manage to locate more vulnerable areas, both on county and also on borough level, especially with the help of sub-indicators (Adger et al., 2004; Skondras et al., 2011).

In relation to an assessment of the social vulnerability Schmidtlein et al. (2008) specify that the impact of scalar changes in vulnerability assessments has never been discussed. The only approach to this issue was to visually interpret the change in spatial patterns. According to Schmidtlein et al. (2008) the relationship between aggregated variables in response to change in scale shifts. Examining the original, unaggregated variables helps interpreting the relationships and mechanisms.

Despite the scientific understanding that vulnerabilities vary spatially and are a local phenomenon, due to a heterogeneous environment and pressures occurring locally diverse, certain publications state the disadvantage of local vulnerability scales and their comparison to higher scales. A comparison of results between scales is supposedly not possible as the normalisation of the variables is always done relative to the full range of values at a particular scale (McLaughlin & Cooper, 2010). The normalisation of the data is hence influenced by the observation scale which makes a comparison across scales difficult. Furthermore, the information content of local assessment units is considered as questionable. Goodchild & Quattrochi (1997) argue that sometimes an aggregation adds information and does not reduce it, emphasising the 'view from distance' (Goodchild & Quattrochi, 1997). In the same context it is expressed that a local level is very uncertain and has little predictive capacities (Holman & Naess, 2009).

Another point has to be raised related to the current results. The applied methodology implies that the counties and districts or in the second step the boroughs are compared with one another. The min-max normalisation stretches for example the borough values to the same scale (0-1) based on a smaller-bigger principle. This means similar values within a small interval will possibly become more stretched during the normalisation pretending a bigger difference and contrast between values that there actually is and altering the general environmental vulnerability results (OECD, 2008). The aforementioned is also observed by McLaughlin & Cooper (2010) stating that the observation scale, either regional or local, influences the outcome and may result in divergent vulnerability perceptions on different scales. Another issue with the min-max normalisation is its' sensitivity to outliers, which distorts the normalisation (Jain et al., 2005). This is supported by Shaw & Wheeler (1985) who state the general geographic assumption of spatial contiguity that adjacent areal units are more alike than non-adjacent units. This could possibly influence the results. Further discussion of this is in section 6.7. This is partly why McLaughlin & Cooper (2010) claim that results between different application scales cannot be directly compared. The normalisation of the data and observation scale are very influential. Each result is relative to the level that it has been calculated at and hence it is more difficult to define connections between two scales as the relative calculations dominant the interpretation (McLaughlin & Cooper, 2010). An agreement can be found in Schmidtlein et al. (2008) who also point out the difficulty in interpreting aggregation units.

6.4 Indicator Assessment

Determining the dominant indicators is important for two different aspects. Firstly, discovering the most influencing indicators helps targeting vulnerability reduction plans and designing environment protection policies. Secondly, as stated before and also proven by the current results, the sub-indicators are more important as they describe the environmental vulnerability enhanced (Skondras et al., 2011). Further breaking down the issue of vulnerability can be assumed to assist the evaluation.
The dominant indicators were determined in two different ways: first with a regression analysis and second with working out the contribution to the overall index result of each indicator and sub-indicator (percentage).

6.4.1 Regression Analysis

A regression analysis was chosen to determine the most influential indicators as it discovers the best fit mathematical equation between dependent and independent variables (Walford, 2011). The independent variables are the indicators and the dependent variable is the EVI_{UKc} in this case. Hence, it is determined which indicators influenced the current detected environmental vulnerability. With a regression analysis one expresses that the independent variables to some extent determine the value of the dependent variable.

Everything considered with a certain level of confidence (Walford, 2011). As the EVI_{UK} aggregation is based on a simple summation of indicators, a linear regression analysis seemed appropriate in order to model the relationship between independent and dependent variables. The assumption for this analysis is that certain indicators (independent variables) will not be selected as they do not contribute to the dependent variable significantly, hence only the most influential indicators are included in the regression analysis (Birkmann, 2007). A common strategy to achieve this is a stepwise backward regression analysis. This means that one starts off with all variables in the equation and then step-by-step reduces the variables. The variables who contribute the least to the sums of squares are eliminated until only those remain that add a statistical significance to the regression equation (Shaw & Wheeler, 1985).
Considering the amount of indicators (45) and the observations (counties/districts = 121) the variables-observation ratio did not allow a stepwise backward regression analysis from the start. Based on univariate analysis and multicollinearity tests the number of indicators had to be minimised before applying the stepwise regression analysis. During the univariate comparison, the direct assessment whether an indicator contributes statistically significant to the EVI_{UK} result, 21 indicators were eliminated (Tab. 8). In the multicollinearity test another seven indicators were excluded before further two were removed in the regression analysis (Tab. 8). With the remaining fifteen indicators a stepwise backward regression analysis was conducted. The resulting equation is:

$$\begin{aligned} EVIukreg = {} & 0.254 + 0.019 * min\ Temperature + \ 0.051 * Tide + 0.025 \\ & * Coastlength + 0.053 * Slides + -0.0006 * Fertiliser + 0.022 \\ & * Population\ Change + -0.154 * River\ Water\ Quality + 0.088 \\ & * Air\ Quality + 0.08 * Carbon\ Emissions + -0.0003\ * Waste \\ & + 0.01 * Excavation + 0.032 * Groundwater + -0.077 \\ & * Econetwork + 0.052 * Land\ Cover\ Diversity + 0.053 \\ & * Land\ Cover\ Change \end{aligned}$$

The stepwise backward regression analysis includes fifteen indicators as they are statistically significant for the EVI_{UKc} result. Hence, these are the indicators that are most dominant for the EVI_{UK} analysis. The main sub-indicators they belong to are: *pollution and waste* and *land use and energy*. This indicates that the remaining sub-indicator groups are not as important.

Table 8: Exlusion of indicators in univariate, multicollinearity and regression analysis.

Univariate Analysis	Multicollinearity Test	Regression Analysis
Wind	Waste Recycling	SST
Precipitation	Soils	Invasive Species
Max Temperature	Degradation	
Sea Level	Electricity	
Relief	Phenology	
Lowlands	Fishing Efforts	
Endangered Species	Drainage	
Birds		
Floods		
Intensive Agriculture		
Population		
Tourists		
Vehicles		
Pesticides		
Infrastructure		
Fossil Fuels		
Biofuels		
Land Use		
Coastal Settlements		
Marine Reserves		
Nature Reserves		

The EVI_{UK} result from the regression analysis (EVI_{UKreg}) is slightly different than the index result (Tab. 9). The overall result range is alike. The results of the counties vary more. Despite a similar rank for Hampshire the EVI scores differ slightly from one another. Comparably to this are the results for Derbyshire more divergent. The EVI_{UKreg} score for Derbyshire is bigger than in the county-level assessment. Following this is Derbyshire on a higher rank in the regression analysis. The difference between ranks is considerably great for Derbyshire. This analysis indicates that the regression analysis determines very low vulnerabilities for most counties and districts. If the general analysis was based on the regression analysis, Derbyshire would not have been picked as the least vulnerable county.

Table 9: Comparison of EVI_{UKc} and EVI_{UKreg} results.

	Min	Max	Hamp.	Hamp. Rank	Derby.	Derby. Rank
EVI_{UKc}	0.27	0.45	0.44	120	0.32	30
EVI_{UKreg}	0.27	0.46	0.41	115	0.39	103

After the stepwise backward analysis determined the most dominant indicators on county-level, the attempt was also made to apply a stepwise backward regression analysis for the borough-level assessment. The idea was to compare the two results and examine whether the dominant indicators on county and borough-level coincide.

A regression analysis for the borough-level was not possible though. First of all, because all remaining indicators after the univariate analysis were highly correlated with one another and hence should have been removed from the analysis. A second reason is, that the variable-observation ratio was too high for a regression analysis as we are only looking at eight (Derbyshire) and eleven (Hampshire) boroughs. A stepwise backward regression analysis on borough-level could not be conducted therefore.

6.4.2 Dominant Indicators

As the regression analysis did not narrow down the dominant indicator selection reasonably, a second analysis was executed. Based on the average indicator score were the dominant indicators determined, for both individual indicators and also sub-indicators.

To investigate which individual indicators dominate the general EVI_{UKc} assessment on country-level the mean score of each indicator was calculated. Five indicators stood out with high mean scores; *nature reserves* (0.96), *birds* (0.934), *land use* (0.93), l*and cover diversity* (0.87) and *oil diversity* (0.80). These indicators seem to be influential to a great extent for every county and district. One can observe however, that these indicators are highly influenced by outliers in their data-sets. The indicators *nature reserves*, *land use* and partly *soil diversity* all contain drastic outliers in their data-values and therefore the normalisation is severely skewed to high environmental vulnerabilities. 110 counties obtain a normalised value of > 0.90 for *nature reserves*. Similarly are 104 counties normalised for *land use*. In the case of soil diversity still 77 counties are represented with a min-max value of > 0.90 and only three < 0.40. This emphasises that the normalisation and classification of the counties is highly influenced by outliers and therefore not reliable for a dominant indicator evaluation like this. When trying to find dominant indicators which are not influenced by extreme outliers and that have sufficient data coverage for a reliable assessment the dominant indicators are: *land cover diversity* (0.87), *precipitation* (0.73), *maximum temperature* (0.68), *minimum temperature* (0.59) and *carbon emissions* (0.52). It is apparent that three out of those five indicators are *climate* indicators. These pressures cannot be eliminated actively by human actions, but their impact be decreased by mitigation and adaptation actions.

Following the issues with the indicator assessment, looking at the most dominant sub-indicators and their significance seems to be more appropriate. The averaging in the sub-indicator calculation should smooth out the normalisation effects. The examination of dominant sub-indicators on county-level revealed that *land use and energy* (0.47), *climate* (0.46) and *biodiversity* (0.35) have the highest mean calculations. These sub-indicators score the highest within the EVI_{UKc} analysis. For a more detailed result one can assess the results of the two selected counties further and their results on county-level. The percentage contribution of each sub-indicator was calculated. In Hampshire the most dominant sub-indicators are *land use and energy* (31%), *climate* (20%) and *biodiversity* (17%). The results for Derbyshire are: *land use and energy* (32%), *climate* (22%) and *biodiversity* (17%). Clearly the results are identical. This proves that these sub-indicators overall influence the vulnerability outcome the most as both *best* and *worst* county demonstrate their dominance as well as the overall county-level assessment.

The same analysis can be conducted on borough-level. The highest mean score of a sub-indicator have *land use and energy* (0.54), *population* (0.44) and *pollution and waste* (0.42) in Hampshire. In Derbyshire the most dominant sub-indicators are: *climate* (0.50), *pollution and waste* (0.49) and *land use and energy* (0.46). The dominating sub-indicators for both boroughs are *land use and energy* and *pollution and waste*.

6.4.3 Summarise Indicator Results

The stepwise backward regression determined that one third of the indicators are dominant and to some extent explain the dependent variable, EVI_{UKc}. Based on this assessment are the sub-indicators, *pollution and waste* and *land use and energy* mainly required for modelling the environmental vulnerability in England. The sub-indicator examination showed that on county-level the main sub-indicators are *land use and energy*, *pollution and waste* and *climate*. When looking at the two selected boroughs they provide equivalent results with *land use and energy*, *population* and *pollution* (Tab. 10). Therefore the different evaluations, regression analysis, county-level and borough-level represented by the *best* and *worst* county, demonstrate the same results. This proves that not only different evaluation techniques, regression and average score, deliver the same results but also on alternating assessment scales, county and borough-level, the results correspond.

The agreement between techniques and scales underlines that there are distinct pressures influencing the environmental vulnerability in England. Furthermore, it points out that it is irrelevant whether to assess all counties or to pick one or two counties for the dominant indicator assessment as the results will still be representative for whole England. This is also proven by the borough-level assessment which displayed the same results for two different counties. Based on the outcomes the focus for section 6.9.2 will be on the sub-indicators *land use and energy*, *pollution and waste*, *climate* and *population*.

The concurrence in the dominant sub-indicator analysis is obvious. A way to analyse and explain this is it to look more closely at the data and its' aggregation applied on the two assessment scales (Schmidtlein et al., 2008). For nearly all indicators, except a few cases, the same data-sets were applied on county and borough-level. However, as the literature suggests that relationships between variables on different aggregation levels change, it is worthwhile evaluating this for here too (Schmidtlein et al., 2008). Based on the fact that the same data-sets were applied to both assessment levels the variable values themselves are alike. The order of magnitude is equivalent on county and borough-level. This justifies that similar dominant indicators and sub-indicators are identified in both evaluations. Nonetheless, this image shifts when reviewing the normalised data-sets since they are the ones entering the environmental vulnerability model.

Table 10: Summary of sub-indicators identified on different assessment levels and with different methods.

Regression Analysis	County-level	Hampshire	Derbyshire
Climate	Climate		Climate
Pollution & Waste	Biodiversity	Pollution & Waste	Pollution & Waste
Land Use & Energy	Land Use & Energy	Land Use & Energy	Land Use & Energy
		Population	

The differences between county and borough scale data are considerably bigger when normalised to their relative level. For the majority of indicators, for 29, a divergence in applied min-max normalised data can be observed. For a large proportion, eighteen indicators, the borough-level values are higher than the county-level values. This relationship is reversed for only eleven indicators. In contrast to that, seven indicators have not sufficient data on both assessment-levels so that no relationship can be determined. It is noticeable that thirteen of the eighteen indicators that are higher on borough-level belong to the sub-indicators *land use and energy*, *pollution and waste* and *population* which were identified as dominant on borough-level. From the eleven indicators that are higher on county-level eight are part of *land use and energy*, *climate* and *biodiversity*. This is interesting to observe and can partly be considered as an explanation of the dominant sub-indicator evaluation.

Overall the identification of similar dominant sub-indicators suggests that the relationship between indicators, variables and methods does not change relative to their implementation scale or method.

6.5 Z-score Assessment

In the aforementioned result sections the concern was raised repetitively that the min-max normalisation method influences the index results. This is especially crucial for the borough-level assessment as less observation, boroughs, and fewer data-sets are available for the evaluation. Consequently impacts of the methodology are not averaged out as much in the aggregation process (Hudrliková, 2013; Natoli & Zuhair, 2011). The suggestion emerges hence, that the chosen method determines the results. Thus, the environmental vulnerability image created might not result from present issues but from methodology matter only. A way of investigating this argument is applying an alternative normalisation technique and conducting the EVI_{UKb} analysis again as a mean of comparison. The z-score assessment on borough-level is conducted for Hampshire as the county with the highest environmental vulnerability score. A short description of the z-score normalisation is in section 5.4.

An index calculation with z-score normalised data gives particular kind of results. The results range above and below 0, with 0 representing the mean. The scores then indicate whether something is *more/higher than the mean* (> 0) or *less/lower than the mean* (<0). A score of +/-1 represents one standard deviation above or below the mean (Cui, Hens, Zhu, & Zhao, 2004; World Economic Forum, 2002). In this case a score above the mean indicates a higher environmental vulnerability than the mean vulnerability and a score below the mean the opposite, a lower environmental vulnerability. The z-score transformation has to be reversed for some indicators to assure that all positive values refer to the worse and all negative values refer to the better state, guaranteeing the ordinal relationship (Natoli & Zuhair, 2011; World Economic Forum, 2002). An environmental vulnerability map resulting from z-score normalised data has to be interpreted differently and therefore some attention given to this while comparing the results. The initial EVI_{UKb} covers a possible range from 0 to 1, with 0 as the lowest or no environmental vulnerability and 1 as the highest vulnerability. In order to be able to compare the EVI_{UKb} min-max and z-score with one another Yoon (2012) suggests a classification scheme. The approach defines the vulnerability classes based on the mean and standard deviation of the result. For each method the mean and the standard deviation are obtained and then classes formed with one standard deviation above or below the mean, two standard deviation above or below the mean *et cetera* (Yoon, 2012) (Tab. 11). The generated classes can then be interpreted in terms of more and less vulnerable. The class threshold results point out how different the values, from min-max and z-score, itself are and hence, support that a comparison strategy like this is needed as otherwise the result values do not relate to one another.

Table 11: Comparative classes of the EVI_{UKb} min-max and z-score results based on the mean and standard deviation.

Class	Interpretation	EVI_{UK} Min-Max	EVI_{UK} Z-Score
- 3	Lower vulnerable	0.30 – 0.339	
- 2	Less vulnerable	0.34 – 0.379	-0.26 - -0.13
- 1	Slightly less vulnerable	0.38 – 0.421	-0.129- 0.185
+ 1	Slightly more vulnerable	0.42 – 0.46	0.0019 – 0.132
+ 2	More vulnerable	0.461 – 0.50	0.133- -0.264

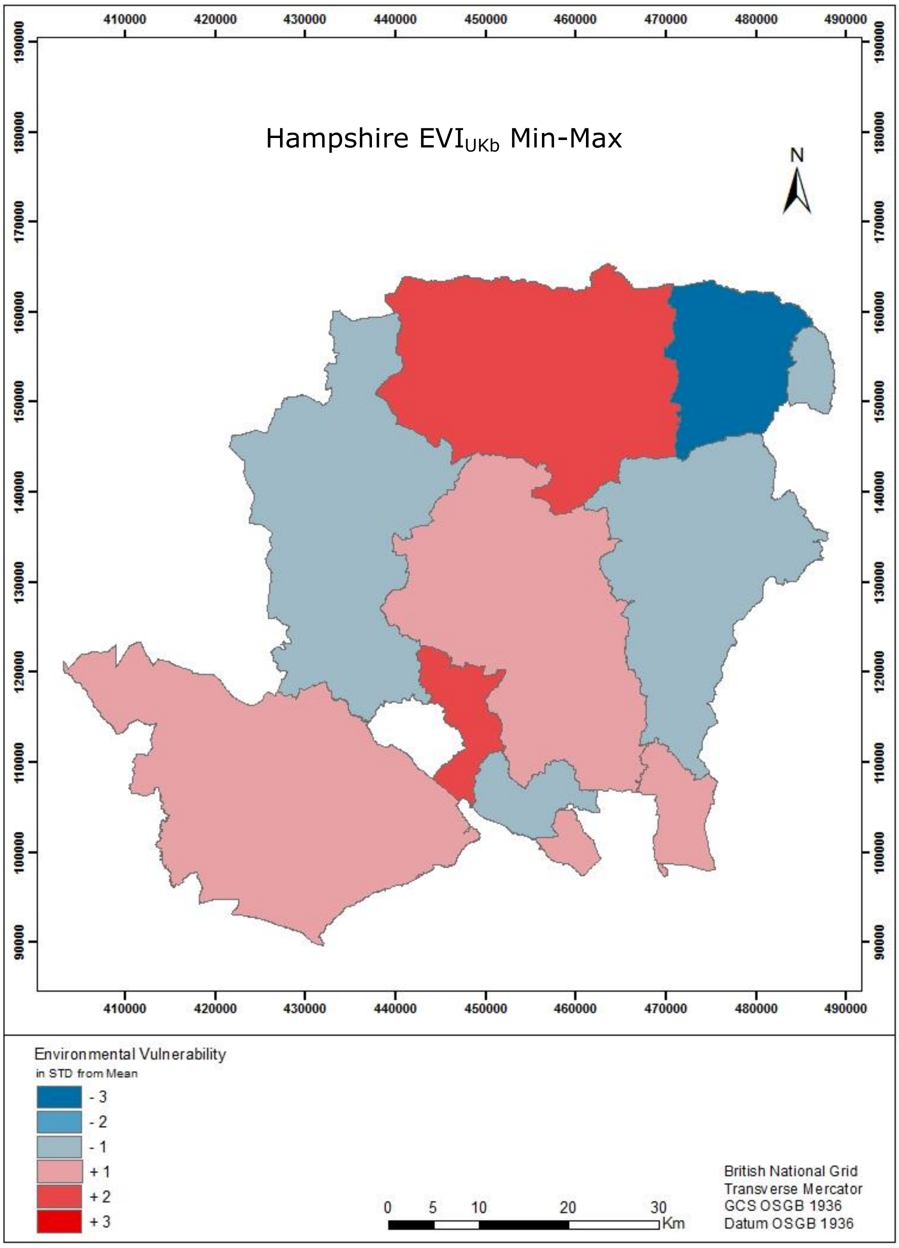

Figure 11: Hampshire EVI$_{UKb}$ min-max normalisation.

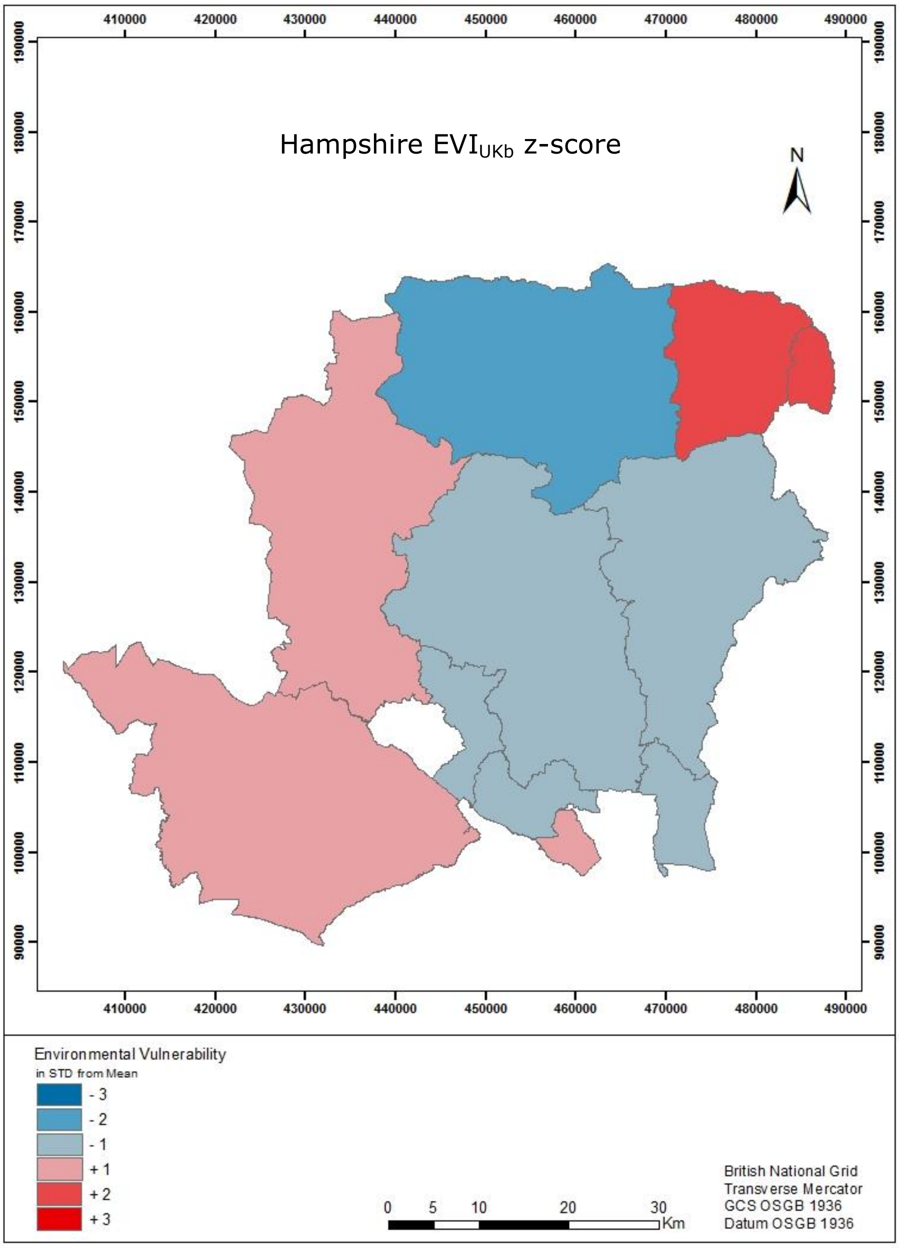

Figure 12: Hampshire EVI_{UKb} z-score normalisation.

Figure 11 and 12 show the EVI_{UKb} calculated with min-max and the EVI_{UKb} calculated with z-scores normalised data but classified to the above described scheme. The results look reasonably different to one another. Even though four boroughs are classified identically the other seven were categorised dissimilar. Three of the boroughs are classified contrarily by one class only but the remaining boroughs are categorised completely differently. The identical boroughs are: New Forest, Gosport, East Hampshire and Fareham.

The divergence in results is also pointed out by the sub-indicators. Figures 40–55 in the appendix show the sub-indicator interpretation of Hampshire boroughs' for the z-score and min-max assessment. The biggest difference in min-max and z-score assessment is depicted by the sub-indicators *land use and energy* and *population and waste.* The boroughs are classified almost oppositely. For the other sub-indicators one to up to four boroughs are categorised identically and the remaining boroughs are classified in another way. The incomparable classification results are also confirmed by the ranks and the rank shift between z-score and min-max assessment (Tab. 12). The ranking order of the two methods changes partly greatly for some boroughs.

Table 12: Showing ranks and rank shift of the min-max and z-score EVI_{UKb} results.

Boroughs	EVI_{UK} Min-Max Rank	EVI_{UK} Z-Score Rank	Rank Shift (Rs)
Hart	1	11	-0.91
Test Valley	5	7	-0.18
Basingstoke and Deane	10	1	0.82
East Hampshire	4	3	0.09
Winchester	9	5	0.36
Rushmoor	2	10	-0.73
Havant	7	4	0.27
Fareham	3	6	-0.27
Eastleigh	11	2	0.82
Gosport	6	8	-0.18
New Forest	8	9	-0.09

These results prove the concern that the outcome obtained, on borough-level, are influenced by the method applied. The evaluation and comparison show that the two methods present very different results. Hence, it expresses that the applied method influences the outcomes of a study immensely. This conclusion is contradictory to a study by (Yoon, 2012). Their comparison between min-max and z-score normalisation declares that there is no significant difference between the methods (Yoon, 2012). One reason for this disagreement can possibly be the small assessment scope in the borough-level assessment. In this assessment the normalisation methods are only applied for eleven boroughs but in the study by Yoon (2012) are almost 200 counties involved. The number of values also has an influence on the normalisation. Based on the general analysis one can say that the conclusions drawn and statements made in the borough-level study are uncertain as they are influenced by the min-max normalisation.

The choice of the right method is not possible. However, depending on the application purpose of a study one can decide on the better and more appropriate method. In this case, despite its' deficiencies, it is still the min-max normalisation method. Biggest disadvantage of the z-score normalisation is its' rather complicated and biased interpretation (World Economic Forum, 2002). As the whole analysis is based on a comparison of results to its' mean result it is difficult to say when something is considered as vulnerable or not. The biggest difficulty arises from the fact that the z-score method does not give any indication on the mean. It is unidentified whether the mean vulnerability already represents a higher or a lower environmental vulnerability. Hence, the assessment of two regions, one that is highly vulnerable and the other that has a low vulnerability, can possibly have the same outcome in a z-score assessment. Similar results are likely as the mean is not fixed on a vulnerability scale and the second part of the assessment is based on the spread around this mean. The mean can either be shifted into the low vulnerability or high vulnerability area. The conclusions that can be drawn only refer to a 'more-or-less' vulnerable but not to a vulnerability as such. This is a particularly difficult result to interpret for policy-makers and stakeholders. First of all the communication of these results is more advanced and also the 'more-or-less' approach is not sufficient for planning tools and policy structures when accurate results are needed. A fitting application area however, can still be identified. Imagine if in a first assessment areas with high vulnerabilities have been categorised but the resources are not sufficient for all vulnerable areas. Therefore a prioritising has to be done and the z-score assessment can help selecting among all highly vulnerable areas which areas are more vulnerable in relation to the high mean vulnerability. The z-score evaluation represents an easy and transparent way of prioritising funding and resources.

6.6 Uncertainty and Sensitivity Analysis

The results presented in this study highly depend on the quality of the composite indicator model. First of all, the quality and the quantity of data influence the model outcomes tremendously (Giannetti et al., 2009). Especially a data-driven model like this one depends on reliable and proper data-sets. Errors can occur from a range of sources like measurement errors, systematic and human error which increase the results uncertainty (Giannetti et al., 2009). Data aggregation and processing might have taken care of the elimination of some errors related to minor inaccuracies in the data-sets. Not only the data themselves but also other factors related to the data processing and model preparation part have an effect on the model accuracy and reliability. For example the quality of the used database, the weighting method applied and the general processing and analysis of GIS and remote sensing data play an important role (Wang et al., 2008). Accepted tools to make statements about composite indicator accuracy and reliability are uncertainty and sensitivity analyses (Saisana et al., 2005). Despite the fact that uncertainty analyses are carried out more often than sensitivity analyses their combined application helps interpreting the results reliability (Saisana et al., 2005). This is particularly important when policy decisions are designed based on the assessment results.
An uncertainty analysis for a composite indicator 'focuses on how uncertainty in the input factors propagates through the structure of the composite indicator and affects the values of the composite indicator' (Saisana et al., 2005). A sensitivity analysis by definition however, 'studies how much each individual source of uncertainty contributes to the output variance' (Saisana et al., 2005).

A method that includes both uncertainty and sensitivity analysis is the Monte Carlo Simulation. The general idea of the Monte Carlo Simulation is to evaluate a models' behaviour based on multiple model simulations and using their results for the uncertainty and sensitivity analysis (Helton, 1993; OECD, 2008; Saisana et al., 2005; L. T. Tran, O'Neill, & Smith, 2009). The various simulations result from probabilistically selected model input variables and the assessment of their effect (Helton, 1993). The Monte Carlo assessment is considered as simple, easy understandable and hence widely applied (Helton, 1993). The uncertainty and sensitivity analysis approach for this study is to select five indicators and estimate their individual and combined effect on the composite indicator result, following the assessment steps of a Monte Carlo Simulation. The process involves several steps: selecting the indicators, selecting ranges of input variables, generating randomly the corresponding independent input variables, normalise data, aggregate and assess the results in form of an uncertainty and sensitivity analysis (Helton, 1993; Saisana et al., 2005). An uncertainty and sensitivity analysis is particularly important when a model is used for policy-making. The analyses indicate how applied weights possibly change results, which help decision-makers and stakeholders interpret the outcomes and adjust their policies (Saisana et al., 2005).

The five indicators were selected based on the previous indicator assessment (section 6.4.3) as the identified dominant indicators will affect the model simulations the most. The influential indicators on county-level are *nature reserves*, *land cover diversity* and *population change*. In addition to these the selection was extended to the dominant sub-indicators and their most influential indicators in this assessment. The sub-indicators are *climate* and *pollution and waste*. The dominant indicators are *precipitation* and *carbon emissions* respectively.
The scope of possible input variables was defined by the range of current input values of each indicator, expanded by 5% of the minimum and maximum value. 100 random input variables were then generated for each indicator within the corresponding value range before being normalised and aggregated as described in the method section. This procedure was conducted for each indicator individually and then for all five combined.

In table 13 are the uncertainty analysis results from the Monte Carlo Simulation summarised compared to the EVI_{UKc} result. The mean and the standard deviation depict how much the composite indicator result is influenced by changes in the input parameters (Helton, 1993). The overview shows that the change in one individual indicator does not have a great effect on the EVI_{UKc} model, when extreme values apply. Additionally, it is also obvious that the impact of the different indicators is in the same range from one another. Furthermore, the uncertainty analysis shows that the simulated results are of the same magnitude as the EVI_{UKc} itself and its' most extreme values. Hence, the change of one indicator is still in the uncertainty range that is already defined by the model. The simulation of *nature reserves* and *land cover diversity* demonstrates that a change of either variable results on average in a lower mean EVI_{UK}. The simulations for *precipitation*, *carbon emissions* and *population change* produce on average a bigger EVI_{UK}. When altering five indicators simultaneously the result range is shifted towards slightly higher EVI_{UK} results. The average EVI_{UK} result is estimated to be generally bigger and would determine a moderately higher environmental vulnerability in England.

Table 13: Monte Carlo Simulation results for the EVI_{UKc}.

Indicator	Min	Mean	Max	Standard Deviation
Precipitation	0.25	0.354	0.449	0.0076
Carbon Emissions	0.262	0.360	0.458	0.0076
Population Change	0.268	0.361	0.451	0.0076
Land Cover Diversity	0.255	0.349	0.438	0.0076
Nature Reserves	0.250	0.348	0.444	0.0076
5 Indicators	0.285	0.403	0.500	0.017
EVI_{UKc}	0.269	0.351	0.447	0.035

In addition to the uncertainty analysis the sensitivity relates input and output directly and assesses the impact of input variables (Helton, 1993). The plot in figure 13 displays all the simulated input variables and the resulting EVI_{UK} output for seven counties. As only one indicator is adjusted the general linear relationship in the model stands out in figure 13. In addition to that it is recognisable that the variation in input values only produces small alterations in output. Interestingly one can also see that the rank order of the counties and district does not shift with the changing input variables.
Overall both uncertainty and sensitivity analysis show that the EVI_{UK} model is reasonably robust and despite changing input data still derives fairly similar environmental vulnerability values. Without doubt a change of several dominant indicators results in slightly more spread out results. However, it has to be noted that this assessment is based on the most dominant indicators and therefore it can be assumes that the estimated changes represent the maximum alterations possible.

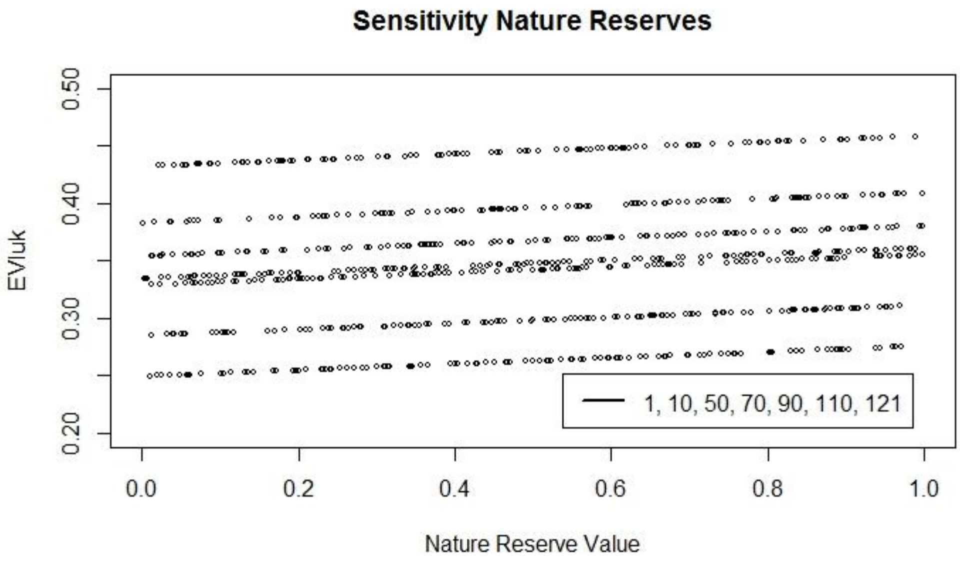

Figure 13: Sensitivity Analysis for *Nature Reserves*.

6.7 Exploratory Comparison between EVI_{UK} and EVI

Noticeably is that the obtained county-level results draw a different image of the environmental vulnerability in England than the preceding EVI assessment from 2004. As this result identified the UK environment to be under severe stress, the question and the incentive arose to investigate the issue of environmental vulnerability more profoundly in order to design actions more effectively. The classification of the UK as *extremely vulnerable* in 2004 initiated this study. The divergent results between EVI and EVI_{UKc}, *extremely vulnerable* and *low to moderate vulnerability* respectively, are striking and demand a thorough comparison. Especially because the results retrieved in this study, that England's environmental vulnerability is low, is supported by a slightly different examination. Moss, Brenkert, & Malone (2001) assessed the vulnerability to climate change, predominantly physical-environmental impacts, of different countries. They determined two different results: how vulnerable and how resilient a country is to climate change. Based on their study they describe the UK as more resilient than vulnerable.

Table 14: EVI UK result and class thresholds on EVI_{UK} scale.

Classification	EVI	EVI on EVI_{UK} scale
UK result	373	0.53
Resilient	≤ 214	≤ 0.306
At Risk	≤ 264	≤ 0.377
Vulnerable	≤ 314	≤ 0.449
Highly Vulnerable	≤ 364	≤ 0.52
Extremely Vulnerable	> 365	> 0.521

In order to compare and evaluate the EVI and EVI_{UKc}, their results had to be rescaled to a common range. The score range of the EVI is from 100 (minimum) to 700 (maximum) and the range of the EVI_{UK} is from 0 to 1. Due to simplicity the EVI results were recalculated to the EVI_{UK} scale (Tab. 14).

The result extent from the county-level assessment ranges from 0.269 to 0.447. The overall UK score of 0.53 from the EVI assessment exceeds this range. Looking at the rescaled EVI class thresholds it is distinct that the highest vulnerability class *extremely vulnerable* already starts at 0.521, just over the mid-point of the scale. This means plainly that almost half of the scale is 'reserved' for the class *extremely vulnerable*. Interestingly is, that the first class *resilient* similarly comprises about one-third of the scale (0-0.3). This means that the other three vulnerability classes share the remaining 0.2 scale points. Unfortunately there is no public documentation on how the vulnerability class thresholds for the EVI were determined. The report that apparently discusses the classification thresholds, Globalizing the Environmental Vulnerability Index (EVI): Proceeding of the EVI Globalization Meeting in August 2001 in Geneva, is not available anymore (Skondras et al., 2011).

For a better understanding how this classification scheme influences the results, the EVI_{UK} results from the county-level assessment were classified according to the classes above and displayed with the same legend (Fig. 14-15) (McLaughlin & Cooper, 2010).

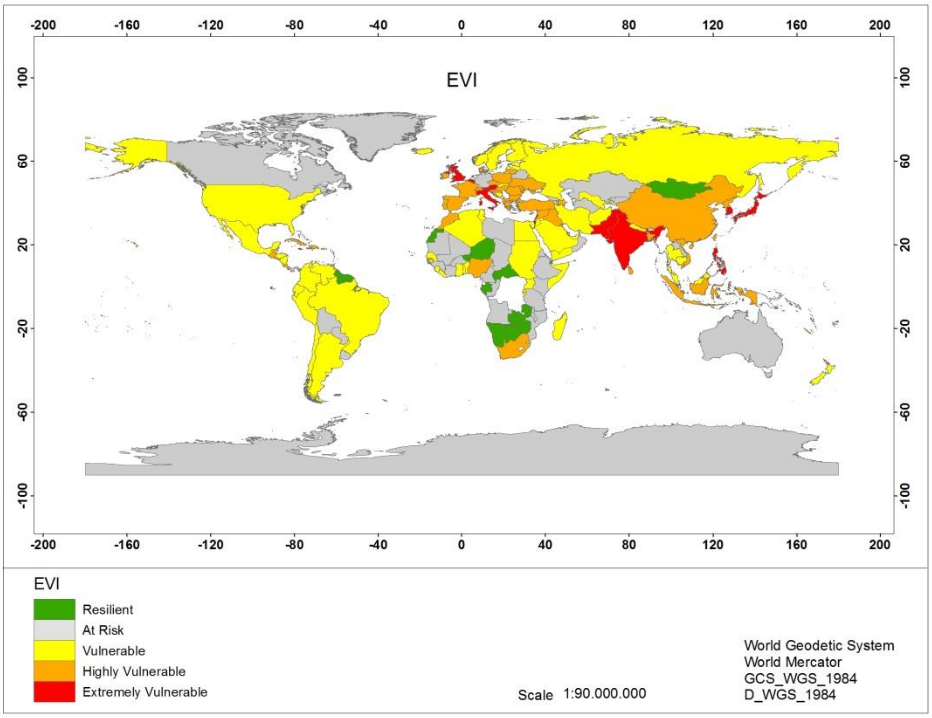

Figure 14: EVI 2004 assessment results.

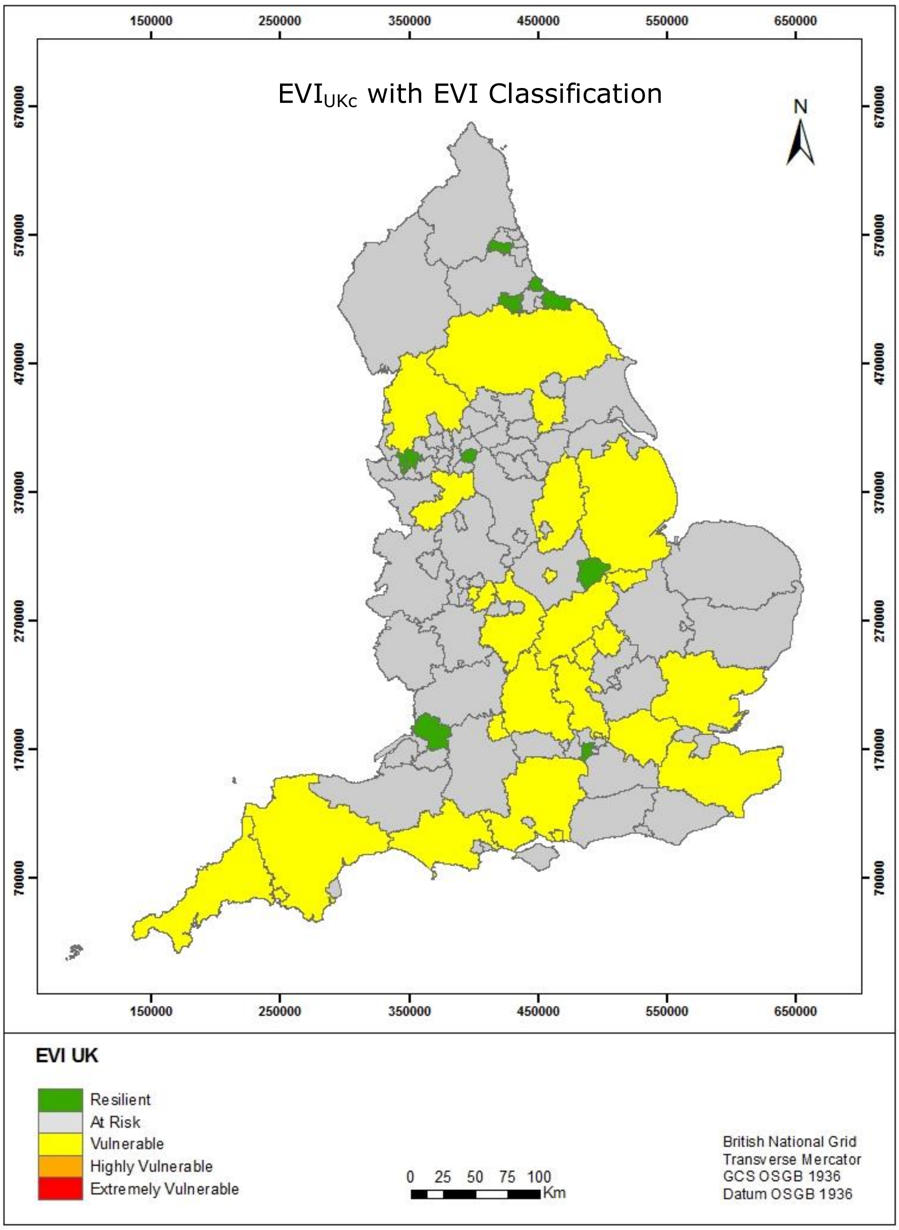

Figure 15: EVI_{UKc} with EVI Classification result.

It can clearly be seen that the classification scheme of the EVI changes the perception of environmental vulnerability in England. The conclusions that would be drawn from figure 15 are slightly different than from the EVI_{UKc} result. The EVI classes determine a little higher environmental vulnerability throughout England and also point out counties and districts that are more vulnerable than others. Planning programmes and policies would seem to be more urgent, however, still far from the initial EVI 2004 result of *extremely vulnerable*. The mean EVI_{UKc} result based on the classification scheme is *at risk* with a score of 0.35.

The first differences in the EVI and EVI_{UK} assessment are of minor importance. Firstly, the indicators included in the EVI and EVI_{UK} are not exactly the same. For the EVI_{UK} the indicators were selected specifically and study area orientated, whereas the EVI indicators intended a comparison worldwide. Hence, few indicators were not applicable for the UK (section 5.1). Secondly, the EVI assessment included Wales, Scotland and Northern Ireland. Due to data issues these countries were excluded, which led to a smaller study area in the EVI_{UK}. These two differences between EVI and EVI_{UK} have to be named for a purpose of completeness but they are not considered to account for big differences in the results. More crucial is the effect of data-sets. For the EVI_{UKc} analysis mainly UK data-sets were applied as they seem to be the most accurate for a UK assessment. In contrast to this the EVI dominantly used data that was globally available and possibly had a coarser resolution. The dissimilarities in results can be partly explained by this. A more detailed evaluation of effects associated with divergent data-sets is beyond the scope of this work. Besides this, one has to indicate that no correlation assessment was executed for the EVI. Hence, indicators were aggregated despite their possible correlations. As already stated in section 5.3 a post-evaluation of the EVI indicators shows that several indicators are correlated with one another and strictly speaking should not have been combined. The EVI results might be influenced by this. More critical than this are the differences in classification scheme between EVI and EVI_{UK}. A pre-classification already starts with the normalisation of the data. While the EVI_{UK} data is scaled between 0 to 1 with fundamentally infinitive options for scores, the EVI data has discrete classes from 1 to 7 (Kaly et al., 2004). The uneven number of seven classes was not chosen randomly but with the incentive to avoid a centre class and therefore forcing the scientists and experts to decide whether a data set is more or less vulnerable (Skondras et al., 2011). At the same time Jacobs, Smith, & Goddard (2004) argues that there is no rule on how to determine cut off thresholds for categorical variables. This makes the scaling subjective and the thresholds arbitrary. Another drawback of the EVI scaling scheme was described by (Skondras et al., 2011). They discovered in the application of the EVI to Greece, while doing a comparison between 2004 and 2010, that changes in the data-sets, due to improvement or deterioration, did not show in the final EVI result. The reason for this is that the data classes (1-7) are not sensitive enough in order to accredit these smaller changes. These are disadvantages that are not as strong in the EVI_{UK}. Based on the normalisation schemes the overall aggregation result scores also differ between EVI and EVI_{UK}.

One plausible explanation for the EVI classes seems to be that it is based on result percentage thresholds. Each class is most likely defined by a percentage of the results. After having obtained the results for the 235 countries in 2004 they were ranked according to their scores and then the highest results classified as *extremely vulnerable*. A possible threshold value for *extremely vulnerable* is the highest 15% as 35 countries of 235 were classified as *extremely vulnerable* (Kaly et al., 2004). This can be easily done since the whole methodology of the EVI is based on comparison to the rest of the data. Reason for this is the data dependent normalisation (Kaly et al., 2004). Likewise, are the results of the EVI_{UK} to be seen. The general advantages and disadvantages of the methodology are discussed in the limitations section (section 6.8). However, at this point it has to be discussed that the EVI methodology and following this also the results are highly data-dependent or more precisely study area-dependent. If a few more countries were included in the assessment and these happened to have very high values for one indicator, the normalisation result of that data-set would be completely shifted and in relation to that scope of the countries the UK might be less vulnerable, first of all for that particular indicator but in the long run also overall (McLaughlin & Cooper, 2010). This is the same case for the EVI_{UK}, especially when considering the different characteristics of counties and districts (section 6.2). Succeeding this, the results of the EVI and also of the EVI_{UK} can only be evaluated in relation to their assessment scopes and not compared with other studies. This is of course a big disadvantage but at the same time one has to understand the main purpose of the EVI study and the target users. The EVI study is targeted at politicians and policy-makers. While its' aim is to assess a countries' environmental vulnerability it also wants to draw attention of the policy-makers to this topic to start discussions and conservation actions (Hsu, Johnson, & Lloyd, 2013; Kaly et al., 2004). One can argue that the EVI results are very misleading (Saisana et al., 2005). This explains the differences in results of EVI and EVI_{UK} and at the same time stresses that it is important to look into a study carefully before taking the conclusions as definite. Besides that, it also underlines that in this case a country specific assessment, following the EVI assessment, is beneficial and gives more precise answers. So far the EVI has not been applied extensively. Most of the studies are part of the validation process of the EVI itself and have a scientific purpose only (Kaly et al., 2004; Kouakou et al., 2013). The selected countries are Fiji, Samoa, Greece, Vanuatu and Tobago (Kouakou et al., 2013). Whether the assessment results were incorporated in policy and planning tools is not documented.

To wrap up this short evaluation it has to be stated that this short assessment verified two previously stated points. First of all it is apparent that a classification scheme influences the perception of an issue and can be used in order to manipulate the results, directing them towards a certain outcome. This is valid for both cases, when one intends to emphasise a problem and also when one tries to underestimate an issue. Secondly, the general result of this evaluation agrees with findings from (McLaughlin & Cooper, 2010). According to their study a zooming in to a study area from low resolution to high resolution shows a decrease in vulnerability. Similarly this relationship is observed with the global EVI assessment concluding with a very high vulnerability for the UK and the national EVI_{UKc} assessment resulting in low to moderate vulnerability.

6.8 Limitations

When analysing this study several limitations have to be accounted for. The main limitations can be found in the methodology and in the interpretation of the results of the composite indicator.

To start with, the selection of indicators was based on many different sources. The attempt was made to define a selection of indicators that cover all possible and recorded pressures in England. However, the sources used for this have their own purpose and might be biased for this. Additionally, as the topic environmental vulnerability is in general very new and has not been addressed in the UK intensively some of the sources dealt either with environmental sustainability or vulnerability of humans to pressures. In these cases assumptions were made that the same pressures also exert stress on the environment and not only on humans.

A second big restriction in this study comes from the data-sets. General drawbacks are incomplete data, limitations in their measurement, availability of information, especially about extrapolations and interpolations (Giannetti et al., 2009). Seeing that the data-sets for this study come from diverse sources often with little meta-data explanation or with a lack of information on their collection, measurement and processing, their interpretation is difficult. Certain data-sets were also not available although they would have been desirable for a proper environmental vulnerability assessment, for example data about the fish stocks (section 5.2). Besides that, in order to populate the indicators, some of them were filled with proxy data. For example for the indicator vehicles, the ideal data would have been the total number of registered vehicles per area. But as this was not available, data related to the travel time at peak hours per county and district was used. The assumption that the more vehicles are on the street the slower the travel time was considered to be valid as a proxy. Another disadvantage related to data is the data modelling process. As described in section 5.3 the first correlation matrix revealed many high correlations. Hence, the most correlated data-sets were slightly adjusted, mainly standardised by the area. Nevertheless, this modelling process possibly has influenced the assessment. Additionally to the aforementioned arguments, it has to be mentioned that a number of indicators were populated with data from global or European data-sets. Their resolution is hence fairly coarse. The aggregation on county or borough-level, a finer resolution, therefore does not present more detailed information. As the composite indicator incorporates numerous indicators and hence, requires many data-sets, the limitation due to data is very influential (Saisana et al., 2005).

Besides that, the normalisation method, min-max, also brought in some disadvantages. The main issue is that the normalisation is highly data-dependent. The central part of the normalisation is to scale the data based on the range of minimum and maximum values. Hence, the min-max method is very sensitive to outliers and classified as not stable or robust (Jain et al., 2005; OECD, 2008). An internal comparison takes place and ranks the data accordingly (Schmidtlein et al., 2008). This has a particular strong and negative effect on the borough-level assessment as Hampshire only has eleven and Derbyshire only eight boroughs. Hence, the normalisation method stretches the data-sets artificially on the scale from 0 to 1, creating differences between boroughs that might not even be there. The overall environmental vulnerability results and their analysis are influenced by this highly as discussed in section 6.5. A negative influence of the min-max normalisations on the county-level assessment was discussed in section 6.4 already. However, to what extend the normalisation methods also controls the EVI_{UKc} result can only be assumed. One can suspect that the bigger assessment scope on county-level averages out disparities more and lowers the min-max effect. The controversy of stretching data-sets of geographically close areas is supported by the geographic law of spatial contiguity which states that areal units which are close to on another are more alike than units non-adjacent (Shaw & Wheeler, 1985). The only aspect that speaks for such a comparative approach is that vulnerability is often seen as not an absolute term and therefore should be assessed in a relational context (Vogel, 2001). As already defined in section 6.5, based on the normalisation scheme applied, the results can only be interpreted in relation to the study scope and area. A comparison to other studies is challenging. This is a major drawback of the methodology. As well as the disadvantage that a min-max normalisation makes temporal comparisons more complicated. When comparing two points in time the data from the earlier time often has to be readjusted (OECD, 2008).

Lastly the generic concept of aggregating indicators is troublesome. Schmidtlein et al., (2008) state that relationship presented between variables that are aggregated areally can both arise from the aggregation process as well as existing relationships between the variables. Differentiating whether the detected relationship result from the former or the latter is complex (Schmidtlein et al., 2008). This issue applies to this study with its' areal assessment levels. Furthermore, the here selected linear aggregation, and also the equal-weighting, is based on missing scientific proof, the aim to develop a comprehensible and easy applicable index and a plain insufficient knowledge of causal relationships (Kaly et al., 2004; OECD, 2008). By choosing the linear aggregation scheme one avoids addressing these problems. It is especially critical to define vulnerability by pointing out its three characteristics, exposure, adaptive capacity and sensitivity, but then neglecting this fact. Villa & McLeod (2002) underlines this as they claim that linear aggregations are appropriate for non-systems, or more precisely non-interacting systems. The environment however, in the context of vulnerability studies and the effects of hazards, definitely represents an interacting-system. Following Villa & McLeod (2002) statement a non-linear aggregation scheme would be more applicable then.

As second big aspect that restrains this study is the general application and interpretability of a composite indicator. This issue is discussed in the literature extensively. First of all it has to be acknowledged that composite indicators have temporal limitations. The variables are static and only draw a single picture in time (McLaughlin & Cooper, 2010). The general idea of an index is that one can also conduct temporal assessments to deduct change, in this case improvement or deterioration, but this has to be done carefully.

Reasons for this are changes in measurement or data collection schemes, availability of new and more detailed data. These facts can alter results and make a temporal comparison difficult (McLaughlin & Cooper, 2010; OECD, 2008).
Furthermore, the interpretation of a composite indicator is complex and has to be done with caution (Freudenberg, 2003; Saisana et al., 2005; Schmidtlein et al., 2008). The biggest problem is that an index expresses a complex process in only one single value. It is questionable whether this is a justified method (Barnett et al., 2008). However, this is a very controversy topic since indices also simplify the analysis of complex topics. Freudenberg (2003) and Singh et al. (2009) put forward that the more transparent and the more details of an index are available the better it can be applied. At the same time one has to approve that an index helps to identify the *best* and the *worst* of something. Only issue arising from this is the interpretation of middle-rank countries for example. Nonetheless, the problem remains on how to interpret the middle ranks (Esty, Levy, Srebotnjak, & de Sherbinin, 2005). But generally one has to see what a composite index is and accept its' limitations: it is a tool mainly for non-specialists like policy-makers but not a scientific profound assessment (Birkmann, 2007; Schmidtlein et al., 2008).

Lastly, no assessment of risk, adaptive capacity or something related was conducted in this assessment. As described in the literature review (section 2) this would have exceeded the scope of the study. Nevertheless, it has to be emphasised that the issues of adaptive capacity, exposure and *et cetera* are important when analysing the topic of vulnerability. This study can therefore not be considered as a complete assessment.

6.9 Implications of EVI_{UK}

Nowadays there is still a gap between scientific work and its' application. Reason for this is that the approaches used for certain assessments, including environmental vulnerability, are still predominantly scientific and therefore not easily implementable for decision-makers. Consequently, it is important to find ways on how to integrate the tools and developed indices into planning and decision-making processes (Birkmann, 2007; Queste & Lauwe, 2006). It is especially important to explore how these approaches can stimulate actions, how they can be applied and by whom on the different levels (Birkmann, 2006).
Thus, this chapter tries to define how the EVI_{UK} can be implied in the English planning and policy process.

6.9.1 General Planning Structure in England

There are several sub-national planning levels that can be distinguished in England. In most parts of the country they have a two tier system, consisting of county and district councils, borough or city councils (UK Government, 2015). The difference between these two tiers is in their responsibilities. The county council is for example in charge of education, transport, public safety, waste management and strategic planning. In contrast to this, districts, boroughs and city councils take care of the rubbish collection, recycling, tax collection and planning applications (Politics.co.uk, 2015; UK Government, 2015). In this study we combined the counties and city districts together in one assessment level in order to cover whole England in the first assessment step. Districts are mainly cities and are otherwise not included within counties.

6.9.2 Current Programmes

The assessment of the current programmes is based on the four sub-indicators that were identified as the ones causing Englands' environmental vulnerability the most: *climate*, *pollution and waste*, *land use and energy* and *population*. In addition to that the focus is on Hampshire and Derbyshire as the *worst* and *best* county respectively. It would be interesting to see whether their policies are varying and the divergent classification can be explained by this.

The topic of *climate* is generally discussed as in climate change. There a several reports published which address this topic. For example UK Climate Change Risk Assessment: Government Report or the National Adaptation Programme. Making the Country Resilient to a Changing Climate (Defra, 2012, 2013c). These reports and also the Natural Environment White Paper assess the issue on a very broad scale and identify the main national problem: greenhouse gas emissions (Defra, 2014b). In the UK Climate Projections 2009 (UKCP09) they specify that carbon reduction and increasing resilience are the main things the population can actively influence and change. As part of the Climate Change Act 2008 the national government sets the aim of reducing carbon emissions by 80% by 2050 (HM Government, 2008). The aforementioned reports outline general strategies. However, they all refer to the regional and local level as the levels that actively have to apply concrete actions (Defra, 2013c). In order to succeed and especially conserve nature environment areas, management programmes are initiated, like the Nature Improvement Area (Defra, 2013c) or the Local Nature Partnerships (Defra, 2014b), that focus on local involvement and responsibility. To put an even stronger emphasis on local engagement the local government association was formed and as part of their main task also work on the topic climate change (Local Government Association, 2014). Their association is supposed to publish work and provide a platform for local governments to share information and best practice related to climate change. A strong local government network is ideally created (Local Government Association, 2014). Since 2012 local governments can sign up for Climate Local. Hampshire is part of Climate Local since 2012, so are the borough councils Erewash (Derby), Eastleigh (Hamp), Test Valley (Hamp) and Basingstoke and Deane (Hamp) (Local Government Association, 2015). Both counties, Hampshire and Derbyshire, have their action plans on how to reduce carbon emissions and make their county more energy efficient. The same can be said about the boroughs. Despite them following the guidelines given by the counties, they have their own management plans and priority actions. The main action points are educating the population, giving guidelines and advices on how to reduce emissions in order to create an incentive and consciousness for carbon emissions. Besides that the councils act themselves, as in a role-model function, to reduce carbon emissions and energy consumption in lowering lightning, installing solar panels on government buildings, introducing renewable energy sources to public schools and investing into infrastructure making it more resilient to weather conditions (Derbyshire County Council, 2014b; Hampshire County Council, 2014a).

In order to achieve the governmental aim of reducing carbon emissions by 80% by 2050, Hampshire follows the intermediate target of reducing carbon emissions by 20% by 2015 based on the 2010 emission status (Hampshire County Council, 2014a, 2014b). The carbon emissions in 2010 reach approximately 10.200 kt CO_2. The desired emission rate by 2015 is therefore around 8.200 kt CO_2. After two years, in 2012, Hampshire succeeded to reduce their carbon emissions by almost 10%. With more than three years left for the carbon emission reduction efforts, Hampshire seems to meet their target. Derbyshire follows the 'Low Carbon Transition Plan' which was developed by the UK government (HM Government, 2009). Their aim is to decrease their carbon emissions by 18% based on the 2008 emission benchmark until 2020. Hence, the approximately 9.000 kt CO_2 of 2008 have to be reduced to about 7.400 kt CO_2. Derbyshire cut their emissions by about 8% in 2012. With eight years remaining until 2020 Derbyshire seems to accomplish their goals. Despite the different time-plans of Hampshire and Derbyshire one can notice that Hampshire has higher reduction targets in a shorter period. Within two years only, 2010–2012, Hampshire decreases their carbon

emissions by almost 10% while Derbyshire only achieved a cut of 3% in the same time period. However, it has to be stated that the overall carbon emissions in 2012 are lower by about 900 kt CO_2 in Derbyshire than in Hampshire.
Another focus in the carbon reduction sector is to decrease energy consumption. The general aim is to lower energy consumption by 40% until 2020 (HM Government, 2009). Comparable statistics are available from 2007 and 2012. In that period Derbyshire managed to reduce their electricity consumption by 10%. The boroughs of Derbyshire itself even achieved an average reduction of 11%. The highest decrease can be observed in Derbyshire Dales with roughly 18%. Hampshire has not succeeded in a similar good reduction yet. The county overall lowered the electricity usage by about 5% whereas the borough average is 6%. Interestingly is that Test Valley and Winchester did not reduce but increase their energy consumption in the same period while Rushmoor sticks out with an reduction of almost 15%.

The second sub-indicator that needs to be discussed is *population*. Finding official papers on the planning strategies surrounding population was not possible. However, two reports were found that address the topic (McDougall, 2010; Murray, 2008). Both reports describe the UK as overpopulated. McDougall (2010) already speaks of a state that is environmentally and also economically unsustainable. Hence, they suggest a wide education and awareness campaign to encourage a 'stop-at-two' children policy and avoid unwanted conceptions. In addition to that they propose a more balanced migration policy and improvements in employment strategy of the local population. If these advises succeeded the only problem remaining would be the aging population (McDougall, 2010). The average population change rate in England is +2.2%. Derbyshire, with a change rate of 1.6%, is below this. Hampshire however, with +3%, exceeds the country average. The county councils do not address the issue of population. Both counties are not particular urban counties. 6% of Derbyshire can be considered as urban and 9% of Hampshire. As most population changes appear in urban areas this could explain why neither Hampshire nor Derbyshire have a population plan.

Another aspect of the *population* sub-indicator is the pressure related to vehicles. To lower the impacts of vehicles two different approaches are followed. First of all there are strict regulations that have to be followed concerning the vehicles' emissions. Cars with lower carbon emissions receive financial favours in form of tax reductions. Additionally the introduction of vehicle excise duty (VED) took place

in 2001 (environmental protection uk, 2015). The main standards followed by the UK for vehicle emissions are given by the EU (European Commission, 2015). The second approach followed is to inform and educate the public on alternative transportation means and show them the benefits of public transport, car-sharing and not using the car for short distances (environmental protection uk, 2015). Again the topic of vehicles is not emphasised by local governments.
Derbyshire however, accomplished reducing their traffic density between 2006 and 2013 as the travel time decreased by 0.03 minutes per mile. In contrast to that Hampshire's' traffic density did not change in the same period.

Lastly the topic tourism is part of the *population* sub-indicator. VisitEngland argues that the highest importance is to have a proper plan for tourism in an area. When the plans are managed well and implied correctly, tourism and environmental conversation can go together. Therefore, VisitEngland worked out principles for a destination management plan. The application of the management plan is on local level and intends to allow tourism activity in natural environments but minimise their negative impact (VisitEngland, 2012). Each council should have one designated destination manager, who gets support and guidance information (Defra, 2014b). The general tourist numbers are increasing in England. In the East Midlands, the region of Derbyshire, there was an increase in tourist visits of 22% between 2002 and 2013. A similar increase was observed in South East with 19%. In Hampshire itself the tourist numbers increased within three years by 10%. These trends show that tourism intensifies and hence also the pressure resulting from tourists will become more important. Unfortunately there are no tourist numbers for Derbyshire. Considering that the Peak District National Park is partly in the territories of Derbyshire, which is famous for hiking and other outdoor activities, it would be important to know the exact tourist numbers and their development in order to estimate their impact.

The third sub-indicator that stood out in causing a big proportion of the environments' vulnerability is *pollution*. A big factor of pollution is carbon emissions. This was, however, already discussed in the context of climate. In the same context the topic of energy reduction was covered. The main indicator left from the sub-indicator *pollution* now is *waste*. On national level the UK government published one big appeal on waste and food waste reduction (Defra, Environment Agency, & Truss, 2015). Furthermore, Defra issued a report on recycling with guidelines (Defra, 2013a). The general aim is to prevent waste and if not possible at least recycle as much as possible. The main responsibility for waste reduction and recycling is given to local authorities as they are also in charge of the waste collection within their territories. As a helpful instrument the Local Authority Recycling Advisory Committee (LARAC) was found. Each borough has a waste and resource manager who is part of the LARAC committee to design actions together and share good practice information (LARAC, 2015). Central part of the job is to educate the population on how to reduce waste in their household and what effective recycling looks like (Defra, 2013a). Hampshire's aim is to recycle 60% of their household waste by 2020. In 2014 about 40% was already recycled. This means that with the current state another 130.000t have to be recycled in Hampshire by 2020. Derbyshire aims to increase their recycling to 55% of the household waste until 2020 (Derbyshire County Council, 2014a). However, in 2014 they already recycled 46%, which indicates that they are already on a good way to reach their target.

Lastly, the sub-indicator *land use and energy* dominates the environmental vulnerability assessment. The most influential indicators are *land use* and *nature reserves*. Both indicators represent the natural environment: the *land use* indicator in form of forest areas that exist in an area and *nature reserves* as those natural environments that are under protection. A high vulnerability score for these two indicators expresses that only small forest areas are existent and likewise only small natural areas are protected. Both counties contain areas of a national park. In Derbyshire are parts of Peak District National Park. Overall the national park area within a Derbyshire is 89.200ha. Combined with additional nature reserve areas, including the natural environments, Derbyshire holds 90.800ha (36%) of nature areas. In Hampshire the New Forest National Park is situated and covers an area of 53.500ha. In total the Hampshire contains 120.000ha (32%) of nature areas. In order to maintain and improve Hampshire's biodiversity and natural sites the scheme for Sites of Importance for Nature Conservation in Hampshire (SINC) is implemented (Hampshire County Council, 2015). Part of the scheme is to identify relevant sites and to create a management plan for them. The different wildlife and nature conservation agencies, within Hampshire and also on national level, provide guidance and advice for this. 9% of Hampshire's land area is under the scheme (Hampshire County Council, 2015). The Biodiversity Action Plan specifies the species and nature areas that are crucial to conserve (Hampshire Biodiversity Partnership, 2000). However, the management and conservation processes are specified in individual action plans, accustomed to the distinct habitats. This is accompanied by species action plans that focus on individual species (Hampshire Biodiversity

Partnership, 2011). In terms of nature conservation Derbyshire implemented two biodiversity action plans: one for the lowland areas and another one for the Peak District National Park (Derbyshire Biodiversity, 2015a). As the Peak District is a special nature area it is further divided into fifteen habitat action plans and seven species action plans (Derbyshire Biodiversity, 2015b). Next to a biodiversity action plan Derbyshire focuses on local nature reserves. Currently 46 local nature areas are managed within Derbyshire (Derbyshire County Council, 2015). Each plan specifies measurements and actions precisely for one habitat or species to achieve maximum success in their conservation.

6.9.3 Suitable Implication Level in England

McLaughlin & Cooper (2010) specify the most appropriate action on each level, arguing that a nested approach is very valuable. The global-scale is for international approaches that need to be coordinated and global policies that require to be discussed. Assessments on national-level then help to design national policies and especially prioritising resources. Lastly, McLaughlin & Cooper (2010) identify the local level for the practical responses.

The description of the current environmental programmes in England (section 6.7.2) shows that also in England more than just one administrative level is involved in addressing the different pressures. The general opinion is that when it comes to the quality of natural environment all levels, global, regional and local, have to be included in order to be successful (Natural England, 2008). The Department for Communities and Local Governments specifies this and says that national plans are essential for giving guidelines to local authorities on conserving the environment (Defra, 2012; Department for Communities and Local Government, 2012). There are several reasons that justify this top-to-bottom principle when it comes to guidelines and strategies. First of all, it is always helpful to have an overview of the most important problems and issues that require consideration. Secondly, one has to look at it from an economic point of view. A national assessment can already eliminate pressures from the list of potential threats and highlight those that need more attention. So when a county now conducts an assessment they can already target their assessment and reduce resources and efforts. Additionally to this, it is also reasonable that national departments and institutions publish guidelines and instruction for problem solutions. The national level often has more resources and easier access to experts and research institutions than single counties or even borough councils. Hence, the national level publishes the reports which are then available to all counties, districts and boroughs. This is more economically sustainable than if each county or district conducts their own study.

This is differently when it comes to applying actions. Several problems have their roots in local activity, for example soil degradation or the amount of waste produced (Defra, 2013a). Therefore, the action should be from bottom-to-top. Wang et al. (2008) supports this as they underline that environmental vulnerability is strongly connected to socio-economic factors. Most of the programmes mentioned in section 6.9.2 point out the importance of local levels (Defra, 2014b; Local Government Association, 2014). Reasons for this is that actions conducted on local level are more directed and thus, more effective (Sietz, 2014; Tavares & Pinto dos Santos, 2013). Especially the Town and Country Planning Association (2012) states numerous laws that indicate the role and importance of local authorities. The town and country planning association also specifies that the crucial aspect is the planning part. Proper planning frameworks and policies are the most essential tools to direct development and to undertake action reducing impacts on the environment, as it is fundamental to deliver the right development in the right place. The localism act highlights the shift from national to local planning and so does the national planning policy framework (Department for Communities and Local Government, 2012). Therefore, the general order of action is that the national level publishes general guidelines and strategies and the local level uses them for their detailed planning. Leaving the final planning to local communities has several advantages. Firstly, local experts with their local knowledge can target actions more precisely. Secondly, engaging local communities in the planning process means active participation and community-based development, which often results in general acceptance of the activities, personal association with the problem and hence a greater engagement which again leads to better results (Town and Country Planning Association, 2012). Furthermore, an estimation showed that local planning responsibility can create about 70,000 jobs. These jobs would be dealing with climate change and energy efficiency within counties, districts and boroughs, which means that local planning also has an economic advantage in the context of employment rates (Town and Country Planning Association, 2012).

Based on the above assessment and the results obtained, it seems that the most suitable application level for the EVI_{UK} assessment is the county-level. Firstly, the discussion above shows the benefits of local planning and strategic. This still does not give a differentiation between borough and county-council, as both councils are considered as local councils. However, the results of the borough-level EVI_{UKb} assessment turned out not to be reliably due to the limitations in methodology (section. 6.5). Furthermore, it seems also very optimistic to give the main responsibility to the borough councils as they are partly very small and only responsible for a small area. For example the smallest borough in Hampshire only covers about 40 km^2 which is about 1% of the county area and in Derbyshire the smallest borough is 66 km^2 big and 2.6% of the county area. County councils however, have a reasonable size, resources and responsibility. While the main coordination and planning sovereignty is on county-level, it does not mean that borough-levels are excluded. Their expert knowledge and input is still needed and should be included in the planning and implementation process. Fekete et al. (2010) conducted a study to a similar topic in Germany. They describe the county-level as a suitable implementation level as they are homogenous units and on county-level policy-makers and planners can be addressed that have decisive roles in the administrative units. In addition to that, counties are spatial units that can be interlinked to other data and assessments of different topics (Fekete et al., 2010). This implies that even with an adjusted EVI_{UK} for the borough-level assessment, in order to eliminate the methodology error, the borough-level is not the most advisable application level. Based on this reasoning and when looking at this particular study, the county-level is the most suitable implementation level for the EVI_{UK}.

Besides the above, one can say that the strategical environmental assessment (SEA) seems to be an appropriate tool to include the EVI_{UK}. A SEA has to be conducted whenever plans and programmes are made, independent of the administrative level (Office of the Deputy Prime Minister (ODPM), 2005). The SEA process consists of consecutive stages. The first step, stage A, is for collecting the baseline information, identifying the problems, defining the current state of the environment and reveals what information the administrative unit already possesses and which they still need to collect (Office of the Deputy Prime Minister (ODPM), 2005). As the EVI_{UK} determines the main pressures and hazards in an area and also indicates one aspect of the current state of the environment, the EVI_{UK} could be included in stage A of the SEA. The only condition for this is that not similar problems as with the min-max normalisation on borough-level occur.

6.9.4 Recommendations for Policy-makers

The main recommendation for policy-makers is that due to the limitations of indices in general they should acknowledge that their results are mainly guidelines. As the general assessment is compressed to one value certain meanings get lost (Barnett et al., 2008). Nevertheless, the EVI_{UK} still gives an indication on main pressures. As the sub-indicator analysis turned out to be the most reliable one and providing the highest information content, one can suggest for policy-makers to focus on this. With the help of the EVI_{UK} analysis they can determine the results for the sub-indicators and receive a more precise image on the main pressures causing the environmental vulnerability in their territory. In the case of Hampshire this for example shows that the pressures related to *natural hazards* and *population* are not an issue (Appendix Fig. 23-30). Similarly the aspects of *fishery* can be treated with minor importance as the analysis classifies it with lower to moderate vulnerability. In contrast to that *agriculture*, *biodiversity*, *climate*, *pollution and waste* and *land use and energy* stick out as moderately vulnerable. Between these five sub-indicators *agriculture* scores the highest and should be addressed first. The EVI_{UK} assessment definitely leads to a pre-selection of pressures and helps to target more precise evaluations and their funding.

6.10 Future Works

Looking back on this study there a few aspects that can possibly follow this assessment.

First of all, in order to validate the index it can possibly be applied to other countries. These other countries have to fulfil certain criteria: they have to be a developed country, lie in a similar geographical area, possess a coastline and are a federally structured state. An extension to further countries can involve for sure Wales, Scotland and Northern Ireland. They fulfil the mentioned criteria and in addition to that, they were intended to be part the assessment in the indicator selection process. Furthermore Germany, the Netherlands and possibly Poland are manageable countries.

Another aspect that has already been mentioned is that vulnerability assessments should be part of risk assessments. Elements like hazard, risk, exposure and adaptive capacity are very important and essential for the whole topic of vulnerability. As these parts had to be left out in this study, further assessment could possibly look at them so that in the end an overall complete image can be created (Du & Lin, 2012). Following this, it is also essential to investigate the relationship between exposure, sensitivity and adaptive capacity and the defining elements of vulnerability. First of all the dynamics have to be assessed and then the new knowledge could be adapted in more fitting weighting and aggregation schemes.

Lastly the limitation due to the min-max normalisation has been expressed. In section 6.5 it was proven that the borough-level assessment is influenced by the normalisation method. Time-constraints did not allow the same evaluation of the county-level assessment. Instead the dominant indicator interpretation displayed that also the county-level assessment results are influenced by the normalisation. In order to give the current study more reliability this should be assessed, however. Furthermore, it can be of interest to conduct the same study with the same indicators and same data-sets but only apply a date-dependent normalisation scheme. Similarly to the EVI assessment in 2004. It would be interesting to see what kind of effect the different scheme has on the results, especially on the borough-level assessment. Moreover, then it should be assessed to what extent the new results on borough-level might be better and help locating environmental vulnerable areas

7 Conclusion

The idea of vulnerability is to define a system by its exposure to hazards, its sensitivity to experience harm and adaptive capacity to cope with the hazards. In this assessment the attempt was made to define environmental vulnerability by indicators that represent these characteristics. A wide selection of 51 indicators was described therefore aiming at including all environmental vulnerability aspects in this.

The here developed environmental vulnerability index succeeds, despite its limitations, in identifying environmental vulnerable areas on sub-national scales in the UK. With these results the study proves scientific assumptions and opinions that vulnerability is a spatially varying issue. In comparison to the initial EVI the current EVI_{UK} is well adjusted indicator-wise and hence representing the subject of environmental vulnerability in the UK more reliably than the EVI. Interestingly is that the EVI_{UK} results do not rate the environmental vulnerability as high for the UK as the EVI did in 2004. This confirms that results obtained on varying scales convey different images of the problem.

The identification of main indicators causing the environmental vulnerability on both county and borough-level, was difficult due to the normalisation method applied. As already described in previous literature this evaluation also shows that a bigger emphasis should be given to the sub-indicator assessment. The sub-indicator analysis described the main issue groups, as in *land use and energy*, *pollution and waste*, *climate* and *population*, and will help targeting vulnerability reduction policies and design actions that will have a greater positive impact.

The methodological limitations for the borough-level assessment are considerable and hence an application of the EVI_{UK} on a lower scale than the county-level is not recommended without adjustments.

Finally, one has to conclude that the appropriate implementation scale of the EVI_{UK} is the county-level. This is however, a result that is not different to current practice in the UK. In that sense the evaluation does not particularly give new insights into the application structure but instead supports the current system. Nevertheless, one has to acknowledge that this decision is partly based on the fact that the borough-level assessment is not fully reliable.

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Appendix

Table 15: Justification for the excluded indicators.

Index	Indicator	Justification
EVI	Volcanoes	UK is seismically stable (Gibson, Culshaw, Dashwood, & Pennington, 2013)
	Earthquakes	UK is seismically stable (Gibson et al., 2013)
	Tsunamis	UK is seismically stable (Gibson et al., 2013)
	Land Area	County and borough scale for EVI_{UK}
	Country Dispersion	Fragmentation degree of land indicated by *Infrastructure*
	Isolation	Does not apply to UK study as one country
	Borders	not relevant for counties or boroughs
	Environmental Openness	not as important when looking at county and borough level; similar effects are indicated by diseases and endangered species indicators
	Migrations	one single country
	Endemics	Focus on endangered species. This gives a better indication for current threats (vulnerability). IUCN Red List Index, Living Planet Index and the Global Wild Bird Index all look at changes in current populations no extinct once.
	Extinctions	See *Endemics*
	Biotechnology	GMO not grown in UK (Defra, 2014a)
	Spills	no recorded spills in the last years (ITOPF, 2014)
	Sanitation	Developed vs. Developing Country Assessments (Eriksen, Vogel, Ziervogel, Steinbruch, & Nazare, 2008; Esty et al., 2005)
	Environmental Agreements	Agreements are national or regional so therefore no effect when looking at county or borough level
	Conflicts	No conflicts in UK (Eriksen et al.,

		2008; Esty et al., 2005)
CVI	Geomorphology	Too detailed information needed for the UK assessment.
	Coastal Slope	Too detailed information needed for the UK assessment.
	Shoreline Erosion/Accreation	Too detailed information needed for the UK assessment.
ESI	Urban population weighted TSP concentration	Air quality statistics in general included.
	Indoor air pollution from solid fuel use	Not affecting the environment
	National Biodiversity Index	Nature parks and co. are included already.
	Dissolved oxygen concentration	General water quality statistics included.
	Electrical conductivity	General fuel statistics included.
	Percentage change in projected population 2004-2050	No long-term projections included.
	Ecological Footprint per capita	An index itself.
	Generation of hazardous waste	General waste statistics and medicines and chemicals are included.
	Percentage of total forest area that is certified for sustainable management	Protected Forest Area included.
	World Economic Forum Survey on subsidies	No direct effect on environment.
	Salinized area due to irrigation as percentage of total arable land	Land degradation is included.
	Agricultural subsidies	No differences of subsidies within the UK.
	Reducing Human vulnerability	Not relevant for the environment.
	Social and Institutional Capacity	Not relevant for the environment.
	Global Stewardship	Not relevant for the environment.
EPI	Change of Trend in	No trends included but only status

	Carbon Intensity	quo.
	Trend in CO2 per KwH	No trends included but only status quo.
	Access to Electricity	Developed vs. Developing Country Assessments (Eriksen et al., 2008).
	Terrestrial Protected Areas (Global Biome Weighting)	No weighting but protected areas are included.
	Access to Drinking Water	Developed vs. Developing Country Assessments (Eriksen et al., 2008).
	Access to Sanitation	Developed vs. Developing Country Assessments (Eriksen et al., 2008).
	Air pollution - PM2.5 Exceedance	Air quality and carbon emissions included.
	Household Air quality	Not relevant for the environment.
	Child Mortality	Described as an indication of human health.

Table 16: Indicator Descriptions and their Data Sources.

Indicator	Description	Data Source
Wind	Average annual wind speed from 1981-2010 based on monthly aggregations.	MET office UKCP09
Precipitation Max	Average annual rainfall from last 5 years (2007-2011) compared to 30 years average (1981-2010).	MET office UKCP09
Precipitation Min		No data-set available
Temperature Max	Average annual max temperature of the last five years (2007-2010) compared to the average temperature of the last 30 years (1981-2007).	MET office UKCP09
Temperature Min	Average annual min temperature of the last five years (2007-2010) compared to the average temperature of the last 30 years (1981-2007).	MET office UKCP09
Phenology	The average length of growing season (in days) from 1971-2000.	MET office UKCP09
Sea Surface	Average sea surface	AVHRR SST

Temperature	temperature based on daily satellite measurements from 1985-2007.	Product
Sea Level	Average change in sea level within a year based on monthly pressure measurements from 1971-2000.	MET office UKCP09
Tide	The average tide range within a year based on measurements from 2013 based on single measurement sites.	BODC measurements shp
Relief	Altitude range (highest point subtracted from the lowest point in county).	Aster GDEM
Lowlands	Percentage of land area less than or equal to 10m above sea level.	Aster GDEM
Coast length	The length of the coastline of a county as a proxy for the coastal area that is exposed to coastal erosion.	OSDD
Soil Diversity	The Number of different soil types in relation of the county area.	EU Soil WRBFU
Invasive Species	The Number of introduced species per county in the last six years (2009-2014).	Invasive Species Specialist Group
Diseases		No data-set available
Endangered Species	The endangered species density per county (IUCN definitions).	Environmental Agency and Natural England
Birds	The number of birds in relation to the county area in 2013.	Share Geo Open
Slides	Number of landslides recorded since 1990	BGS WMS
Storms		No data-set available
Floods	The percentage of area considered in the flood alert plan per county.	Flood Alert Map from Environment Agency
Fertilisers	Average annual intensity of fertiliser use over the total	UK Government Fertiliser Statistics

	land area related to the crop type in 2013.	
Land Degradation	The percentage area of a county considered as degraded based on the GLADIS degradation classification medium to strong.	GLADiS
Drainage	The percentage area of a county that is drained.	HydroSHEDS shp
Intensive Farming	The water footprint of farm animals and animal products in 2010 per county.	Waterfootprint.org for crop products
Population Density	Total population density in 2013.	UK census data 2013
Population Change	The change in population number between 2010 and 2013.	UK census data 2010-2013
Tourists	The tourist density in 2013.	VisitBritain Statistics
Vehicles	The change of average journey time (flow-weighted) during the weekday morning peak on locally managed 'A' roads in minutes per mile from between 2006-2013.	UK government transport statistics.
Fish Stocks		No data-set available
Fishing Efforts	The average kilo per day catch of fish from 2011.	MMO Fishing Landings
River Water Quality	The river length that is considered to have a poor to bad river water quality based on the River Water Quality Assessment from 1990 to 2006.	Defra Statistics
Pesticides	The percentage of crop areas treated with pesticides and herbicides in 2013.	Defra Statistics
Air Quality	The annual average of PM2.5 in 2010.	Defra Air Quality Statistics
Carbon Emissions	The change in Carbon Emissions between 2005 and 2012 in kT CO2 per county.	DECC
Waste	The total amount of household waste produced per county in	UK government waste statistics

	2013/14.	
Waste Recycling	The total amount of household waste recycled per county in 2013/14.	UK government waste statistics
Electricity	The total consumption of electricity in kWh in 2007.	DECC statistics
Medicines and Chemicals		No data-set available
Infrastructure	The total road length per county area.	UK government transport statistics
Fossil Fuels	The total gas consumption in GWh in 2012.	DECC statistics
Biofuels	The total water footprint of biofuels in litres per litre biofuel for mayor crops.	Waterfootprint.org for biofuel crops
Excavation	The total number of wells and mines combined within a county.	BGS WMS
Groundwater	The percentage of area that is subject to low productivity aquifers.	BGS WMS
Trophic Level		No data-set available
Ecological Network	The percentage of area that is part of the ecological network extent.	Natural England
Land Cover Diversity	The number of land covers within a county.	Digimap Edina
Land Cover	The percentage area that is covered by forests within a county in 2007.	Digimap Edina
Land Cover Change	The change rate in forest cover from 2000 to 2007.	Digimap Edina
Coastal Settlement	The percentage area covered by urban areas which are within a 100 km distance from the coast.	Digimap Edina
Marine Reserves	The size of marine conservation zones that are within an 100 km distance of a counties' coast.	Natural England
Nature Reserves	The percentage area that is considered as national park, national/local nature reserve,	Natural England

	biosphere reserve or natural areas England.	

Table 17: Correlation result and justification.

Indicator 1	Indicator 2	R^2	Justification
Wind	**Temperature max**	-0.61	Fujibe (2009); Wooten (2011)
Temperature max	**Coast length**	-0.61	Ocean regulates the temperature with its' energy storing capacity
Temperature max	**Slides**	0.54	Xiong, Lu, Huang, & Wang (2014)
Temperature min	**Degradation**	0.63	Sivakumar & Ndiang'ui (2007)
Temperature min	**Drainage**	0.52	
Temperature min	**Waste Recycling**	0.52	
Phenology	**SST**	0.64	Dijkstra, Westerman, & Harris (2011); Jaagus & Ahas (2000)
Phenology	**Relief**	0.59	Guyon et al. (2011)
SST	**Econetwork**	0.54	
Coast length	**Fishing Effort**	0.53	Bigger emphasis of fishing in areas with a long coastline
Coast length	**Marine Reserves**	0.72	Longer coastline increases the probability of having a marine reserve
Lowlands	**Tourists**	0.78	
Lowlands	**Land Cover Diversity**	0.64	
Soils	**Degradation**	0.60	Montanarella (2007; Sakurai et al. (1996)
Soils	**Population Density**	0.70	Soil properties were important for first settlements
Soils	**Tourists**	0.70	Population and tourists are highly related
Soils	**Vehicles**	0.58	Vehicles are highly related to population
Soils	**Pesticides**	0.68	Application of pesticides depends on soil
Soils	**Waste Recycling**	0.51	
Soils	**Infrastructure**	0.72	

Soils	**Land Cover Diversity**	0.72	The soil defines the land cover
Soils	**Land Cover Change**	0.50	Korkanc, Ozyuvaci, & Hizal (2008)
Endangered Species	**Tourists**	0.80	Bridges & Oldeman (1999); Montanarella (2007)
Degradation	**Population Density**	0.67	Bridges & Oldeman (1999); Montanarella (2007)
Degradation	**Tourists**	0.59	Bridges & Oldeman (1999); Montanarella (2007)
Degradation	**Vehicles**	0.55	Bridges & Oldeman (1999); Montanarella (2007)
Degradation	**Carbon Emissions**	0.51	Bridges & Oldeman (1999); Montanarella (2007)
Degradation	**Land Cover Diversity**	0.60	Bridges & Oldeman (1999); Montanarella (2007)
Degradation	**Infrastructure**	0.74	Montanarella (2007)
Degradation	**Coastal Settlements**	0.50	Bridges & Oldeman (1999); Montanarella (2007)
Intensive Farming	**River Water Quality**	0.53	
Intensive Farming	**Biofuels**	0.85	Similar data-set; both based on water footprint
Intensive Farming	**Econetwork**	0.51	
Population Density	**Tourists**	0.55	Tourism Alliance (2014); city tourism, 44% of tourists visit cities and towns
Population Density	**Vehicles**	0.61	The more people the more vehicles
Population Density	**Carbon Emissions**	0.54	Liddle (2014); Svirejeva-Hopkins & Schellnhuber (2008)
Population Density	**Infrastructure**	0.97	Balmforth, McManus, & Fowler (2005)
Population	**Land Cover**	0.54	

Density	**Diversity**		
Population Density	**Coastal Settlements**	0.52	CIESIN (2007); Hinrichsen (1998)
Population Change	**Tourists**	0.51	
Tourists	**Vehicles**	0.52	Tourism Alliance (2014)
Tourists	**River Water Quality**	0.99	More people exert more stress on rivers
Tourists	**Pesticides**	0.79	
Tourists	**Electricity**	0.56	Tourism Alliance (2014); the more people the higher the electricity consumption
Tourists	**Land Cover Diversity**	0.79	
Vehicles	**Infrastructure**	0.64	The more vehicles the bigger the stress on roads and the more roads have to be built
Vehicles	**Land Cover Diversity**	0.58	
Fishing Efforts	**Marine Reserves**	0.53	Defra (2013b)
River Water Quality	**Electricity**	0.98	
Pesticides	**Land Cover Diversity**	0.53	
Air Quality	**Biofuels**	0.55	
Carbon Emissions	**Infrastructure**	0.59	Transport is a big contributor to the carbon emissions
Waste	**Waste Recycling**	0.79	Directly related as the amount of waste produced influences the possible amount of waste recycled
Waste Recycling	**Land Cover Diversity**	0.52	
Infrastructure	**Land Cover Diversity**	0.58	
Infrastructure	**Coastal Settlement**	0.62	
Biofuels	**Econetwork**	0.74	
Econetwork	**Land Cover**	0.78	Parliamentary Office of Science and Technology

Intensive Farming	**Nature Reserves**	0.66	(POST) (2008) Intensive farming prevents the foundation of nature reserves

Table 18: EVIUKb result (rounded).

Rank	County/District	EVI_{UKc} Result
1	Bracknell Forest	0.270
2	Redcar and Cleveland	0.280
3	Tameside	0.294
4	South Gloucestershire	0.296
5	St. Helens	0.297
6	Rutland	0.298
7	Knowsley	0.299
8	Hartlepool	0.301
9	Gateshead	0.302
10	Darlington	0.305
11	Stockton-on-Tees	0.306
12	Sunderland	0.307
13	Wirral	0.311
14	Erewash	0.312
15	Bath and North East Somerset	0.312
16	Blackpool	0.313
17	North Somerset	0.314
18	Salford	0.315
19	Bolton	0.315
20	Rochdale	0.316
21	Rotherham	0.316
22	Blackburn with Darwen	0.316
23	Durham	0.317
24	Central Bredfordshire	0.318
25	South Tyneside	0.318
26	Calderdale	0.319
27	Halton	0.319
28	Newcastle upon Tyne	0.320
29	Derbyshire	0.323
30	Bury	0.323
31	Wokingham	0.324
32	Warrington	0.326
33	Worcestershire	0.326
34	Bradford	0.327
35	City of Southampton	0.329
36	Windsor and Maidenhead	0.329
37	Wigan	0.330

38	Cheshire West and Chester	0.331
39	Stockport	0.332
40	North East Lincolnshire	0.334
41	Middlesbrough	0.335
42	Sefton	0.336
43	Thurrock	0.337
44	Surrey	0.338
45	Oldham	0.339
46	Herefordshire	0.339
47	Leeds	0.340
48	Liverpool	0.340
49	Wakefield	0.341
50	Barnsley	0.342
51	Luton	0.344
52	Shropshire	0.344
53	Poole	0.344
54	Coventry	0.345
55	City of Stoke-on-Trent	0.345
56	York	0.346
57	Kirklees	0.347
58	Medway	0.347
59	Trafford	0.348
60	East Riding of Yorkshire	0.348
61	Northumberland	0.349
62	North Tyneside	0.349
63	West Sussex	0.350
64	Sheffield	0.350
65	Isle of Wight	0.350
66	West Berkshire	0.351
67	Bournemouth	0.352
68	Dudley	0.352
69	City of Nottingham	0.352
70	Telford and Wrekin	0.353
71	Norfolk	0.354
72	The City of Brighton and Hull	0.357
73	Somerset	0.358
74	City of Kingston upon Hull	0.358
75	City of Bristol	0.358
76	City of Wolverhampton	0.360
77	Walsall	0.361
78	Torbay	0.361
79	Manchester	0.362
80	Leicestershire	0.363
81	Wiltshire	0.365
82	Gloucestershire	0.365

83	Staffordshire	0.365
84	Hertfordshire	0.366
85	Cambridgeshire	0.367
86	North Lincolnshire	0.369
87	Reading	0.369
88	Suffolk	0.369
89	Cumbria	0.371
90	Doncaster	0.371
91	City of Derby	0.373
92	East Sussex	0.375
93	Isles of Scilly	0.376
94	Southend-on-Sea	0.377
95	Solihull	0.377
96	Warwickshire	0.379
97	Buckinghamshire	0.380
98	City of Leicester	0.380
99	Northamptonshire	0.381
100	City of Portsmouth	0.381
101	Swindon	0.384
102	Nottinghamshire	0.384
103	Bedford	0.385
104	Cheshire East	0.386
105	City of Plymouth	0.387
106	Milton Keynes	0.393
107	Lincolnshire	0.394
108	Lancashire	0.396
109	Oxfordshire	0.398
110	Birmingham	0.40
111	Devon	0.401
112	Sandwell	0.401
113	North Yorkshire	0.409
114	Slough	0.409
115	Dorset	0.419
116	Cornwall	0.420
117	City of Peterborough	0.421
118	Kent	0.427
119	Essex	0.429
120	Hampshire	0.440
121	Greater London Authority	0.447

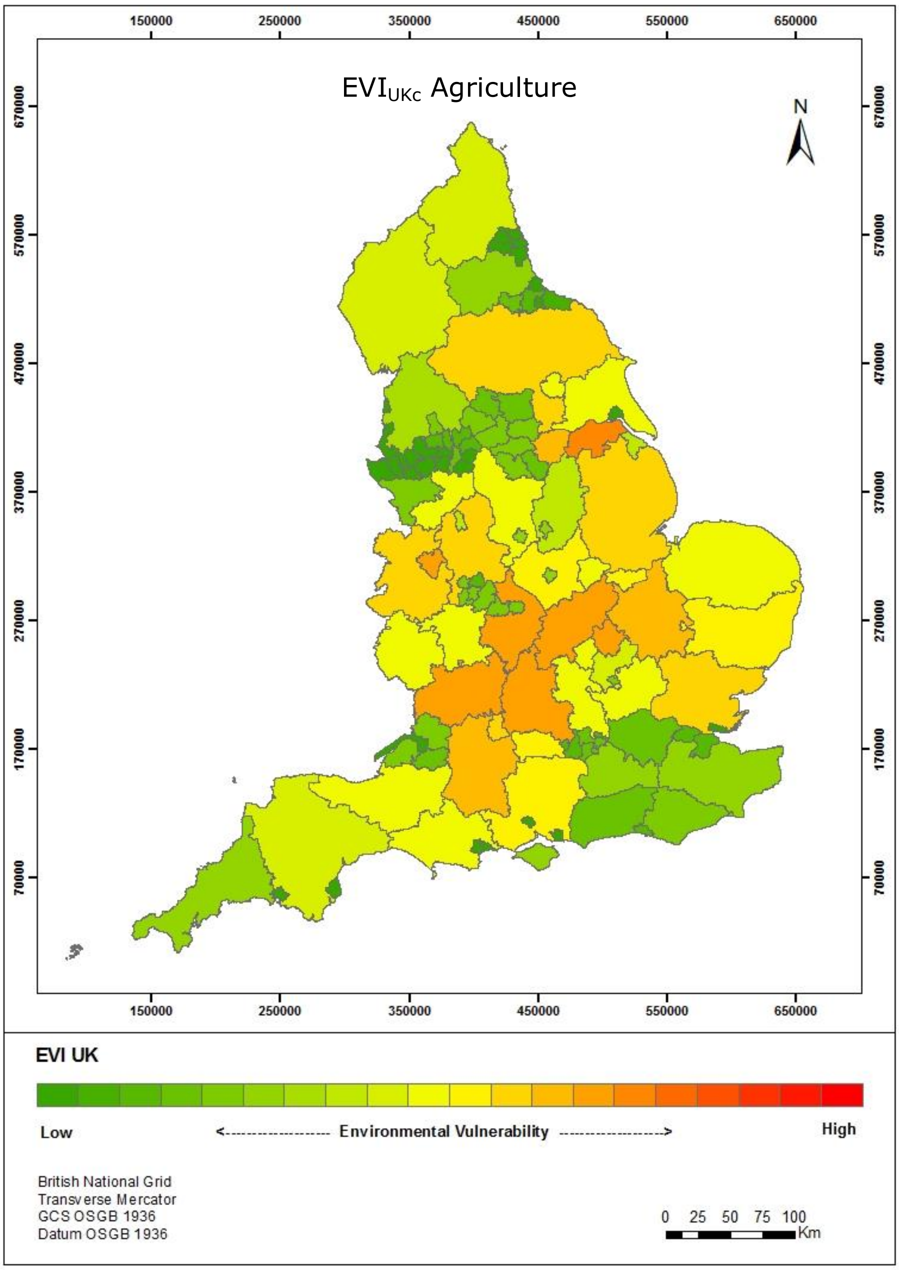

Figure 16: EVI_{UKc} Agriculture result.

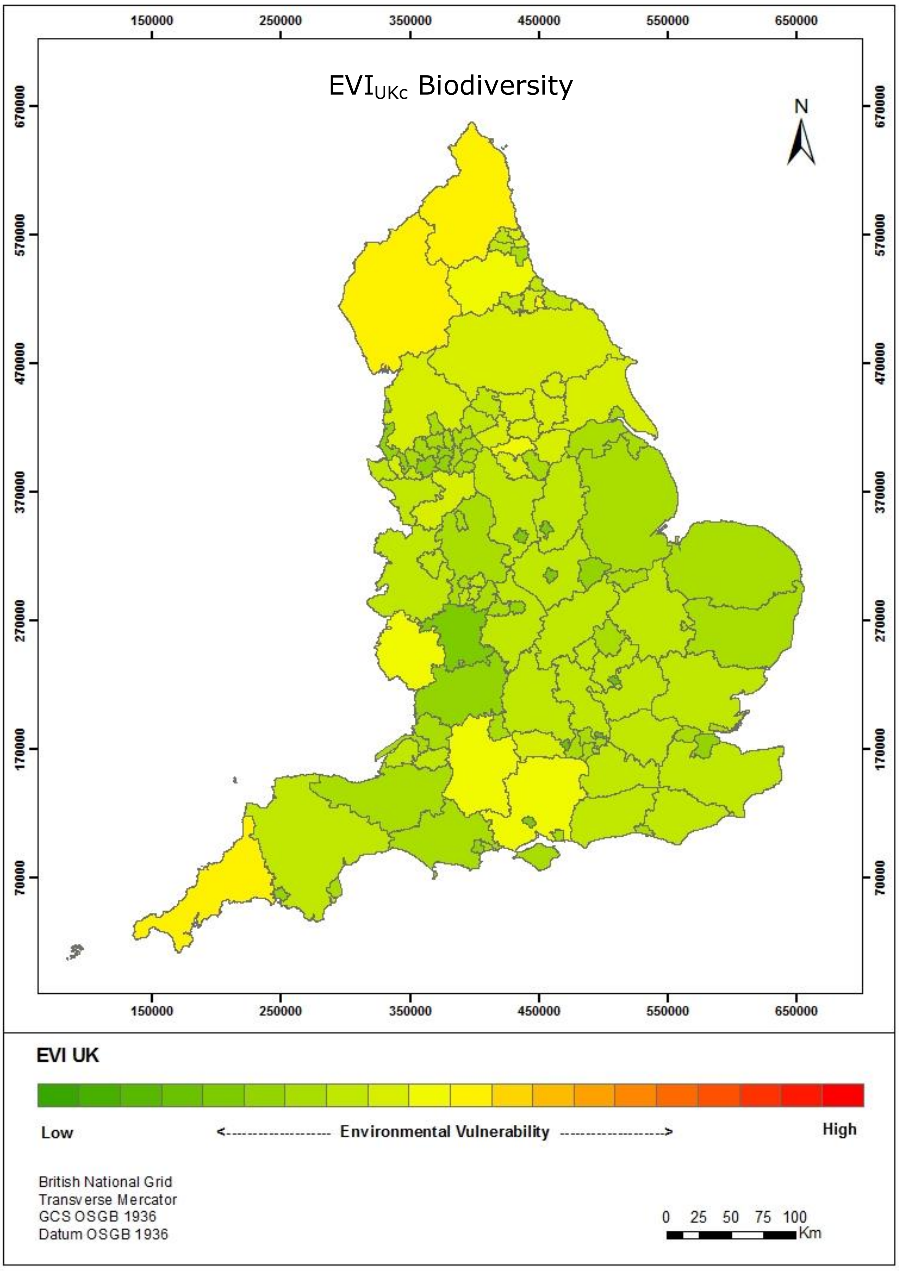

Figure 17: EVI$_{UKc}$ Biodiversity result.

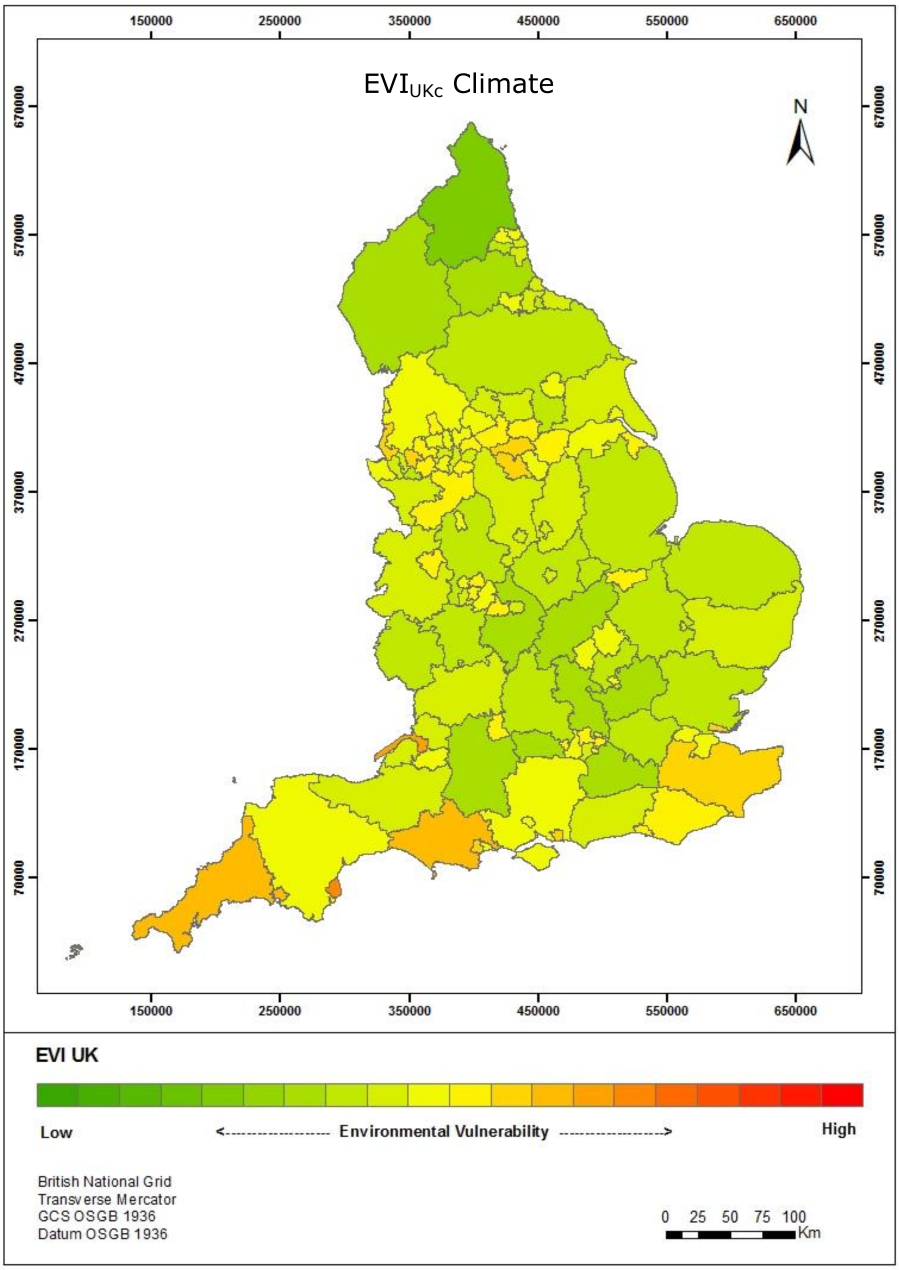

Figure 18: EVI$_{UKc}$ Climate result.

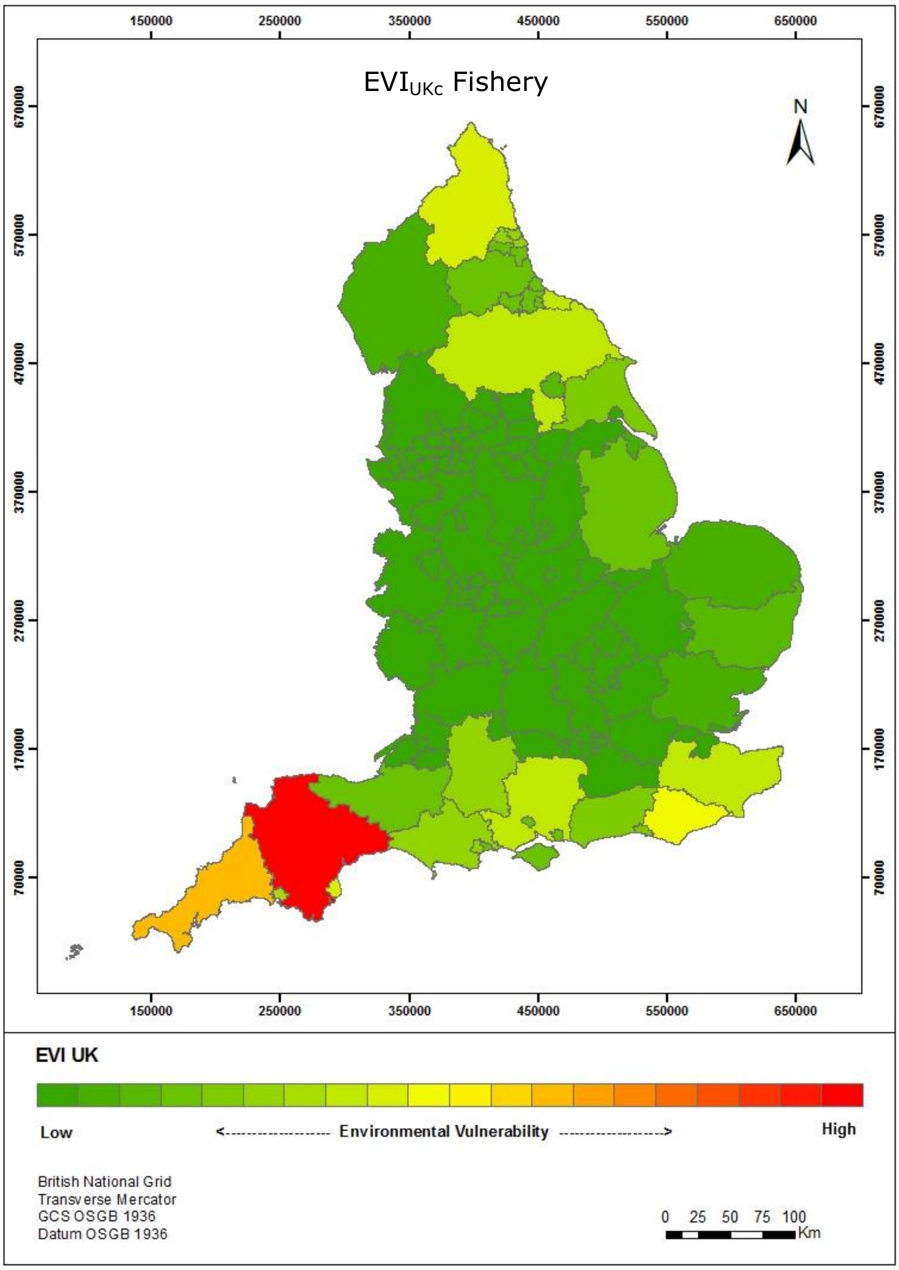

Figure 19: EVI$_{UKc}$ Fishery result.

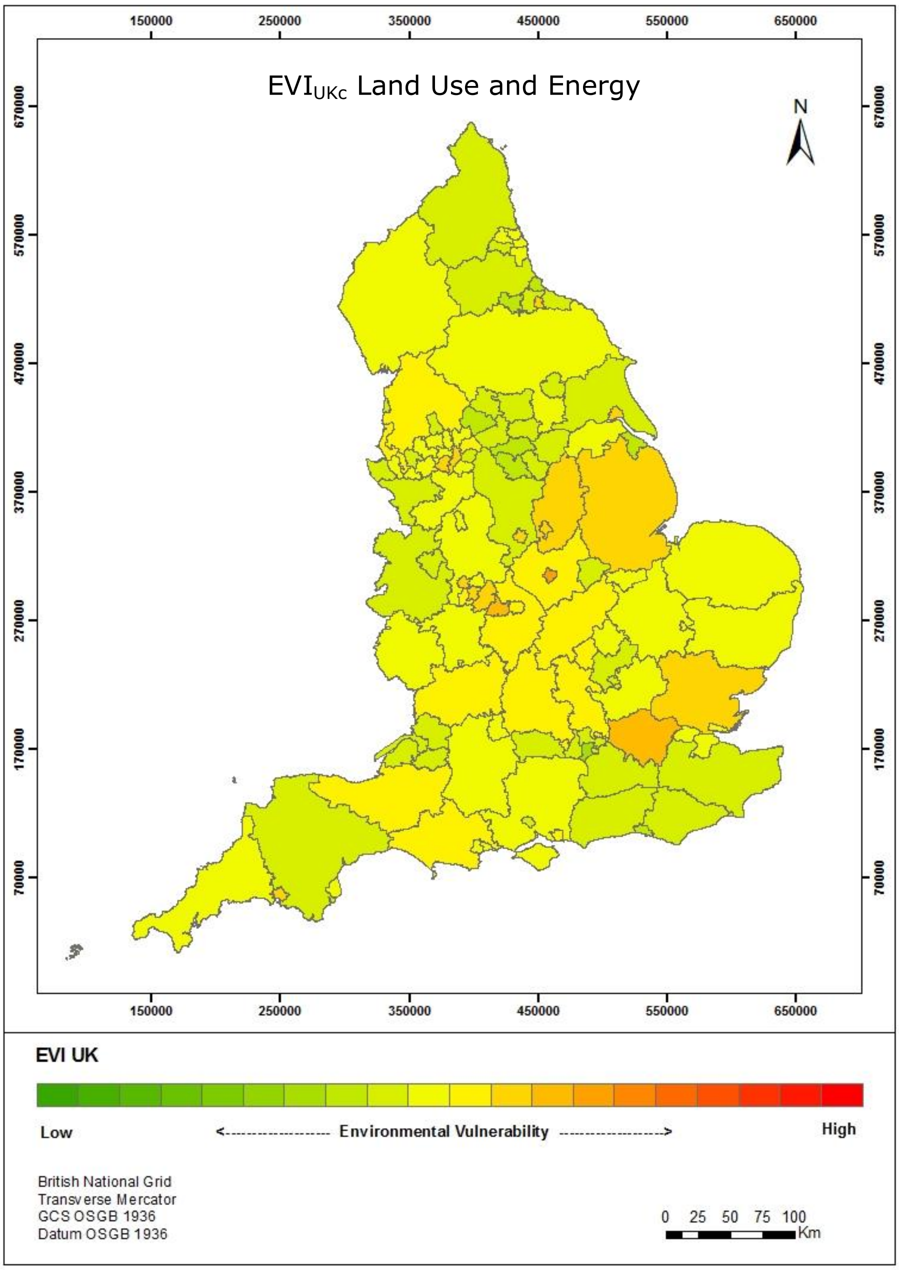

Figure 20: EVI$_{UKc}$ Land Use and Energy result.

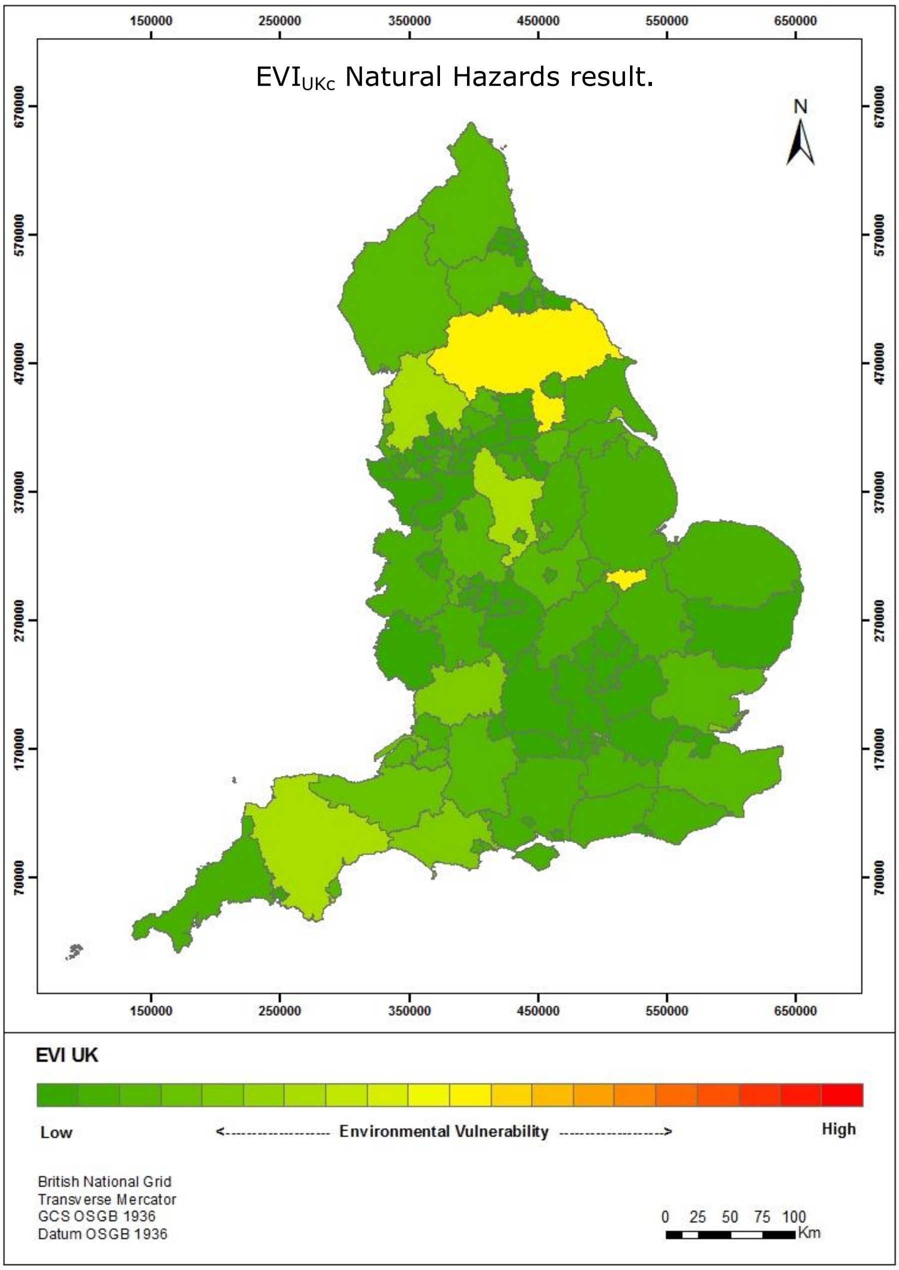

Figure 21: EVI$_{UKc}$ Natural Hazards result.

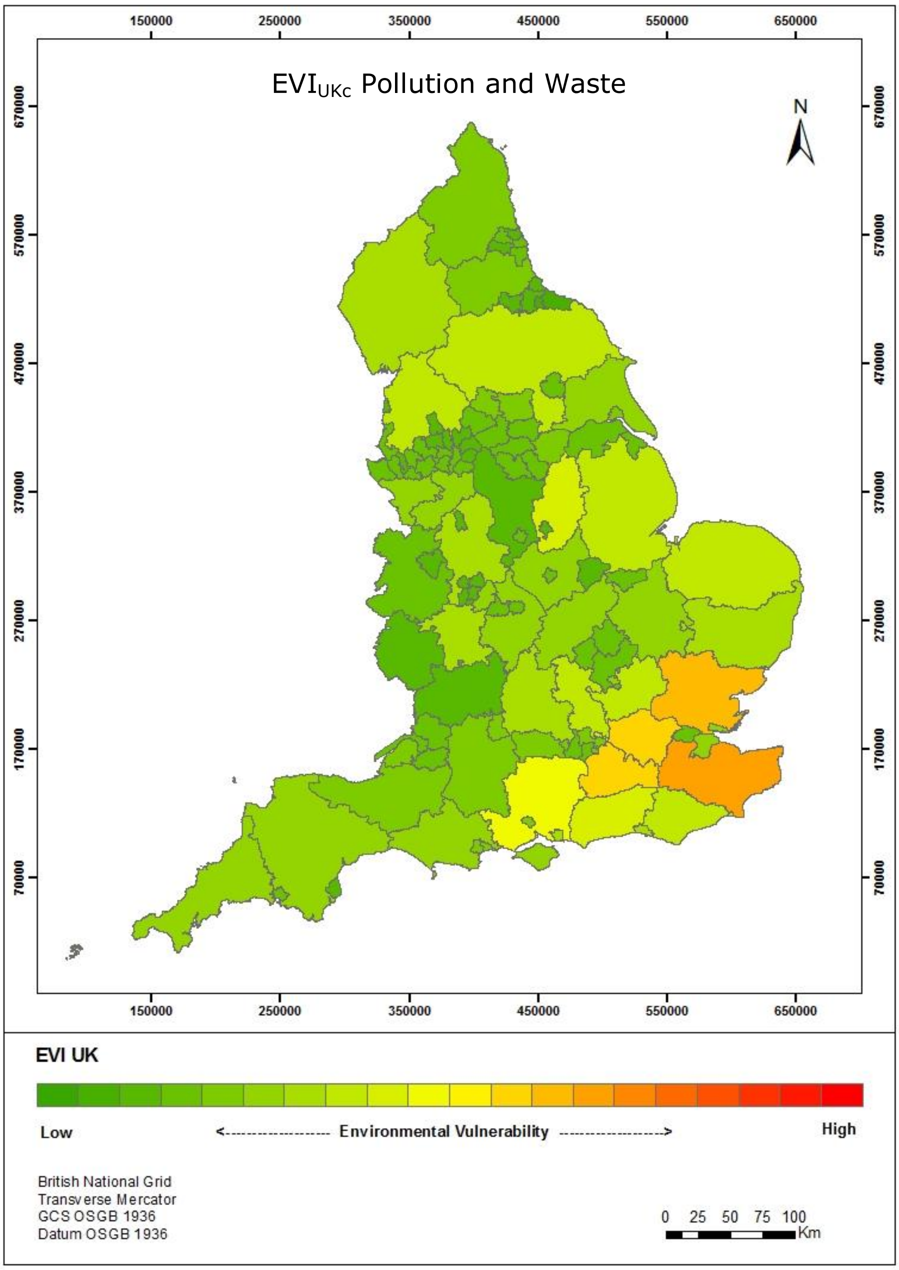

Figure 22: EVI$_{UKc}$ Pollution and Waste result.

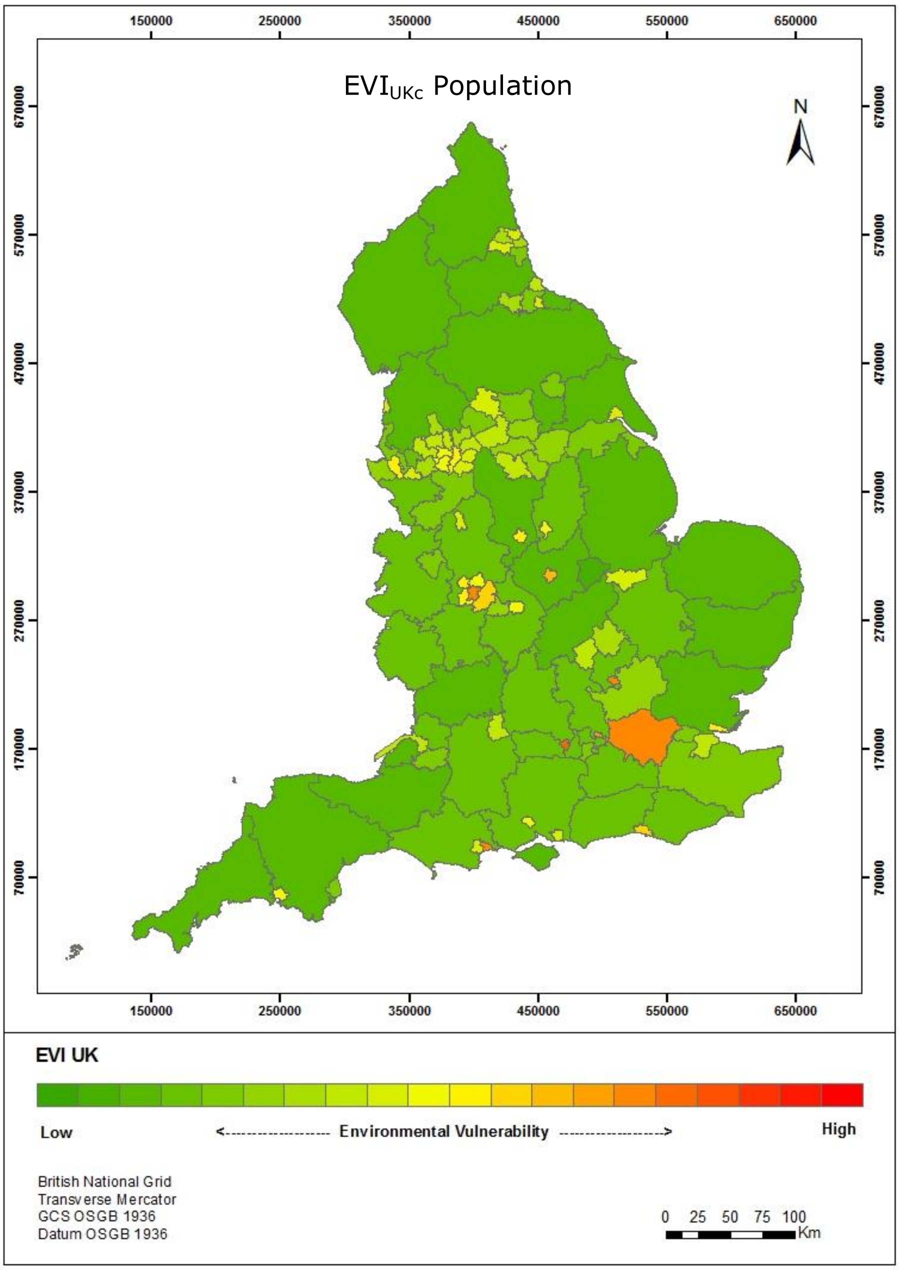

Figure 23: EVI$_{UKc}$ Population result.

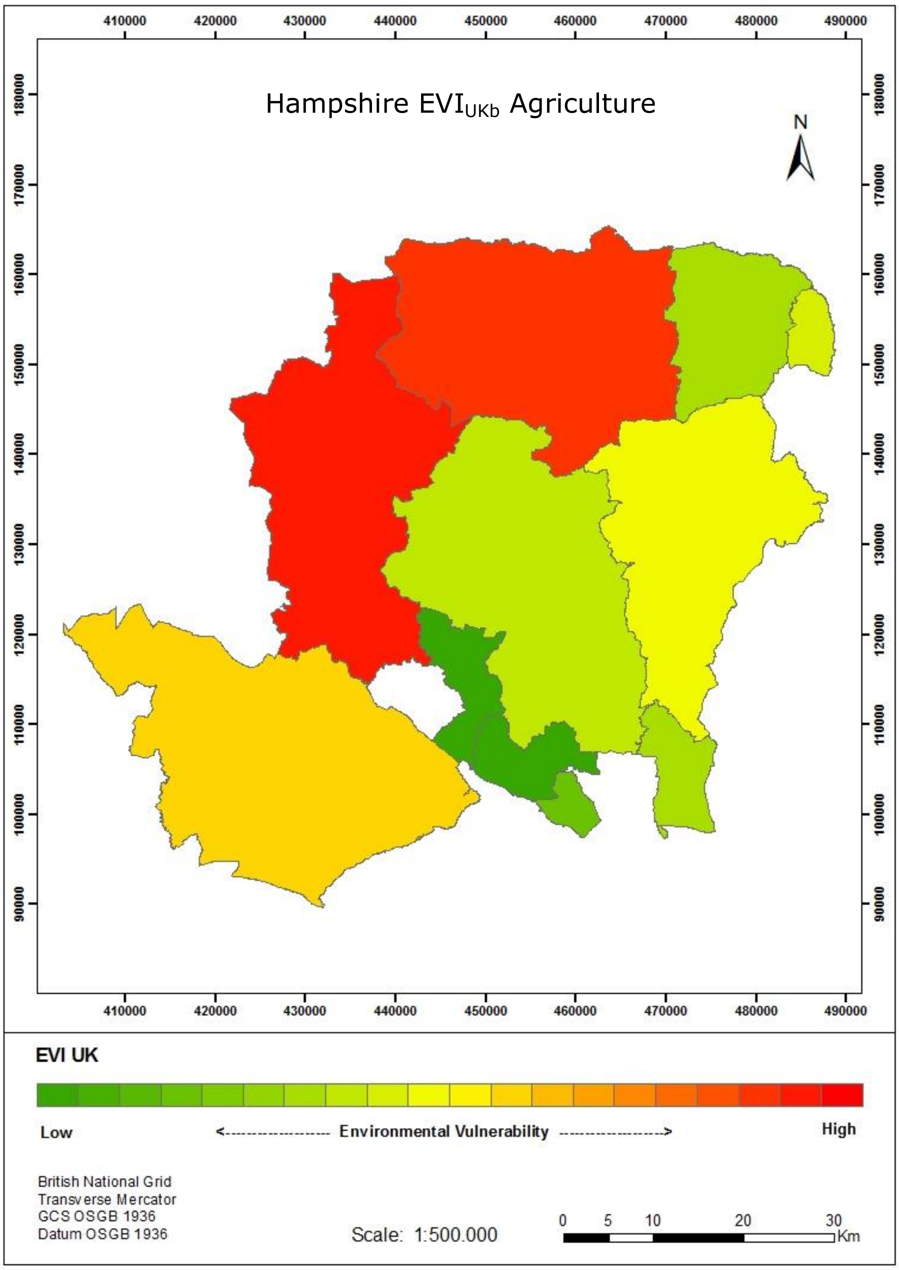

Figure 24: Hampshire EVI_{UKb} Agriculture result.

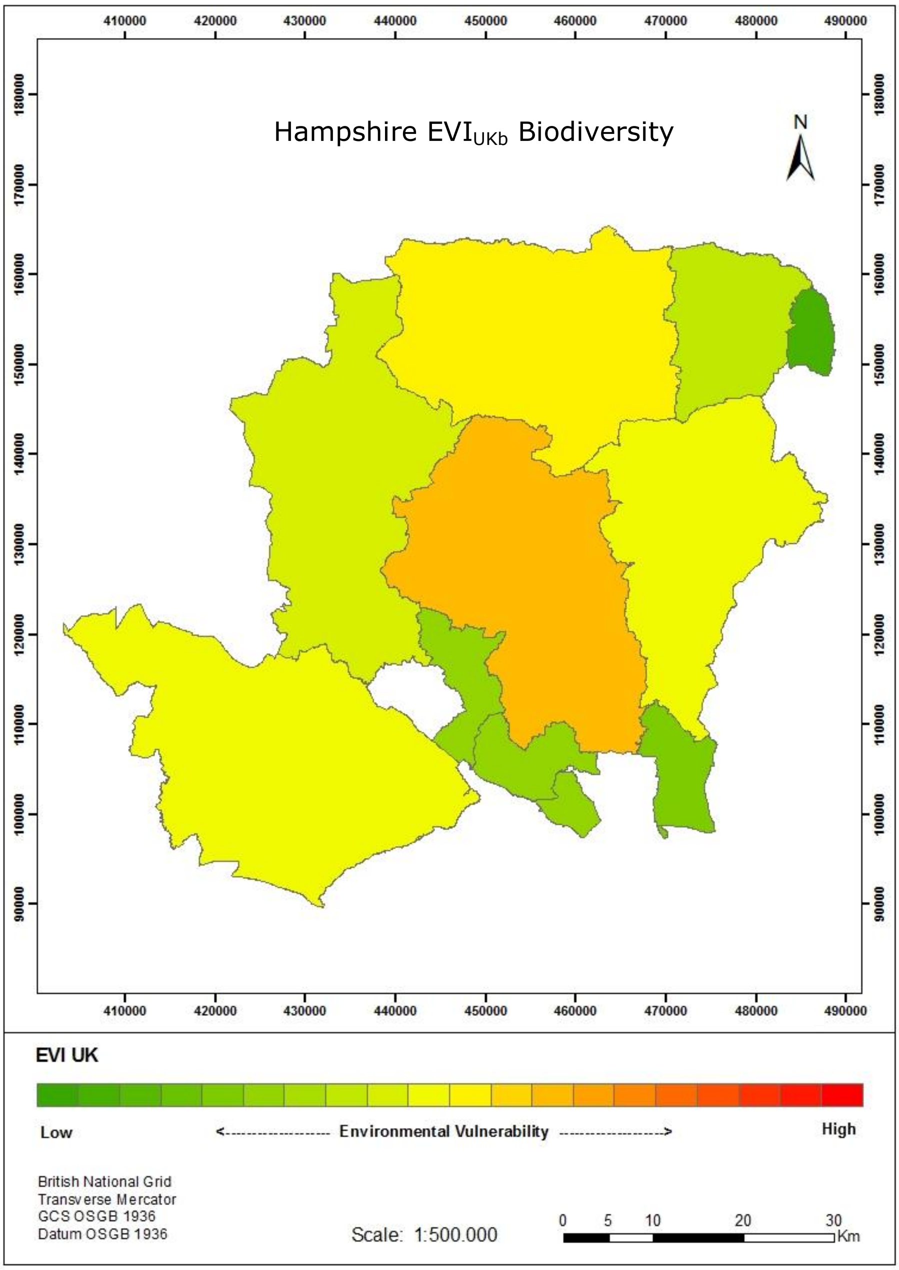

Figure 25: Hampshire EVI_{UKb} Biodiversity result.

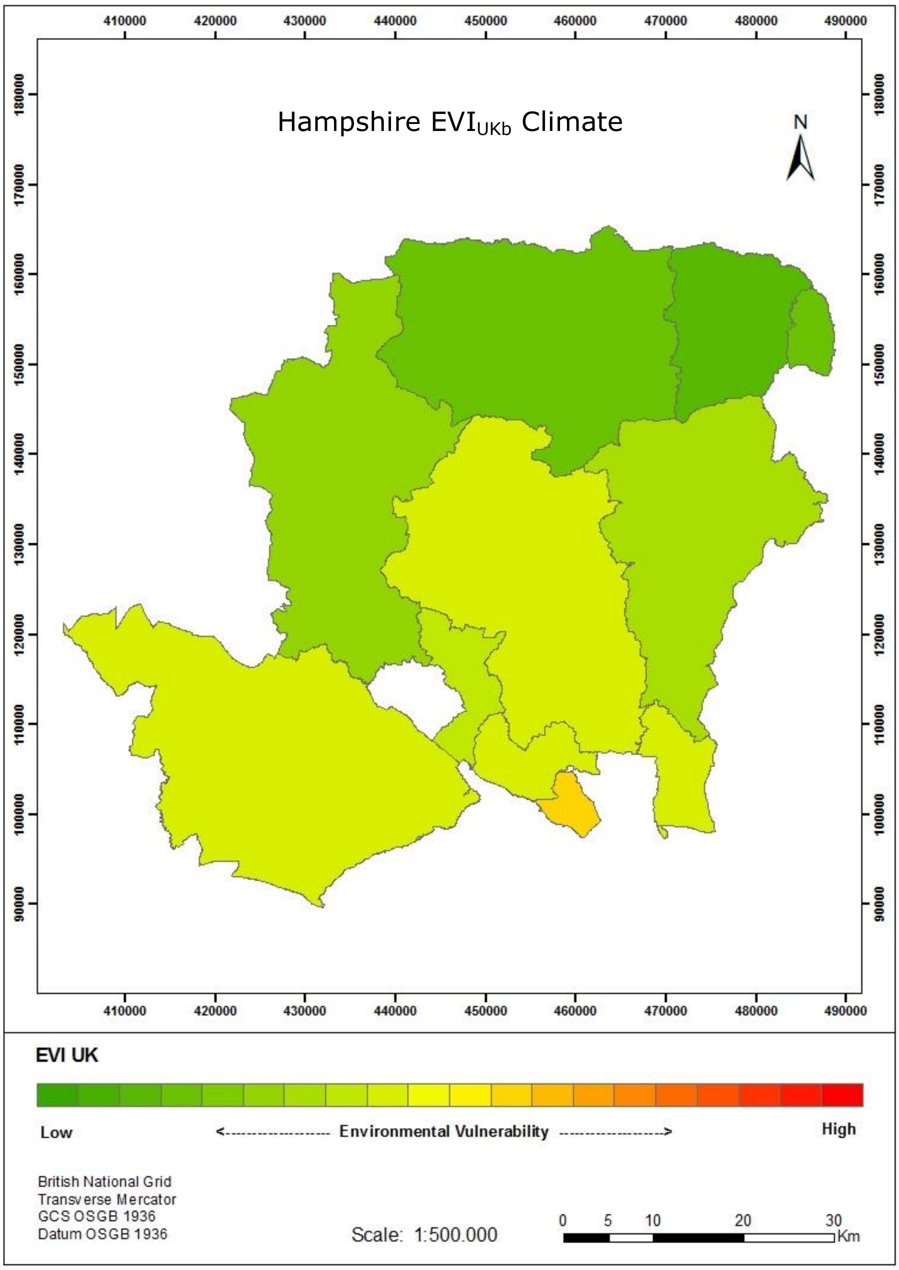

Figure 26: Hampshire EVI_{UKb} Climate result.

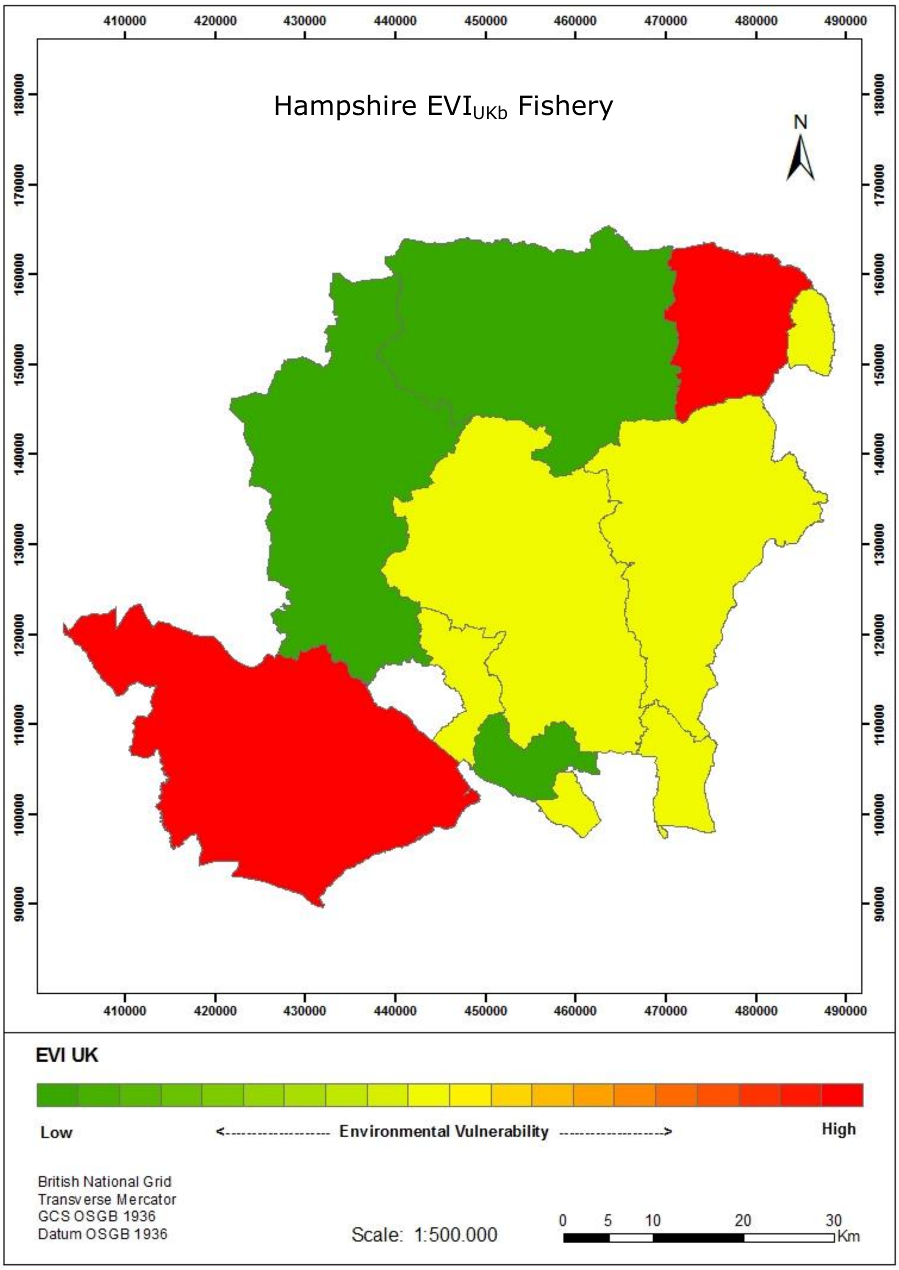

Figure 27: Hampshire EVI_{UKb} Fishery result.

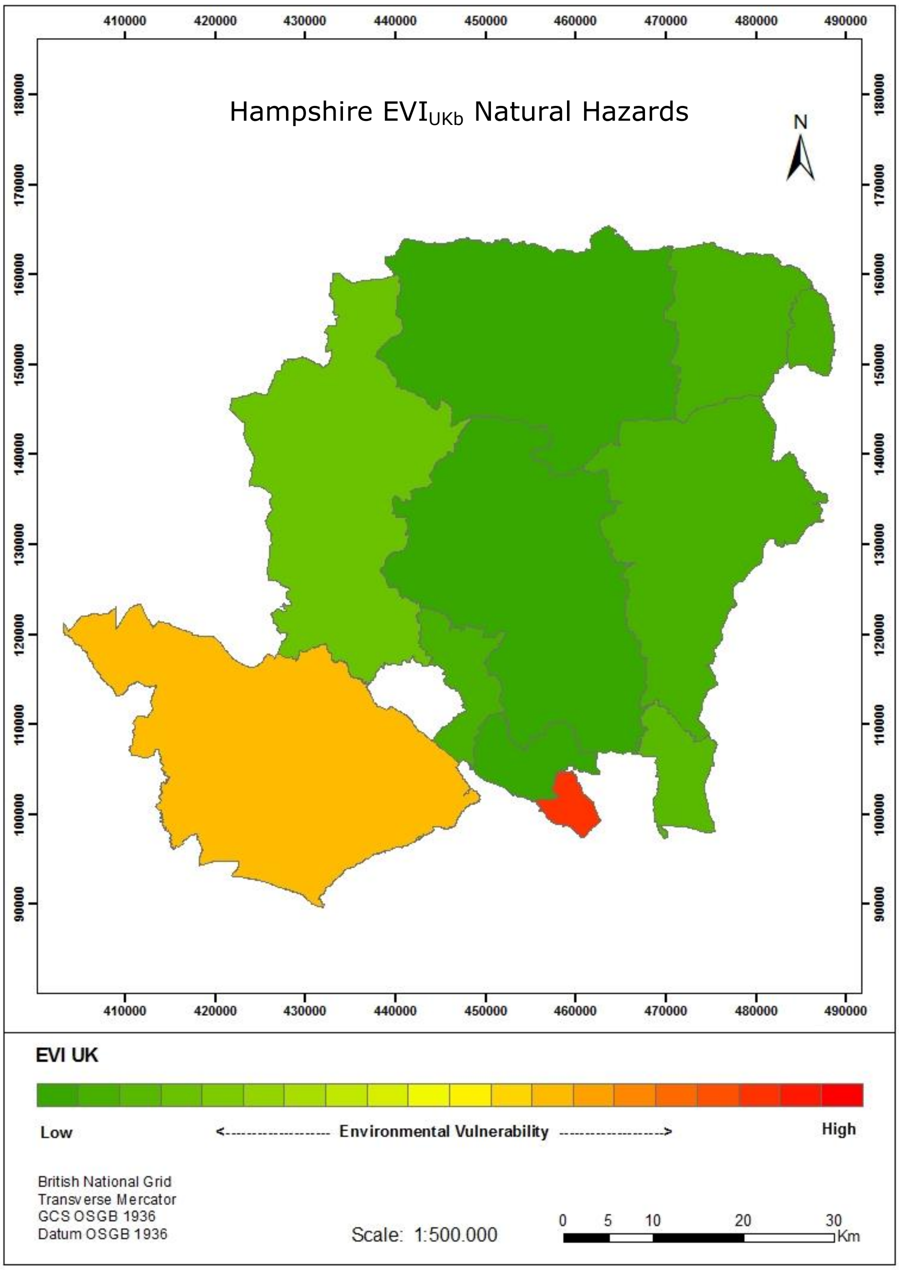

Figure 28: Hampshire EVI_{UKb} Natural Hazards result.

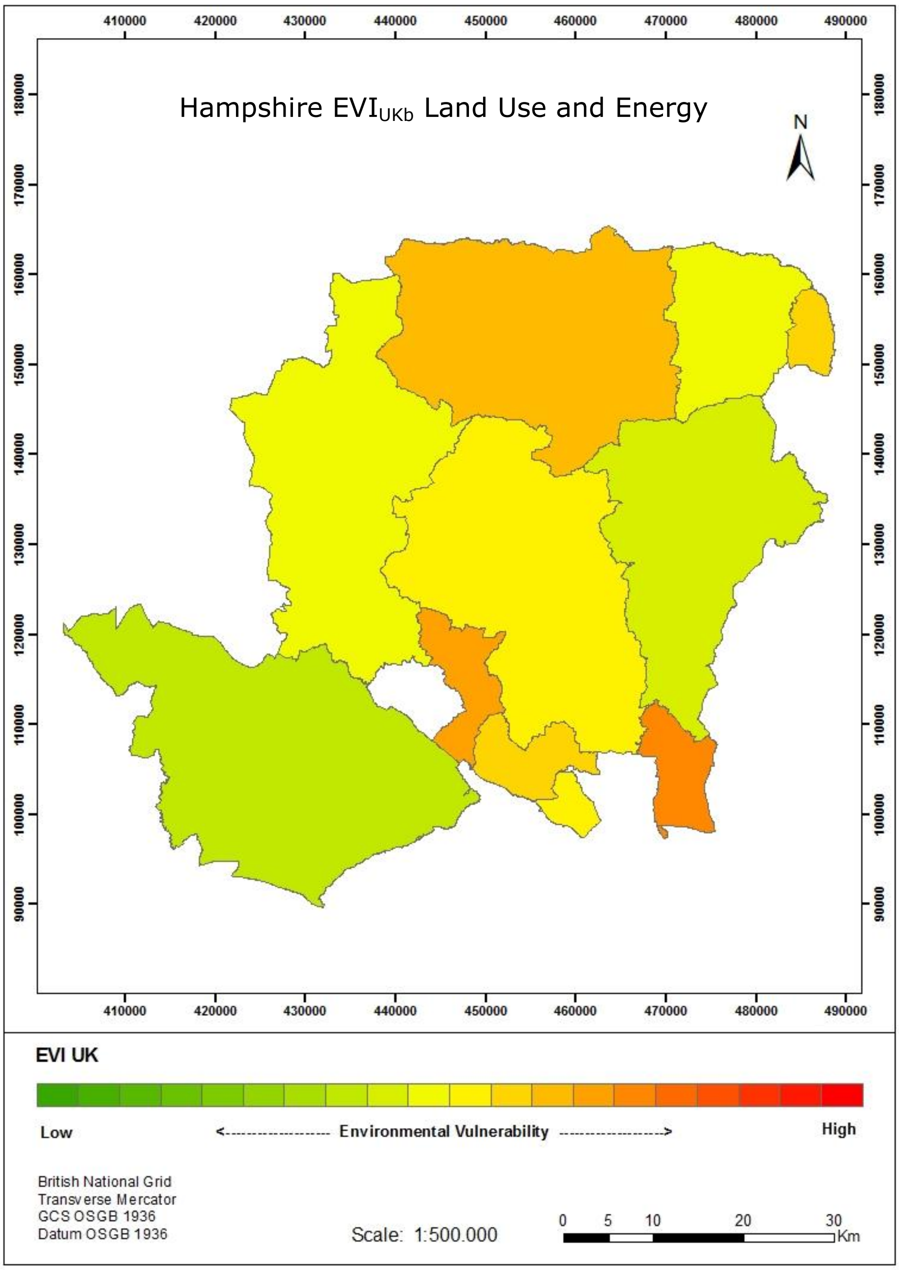

Figure 29: Hampshire EVI_{UKb} Land Use and Energy result.

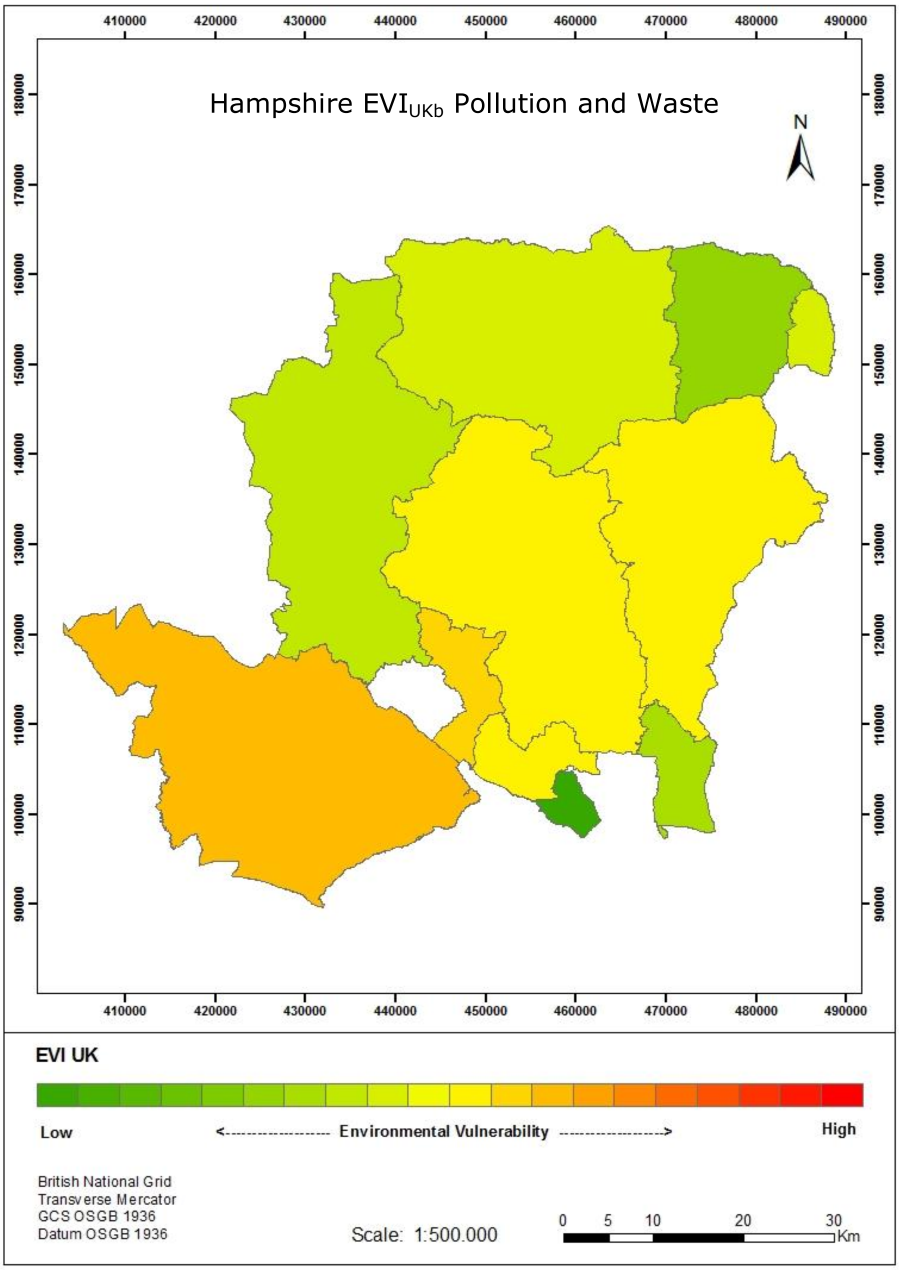

Figure 30: Hampshire EVI_{UKb} Pollution and Waste result.

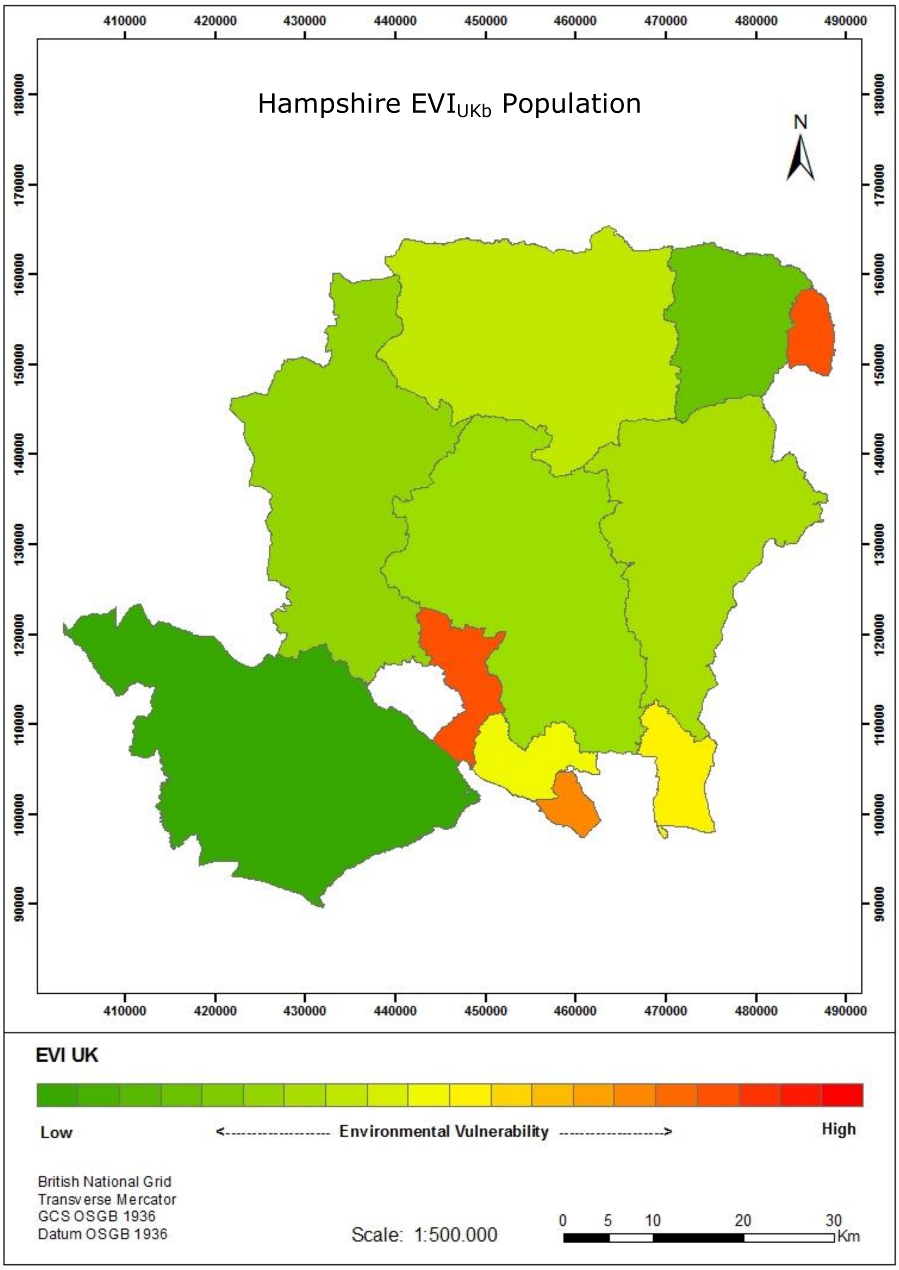

Figure 31: Hampshire EVI_{UKb} Population result.

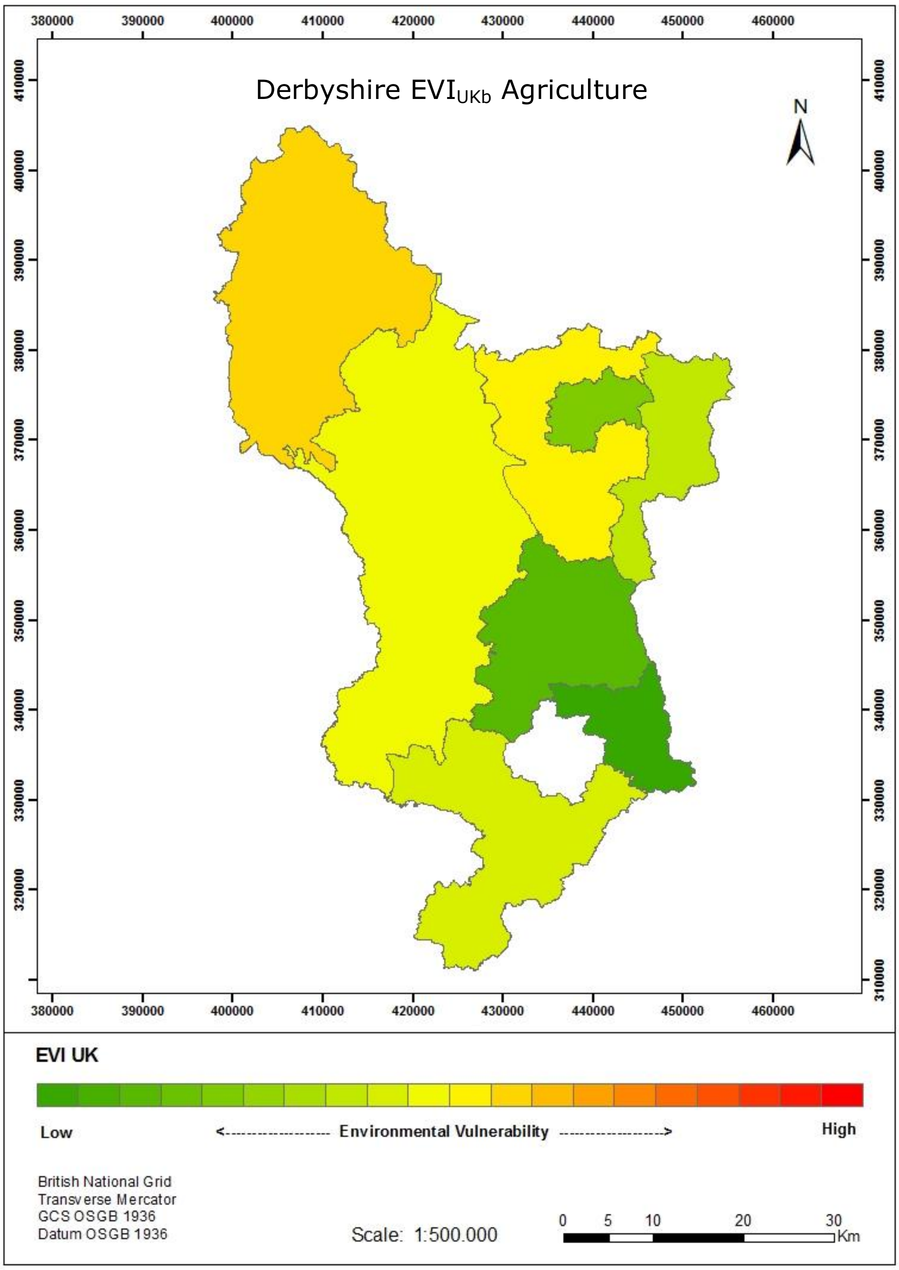

Figure 32: Derbyshire EVI_{UKb} Agriculture result.

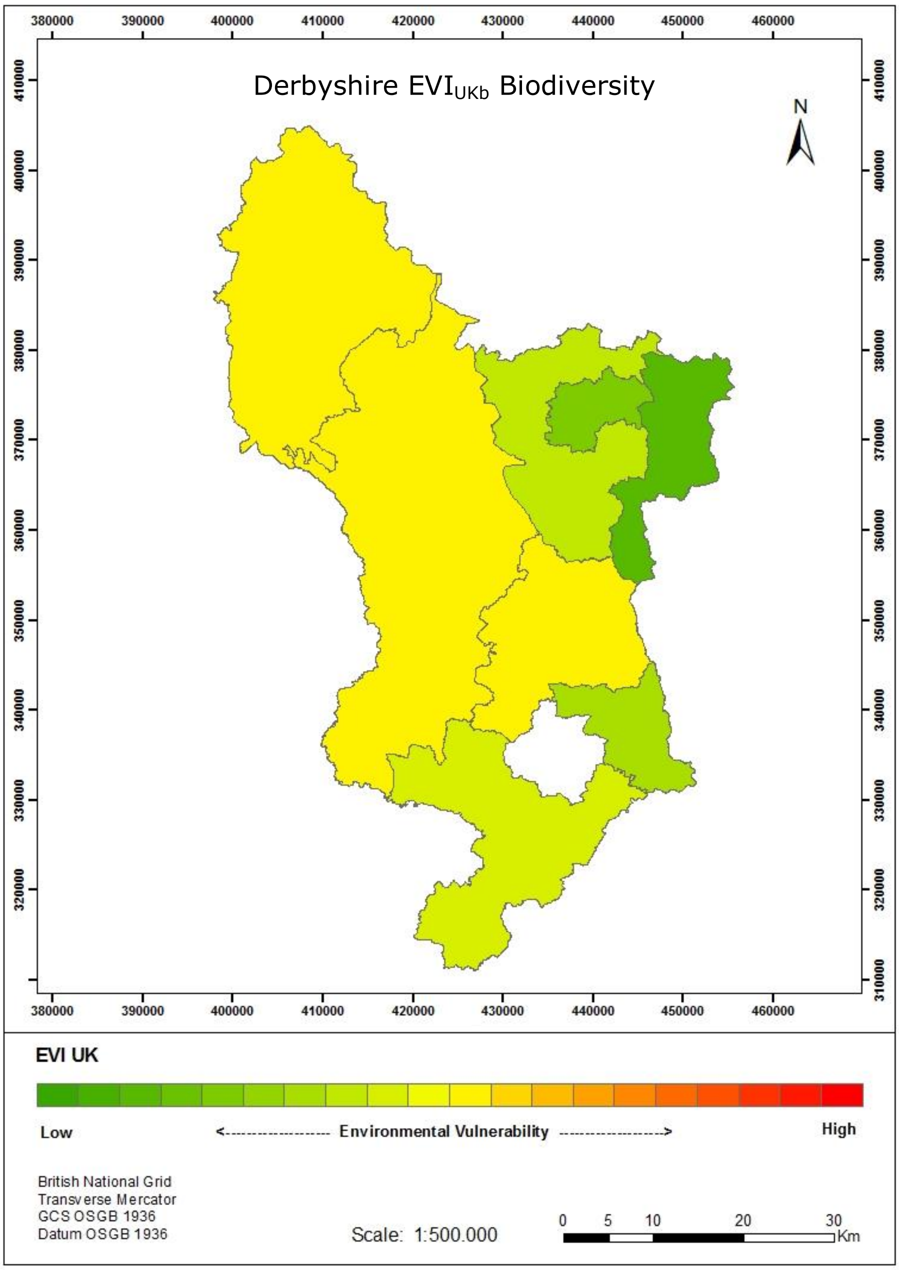

Figure 33: Derbyshire EVI_{UKb} Biodiversity result.

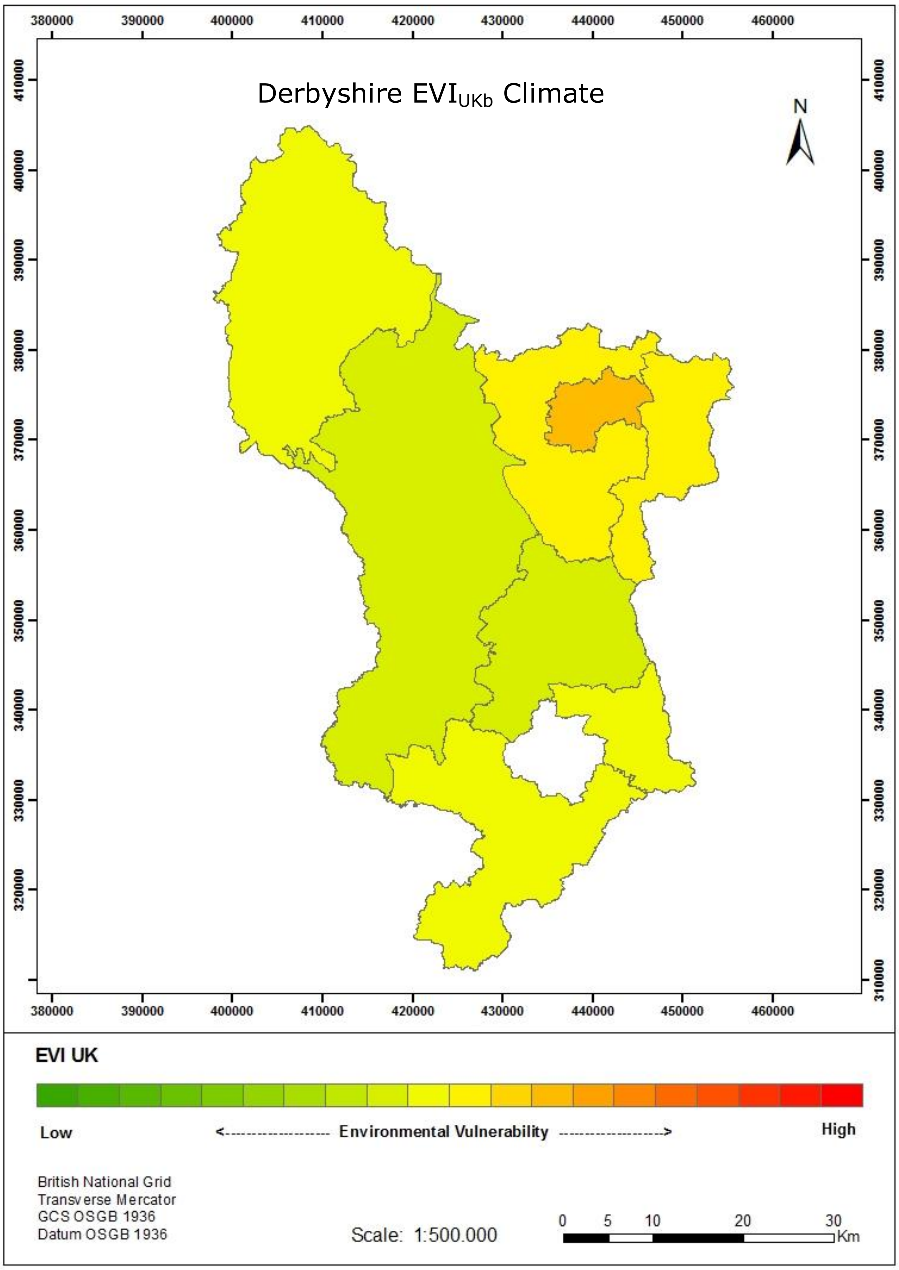

Figure 34: Derbyshire EVI_{UKb} Climate result.

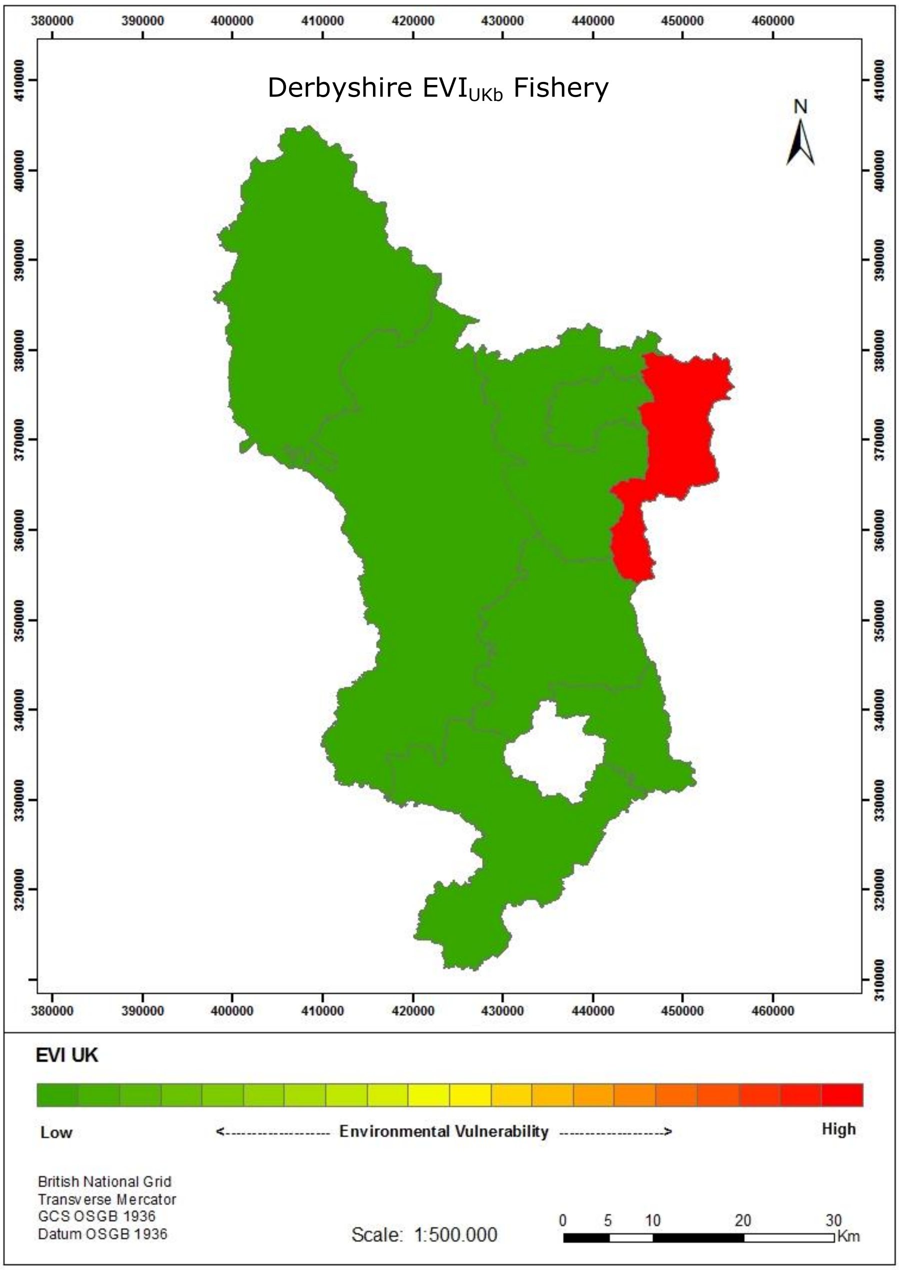

Figure 35: Derbyshire EVI_{UKb} Fishery result.

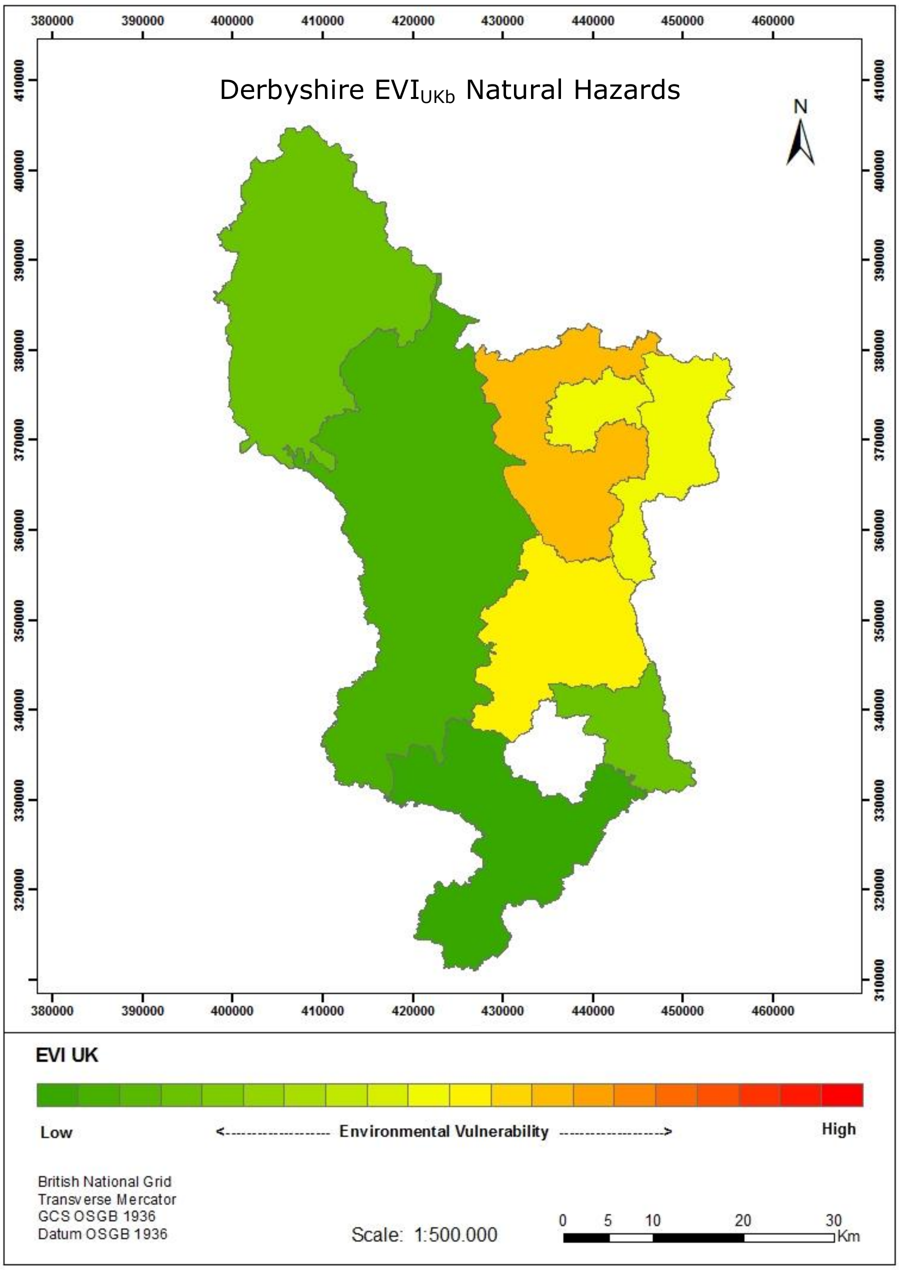

Figure 36: Derbyshire EVI_{UKb} Natural Hazards result.

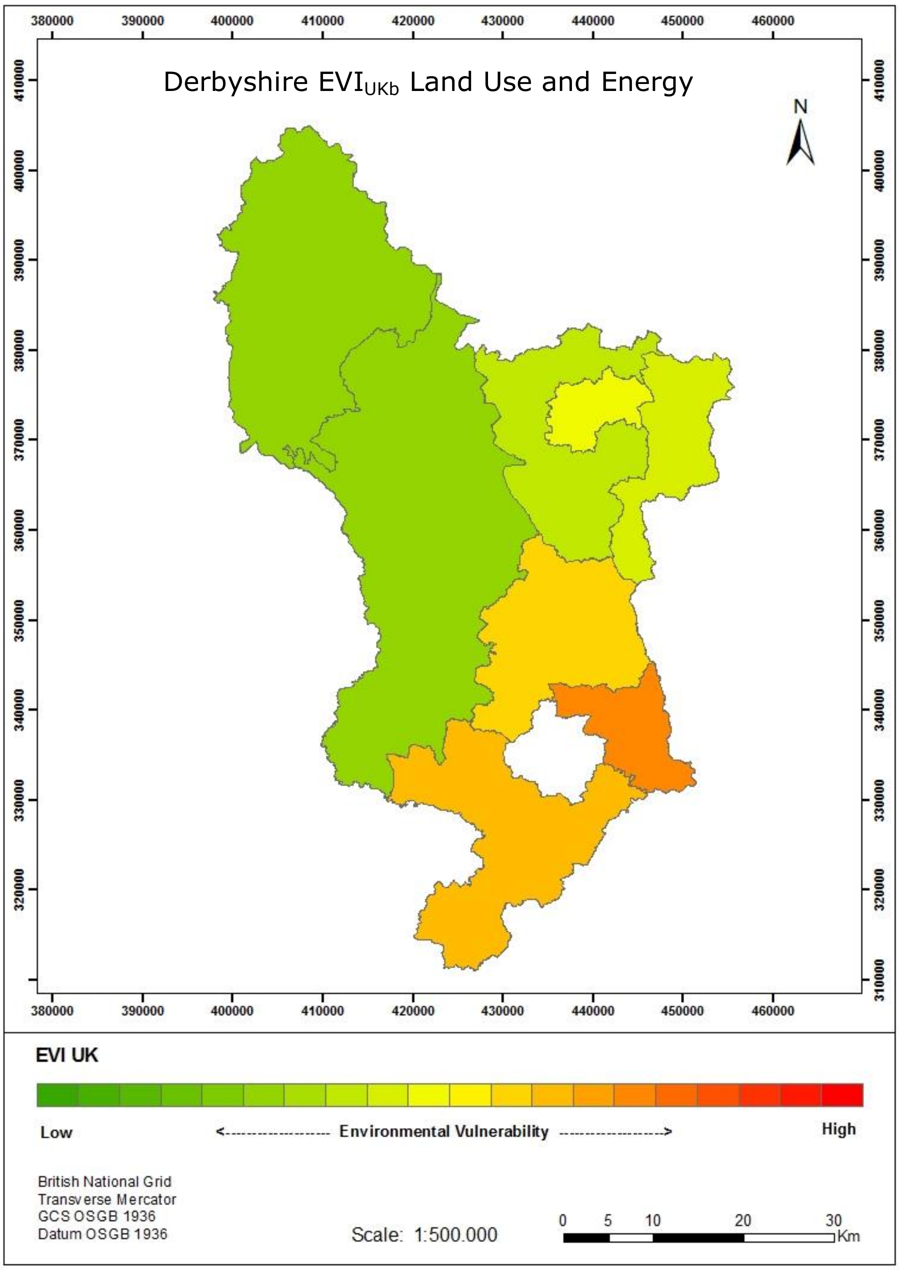

Figure 37: Derbyshire EVI_{UKb} Land Use and Energy result.

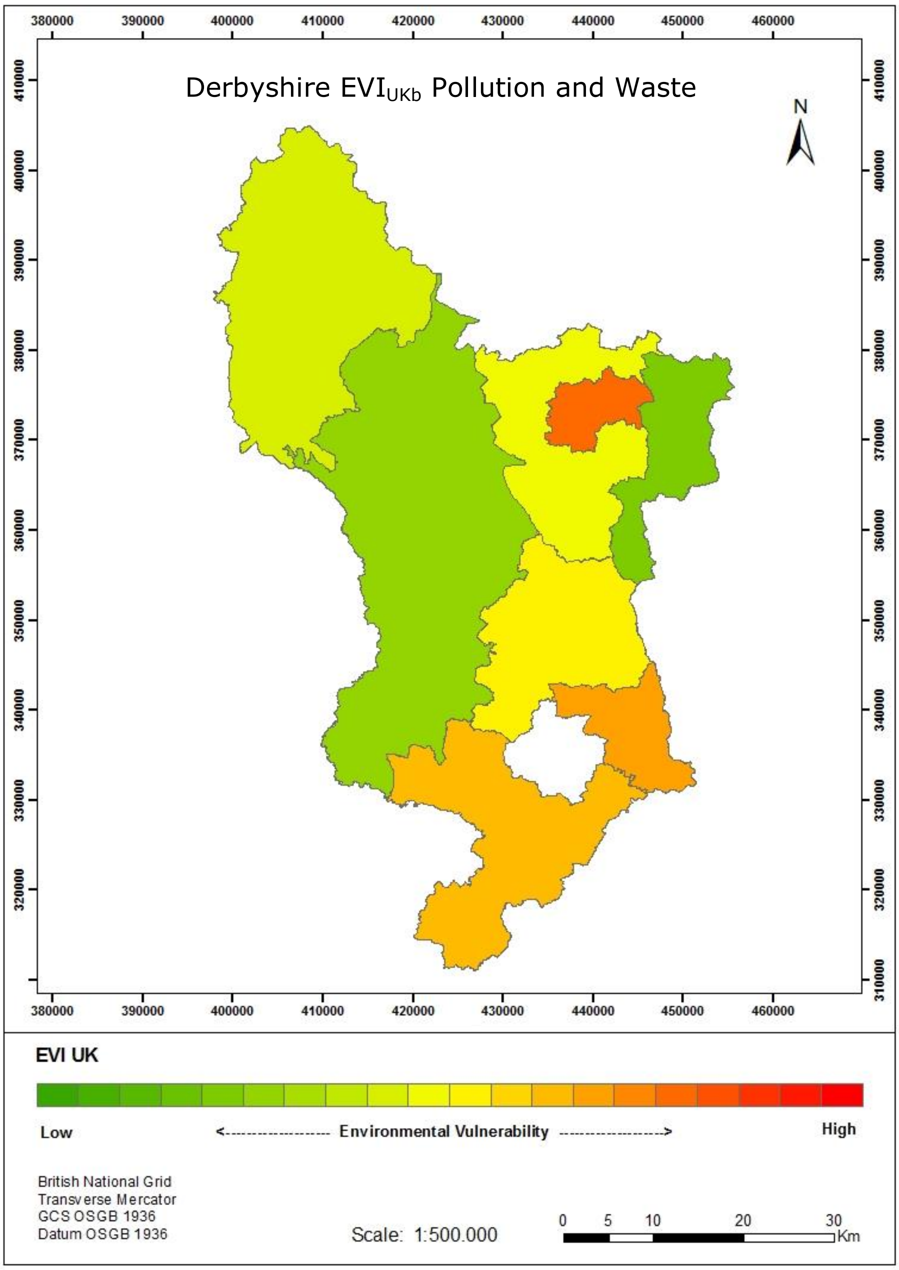

Figure 38: Derbyshire EVI$_{UKb}$ Pollution and Waste result.

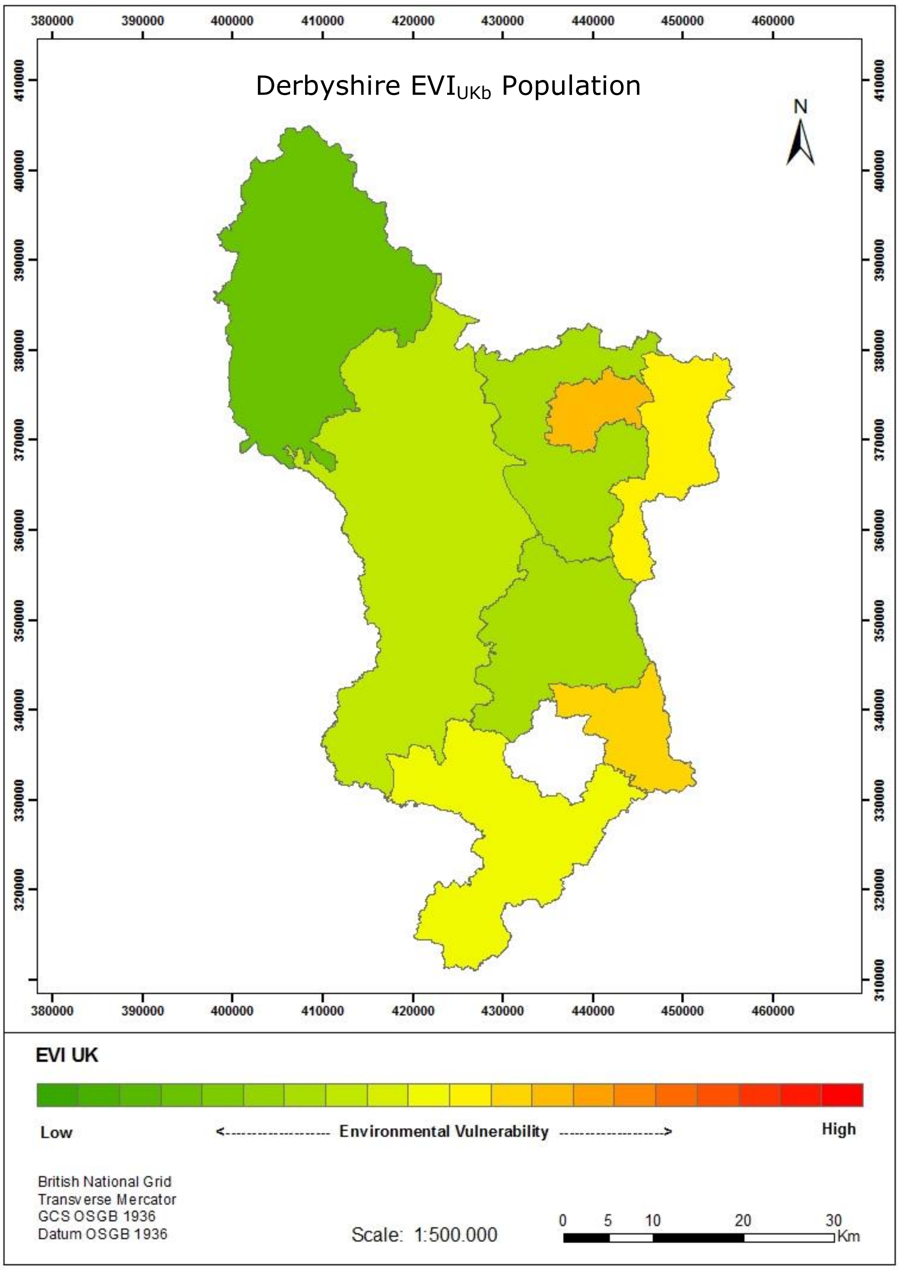

Figure 39: Derbyshire EVI_{UKb} Population result.

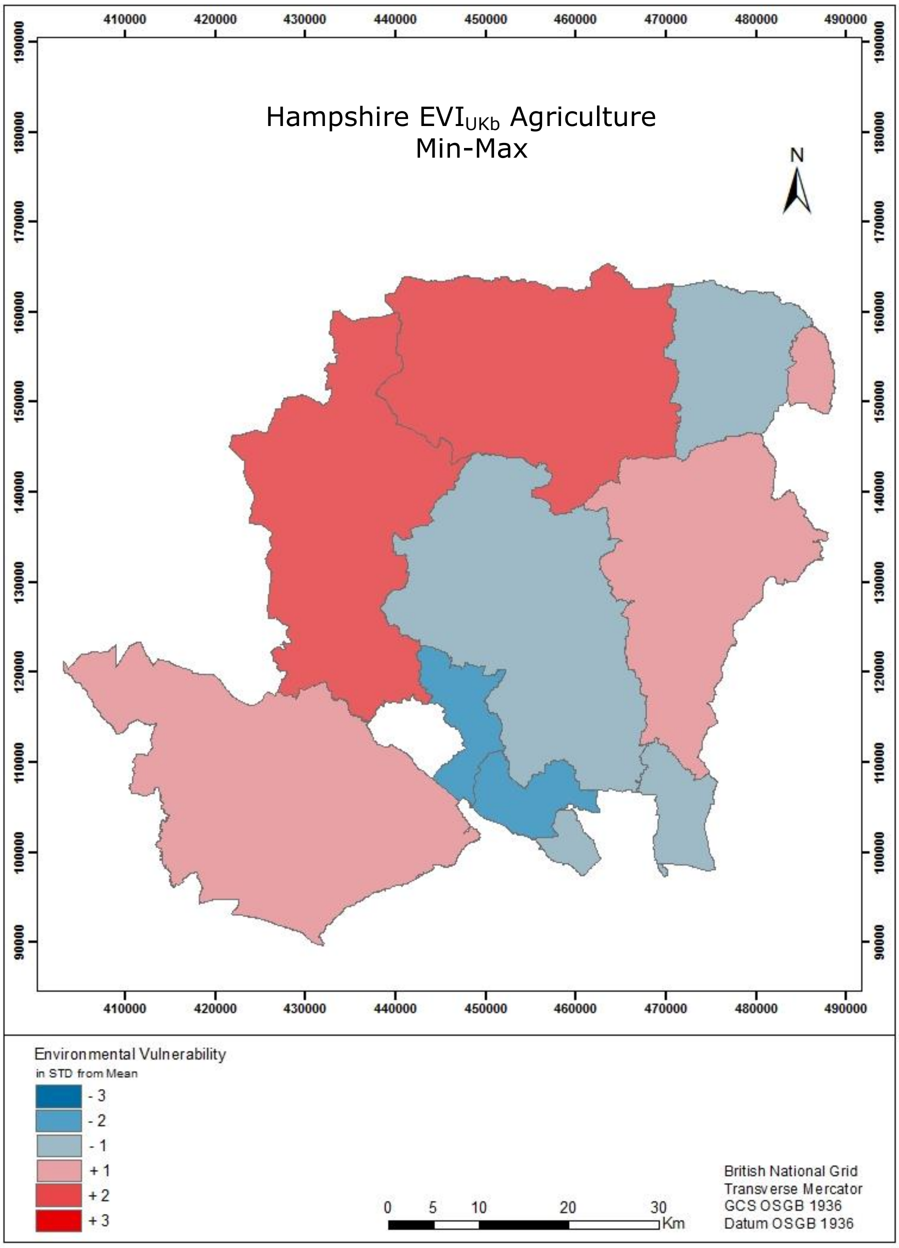

Figure 40: Hampshire EVI_{UKb} Agriculture based on min-max normalisation.

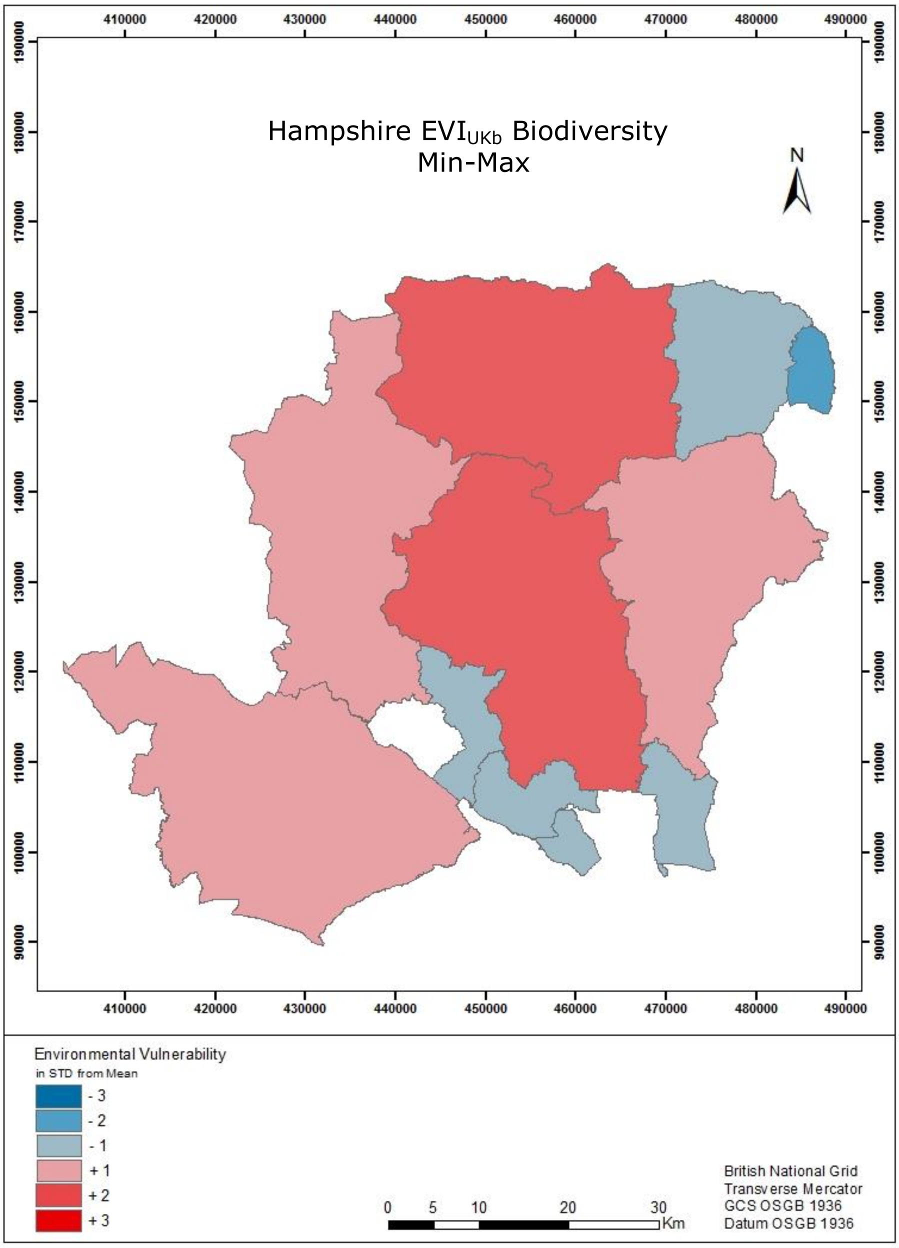

Figure 41: Hampshire EVI_{UKb} Biodiversity based on min-max normalisation.

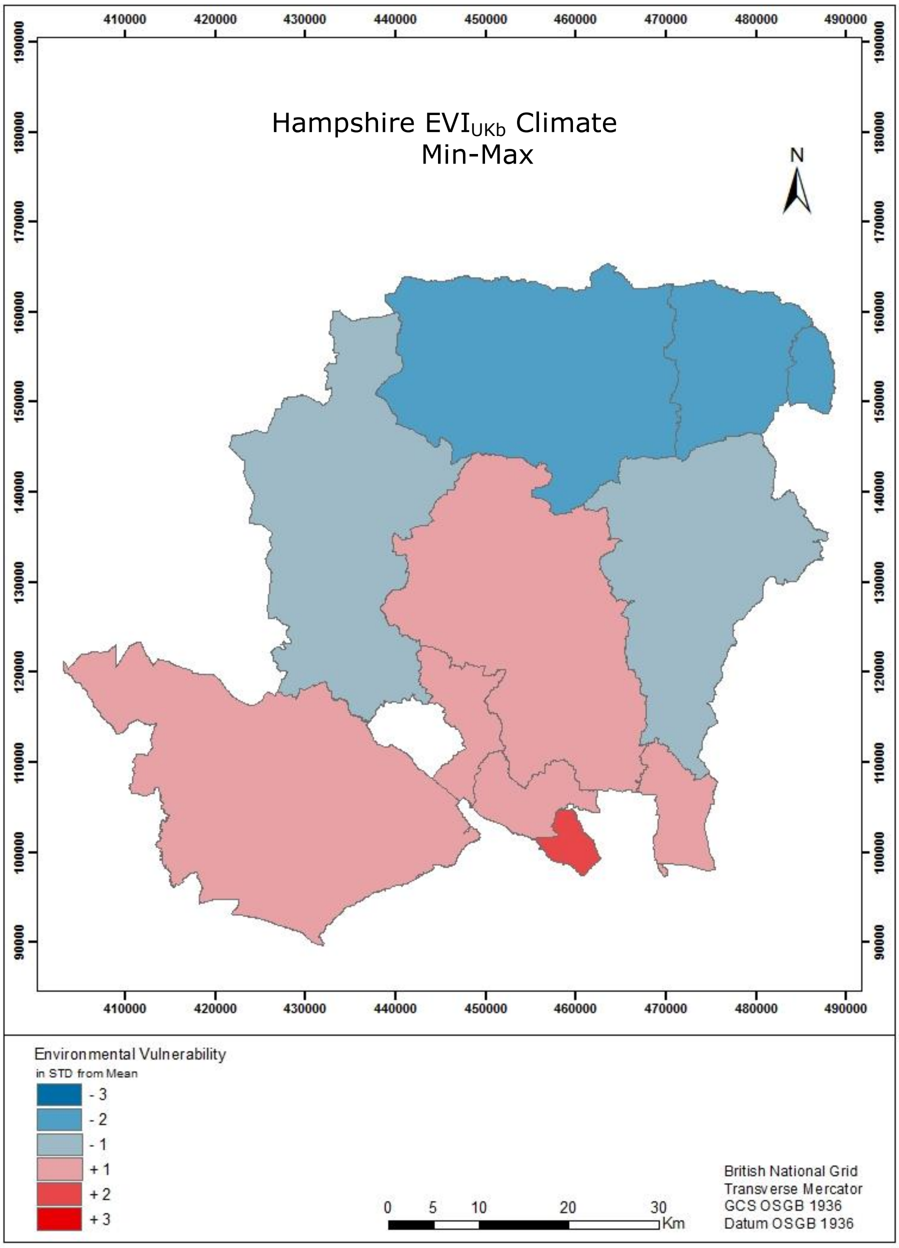

Figure 42: Hampshire EVI_{UKb} Climate based on min-max normalisation.

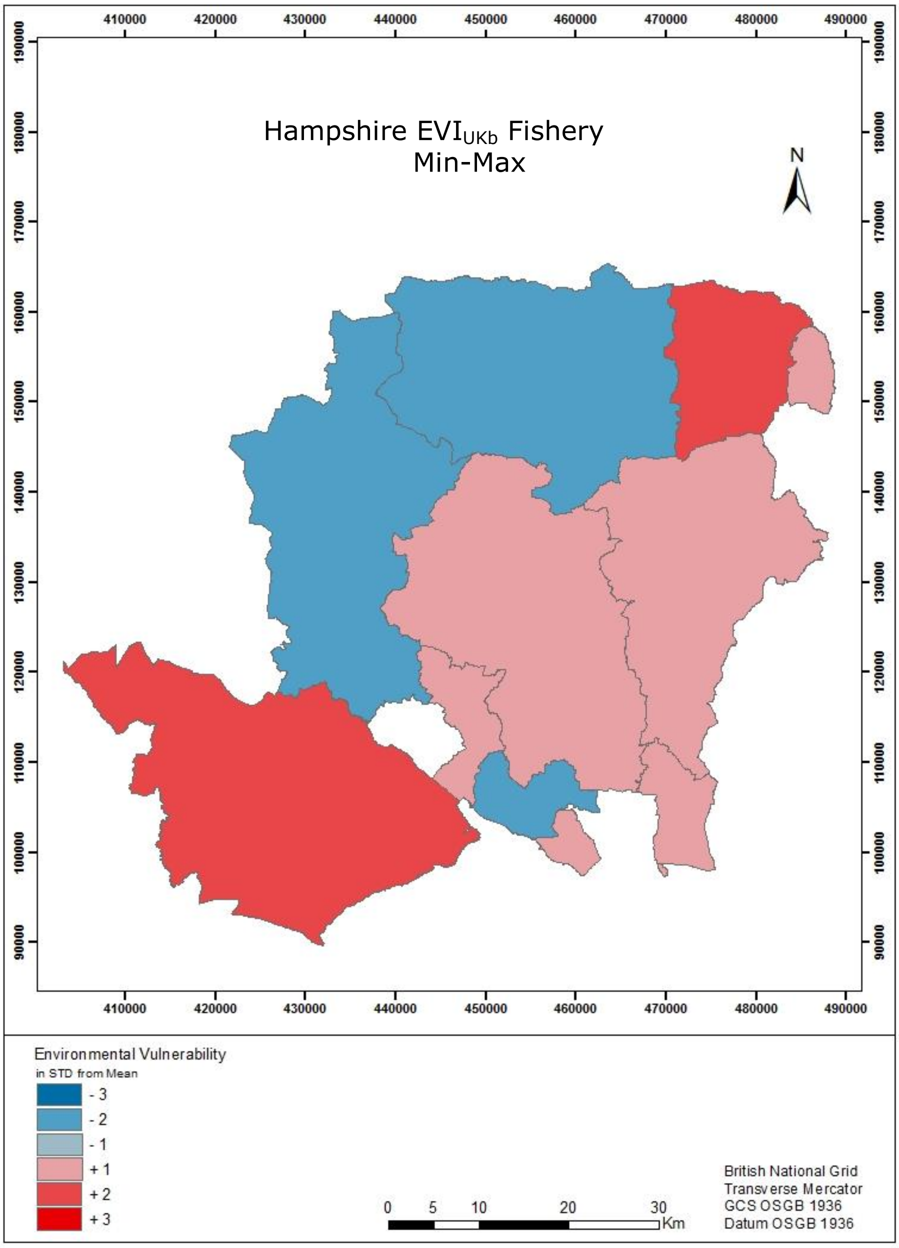

Figure 43: Hampshire EVI$_{UKb}$ Fishery based on min-max normalisation.

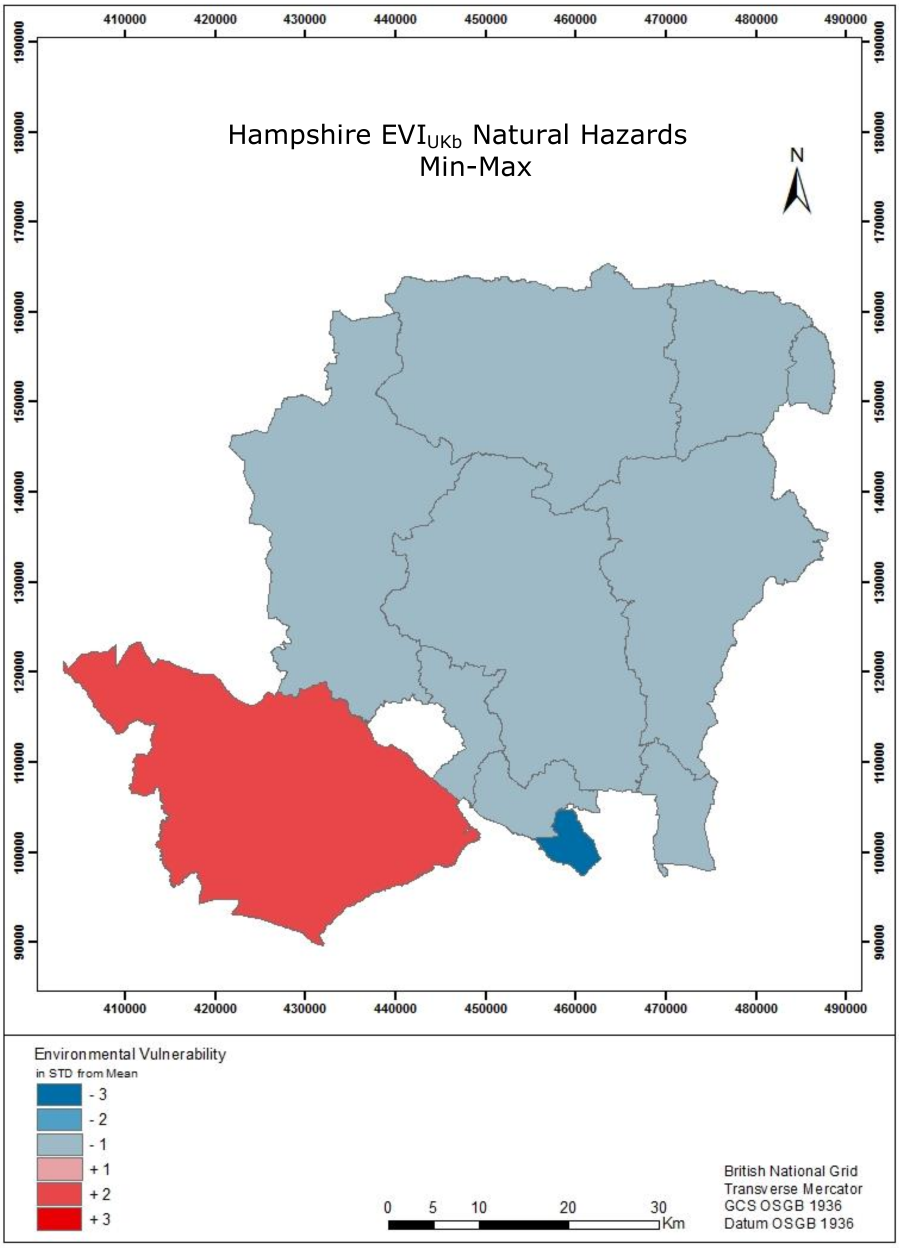

Figure 44: Hampshire EVI$_{UKb}$ Natural Hazards based on min-max normalisation.

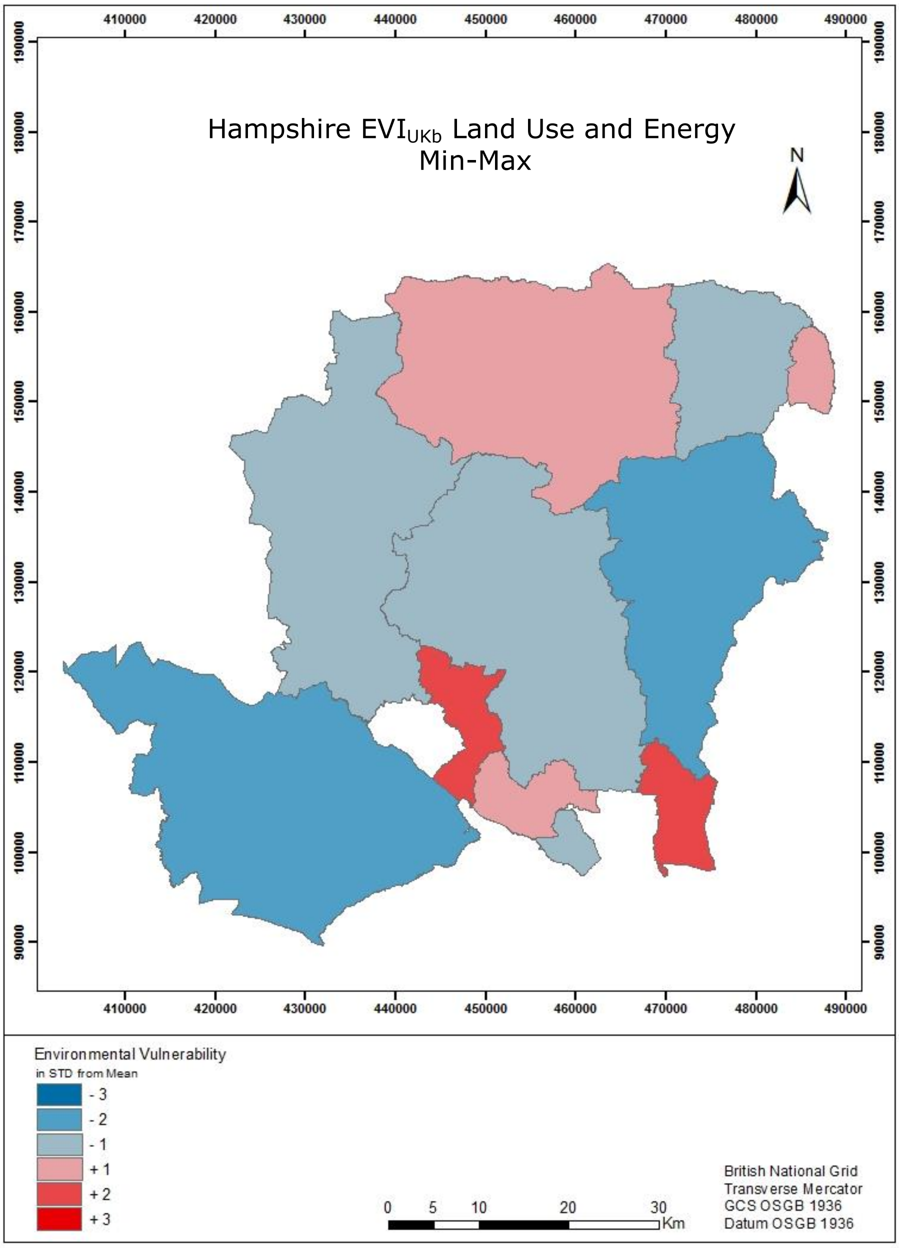

Figure 45: Hampshire EVI$_{UKb}$ Land Use and Energy based on min-max normalisation.

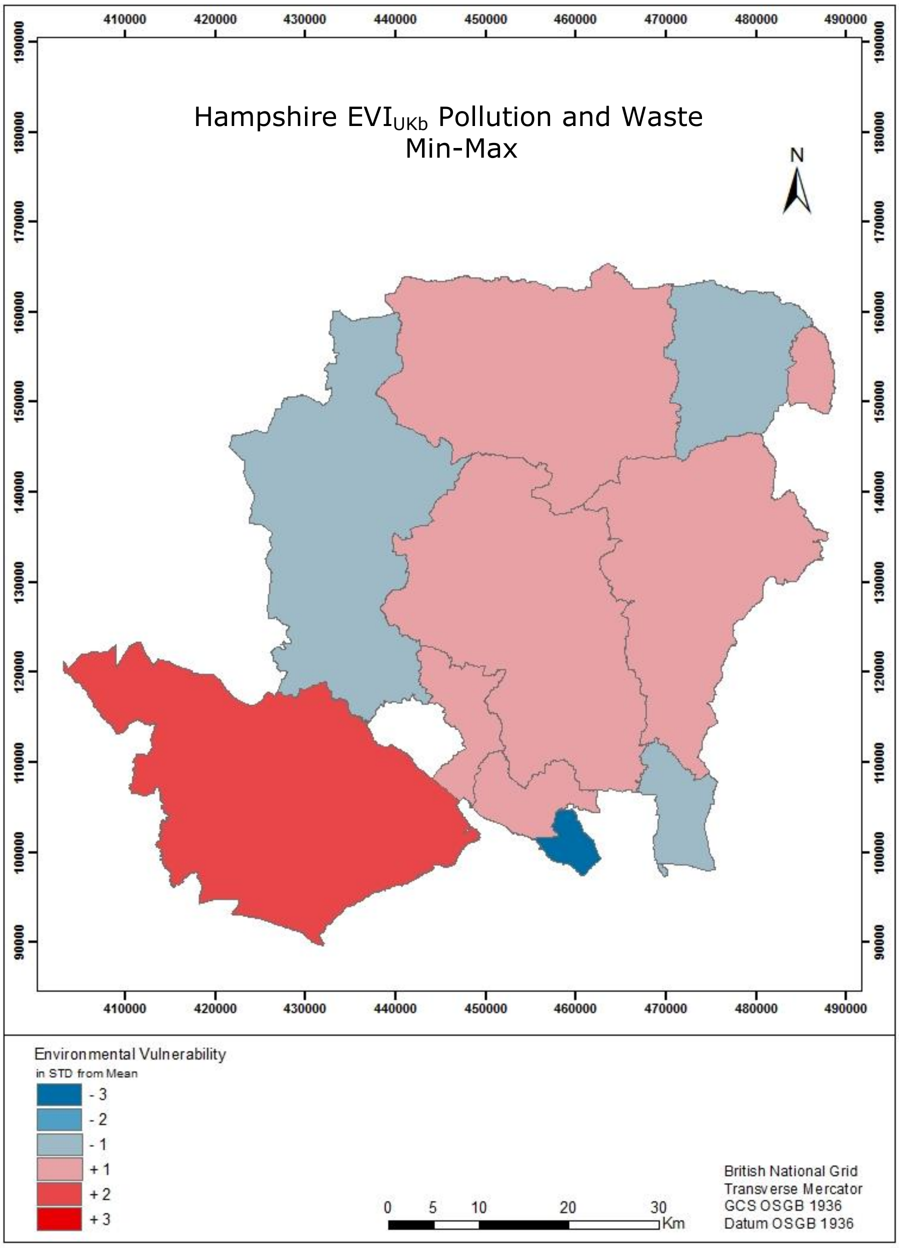

Figure 46: Hampshire EVI$_{UKb}$ Pollution and Waste based on min-max normalisation.

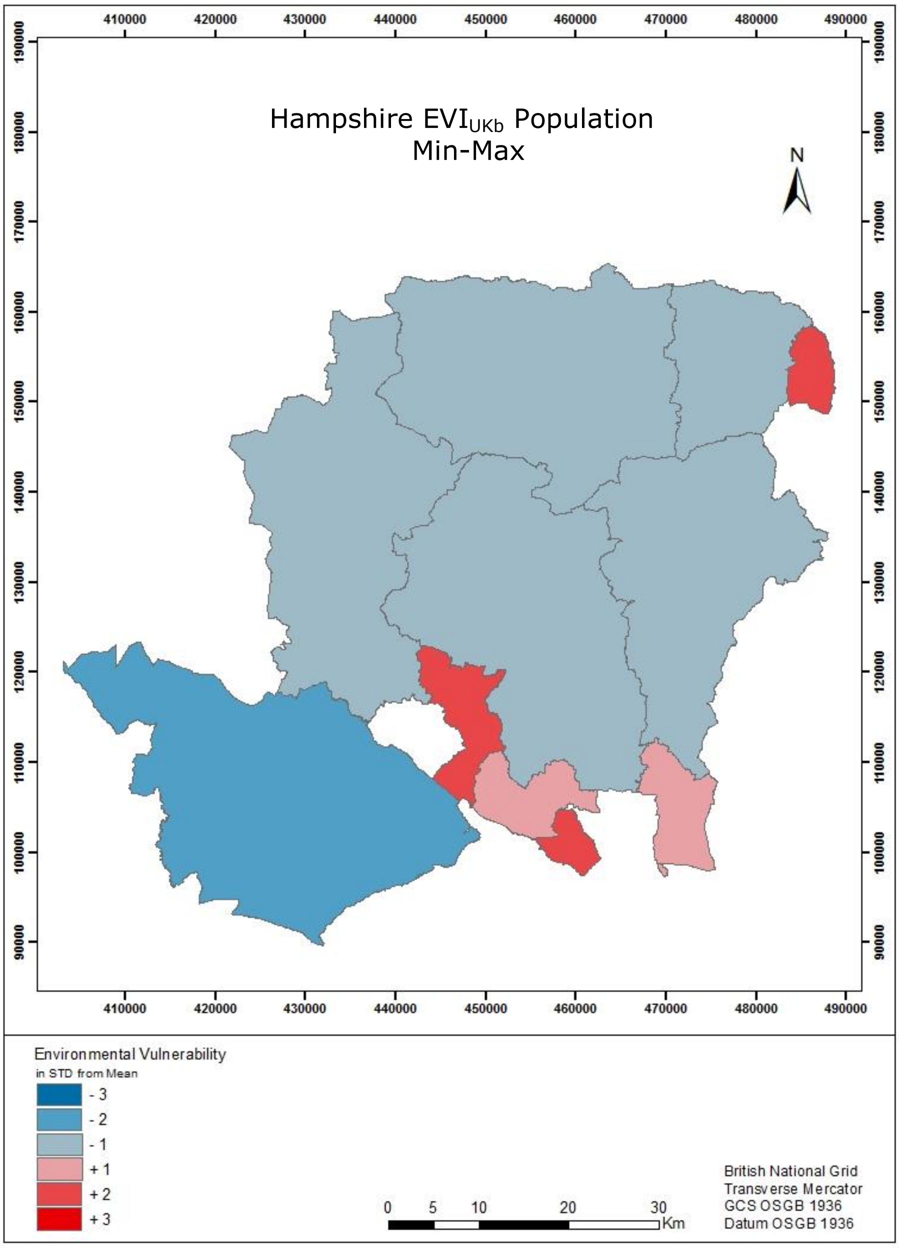

Figure 47: Hampshire EVI_{UKb} Population based on min-max normalisation.

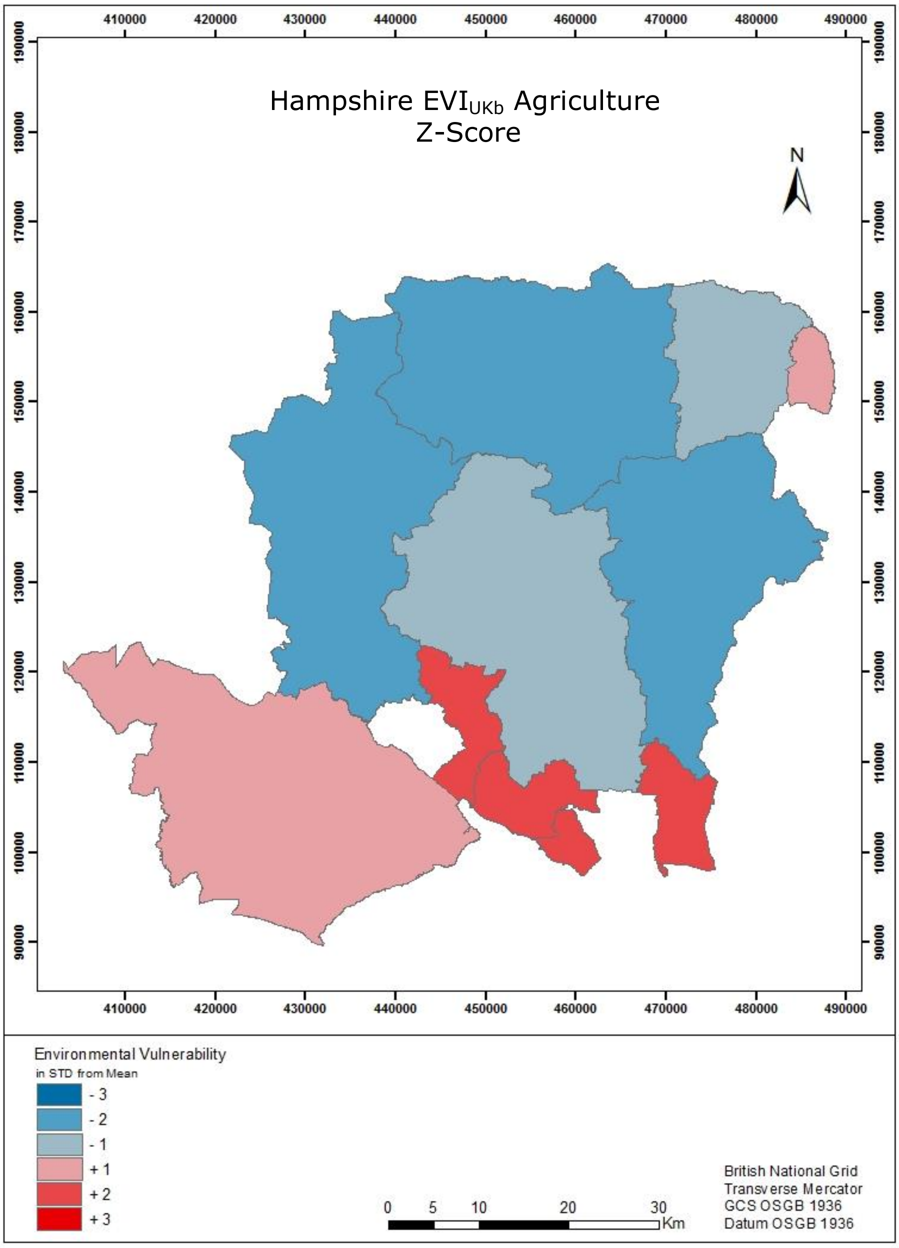

Figure 48: Hampshire EVI_{UKb} Agriculture based on z-score normalisation.

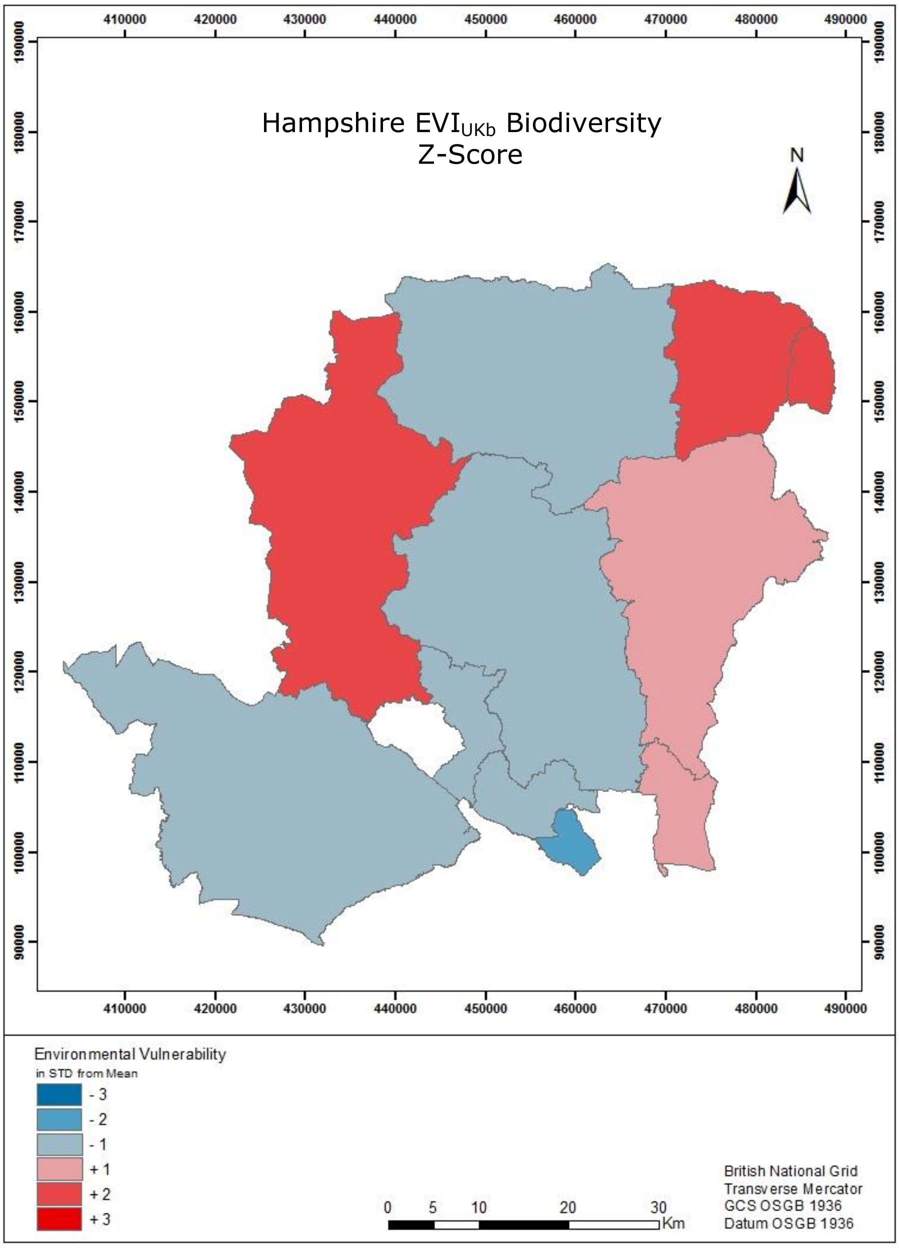

Figure 49: Hampshire EVI_{UKb} Biodiversity based on z-score normalisation.

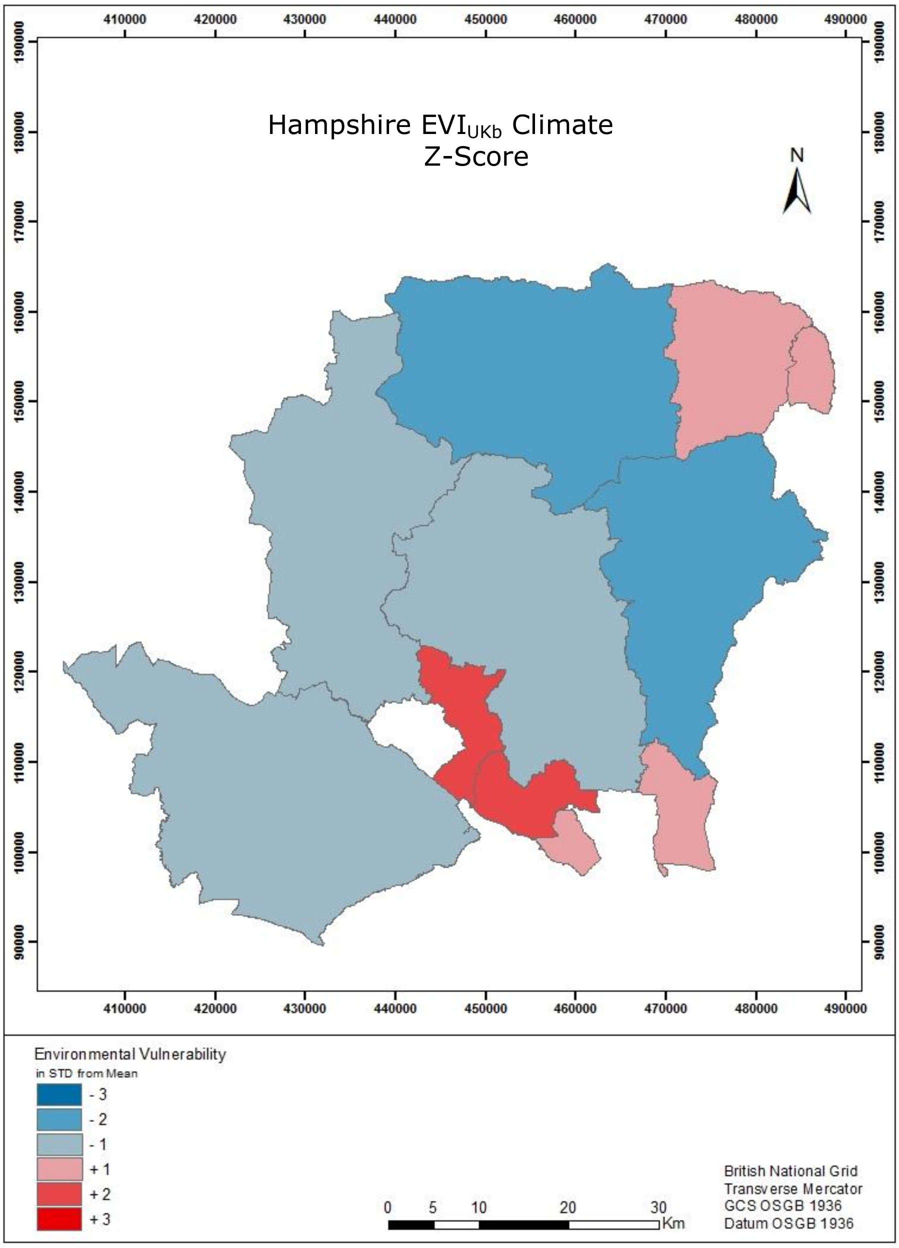

Figure 50: Hampshire EVI$_{UKb}$ Climate based on z-score normalisation.

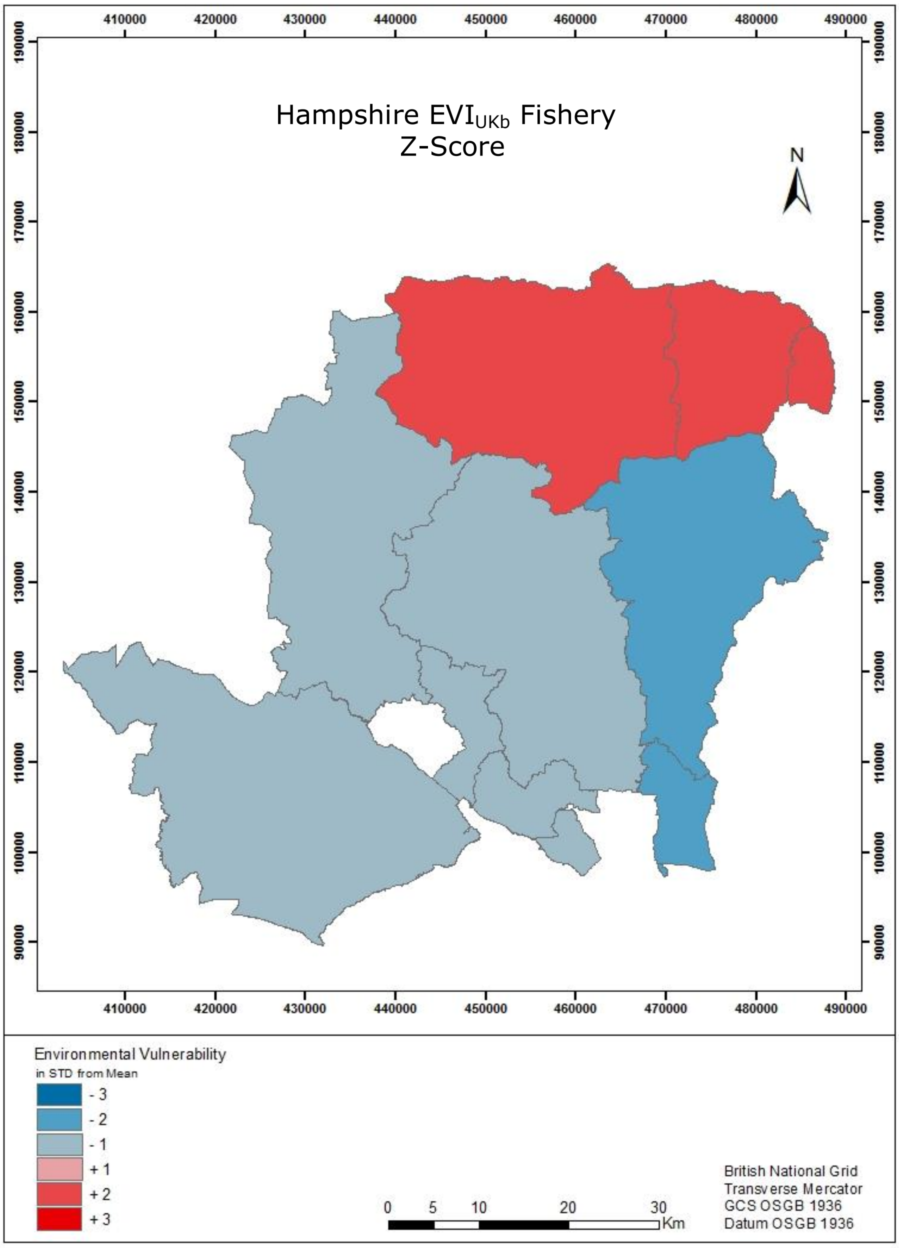

Figure 51: Hampshire EVI_{UKb} Fishery based on z-score normalisation.

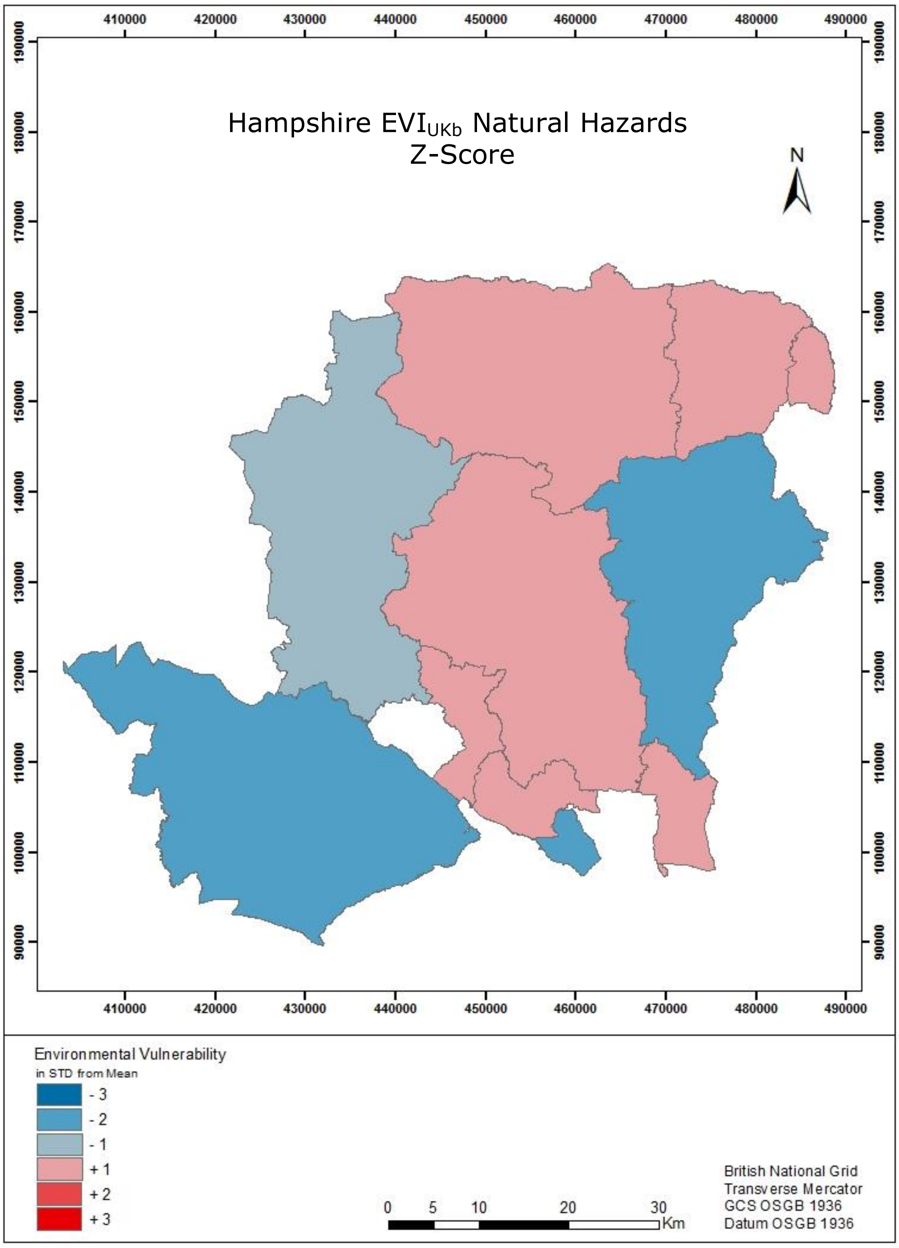

Figure 52: Hampshire EVI_{UKb} Natural Hazards based on z-score normalisation.

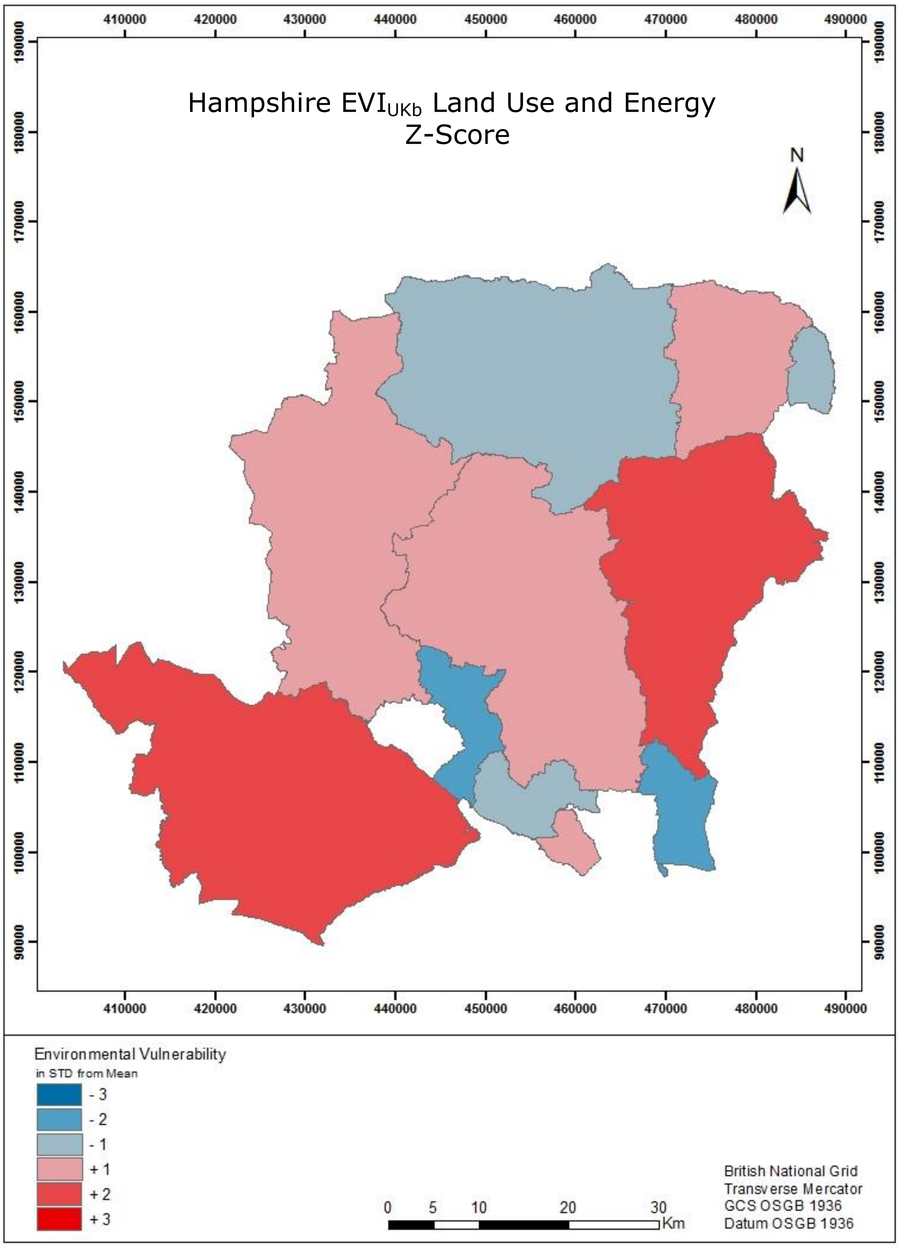

Figure 53: Hampshire EVI_{UKb} Land Use and Energy based on z-score normalisation.

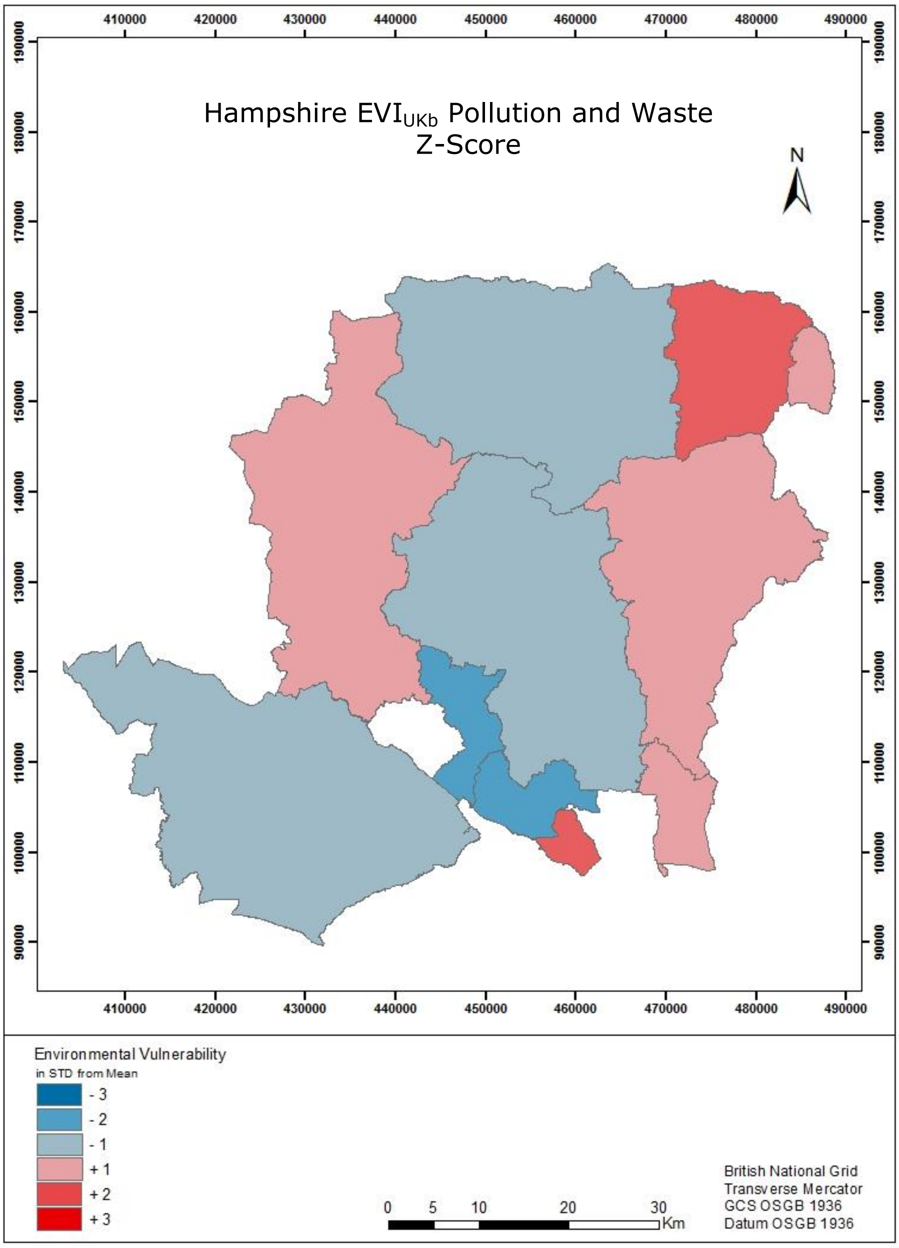

Figure 54: Hampshire EVI_{UKb} Pollution and Waste based on z-score normalisation.

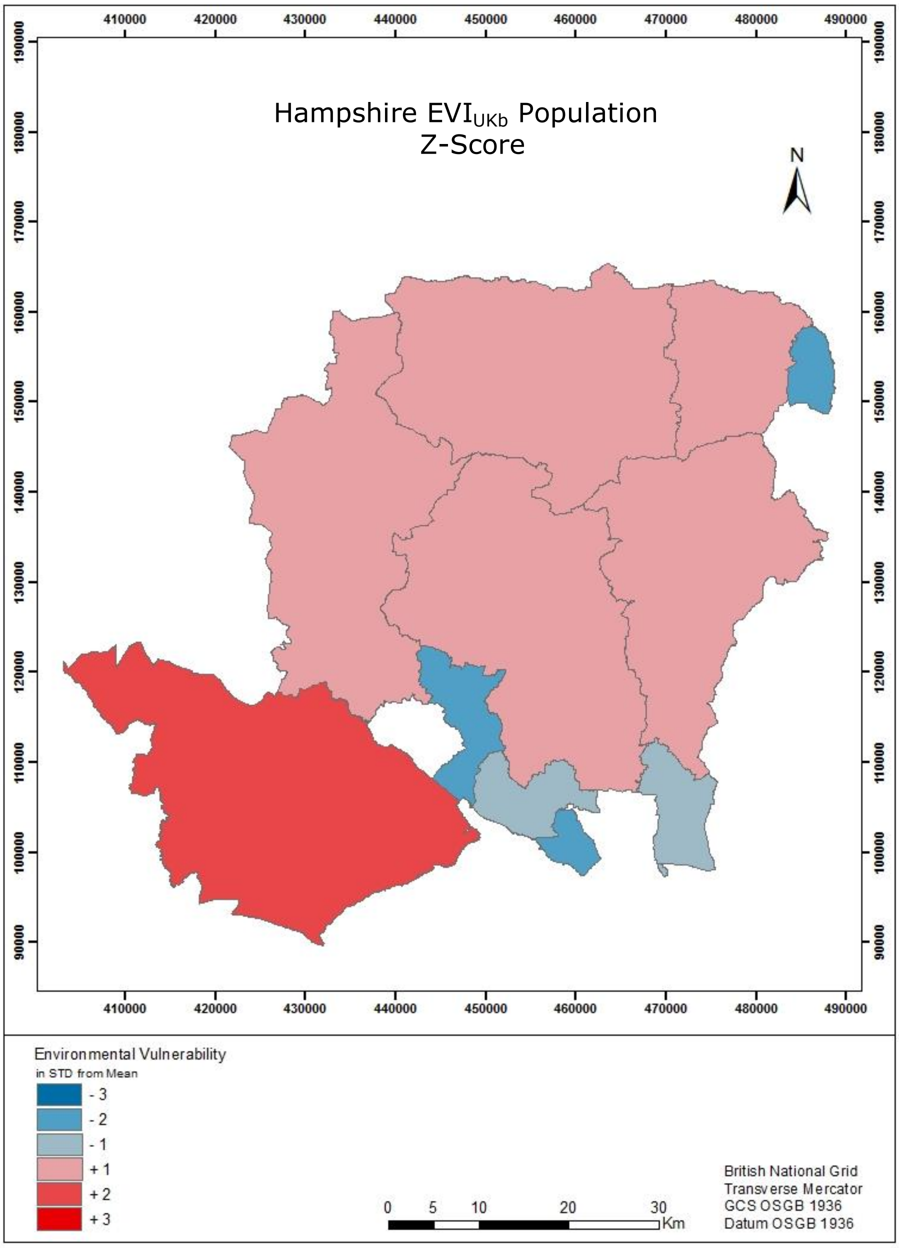

Figure 55: Hampshire EVI_{UKb} Population based on z-score normalisation.