2017

Introducing a Scottish Index of Environmental Disadvantage (SIED)

A geographical identification of the most environmentally disadvantaged areas in the central belt of Scotland to target CSGN actions

Author: B125260 – SMA GROUP 9

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List of Acronyms

Access to Basic Services	ABS
Analytic Hierarchy Process	AHP
Central Scotland Green Network	CSGN
Geographical Information Science	GIS
Multi-Criteria Analysis	MCA
Scottish Index of Environmental Disadvantage	SIED
Scottish Index of Multiple Deprivation	SIMD

1. Introduction

Across the UK and Scotland particularly, studies have shown that environmental inequality is strongly linked with social deprivation (Walker *et al.* 2003). Furthermore, empirical research shows that socioeconomic disadvantaged areas are less capable in dealing with environmental burdens (Fairburn *et al.* 2005). Yet, the literature and geographical evaluations of environmental inequality in Scotland are scarce (Walker *et al.* 2003). The Scottish Index of Multiple Deprivation (SIMD) identifies the most socially deprived areas in Scotland using the seven themes, income, employment, education, health, access to services, crime and housing (Scottish Government 2016). However, the index includes limited environmental factors whilst policy interventions of the last few years also seemed to neglect environmental inequalities (see CSGN 2011). On the basis of these facts the National Planning Framework 3 (NPF3) defined the Central Scotland Green Network (CSGN) as a national development to improve environmental quality by focusing on action in deprived areas as one of the three main priorities (Scottish Government 2014).

In line with the priorities of the CSGN, this study aims to locate the most environmentally disadvantaged areas by introducing a Scottish Index of Environmental Disadvantage SIED so that CSGN interventions can be geographically targeted. To ensure that socioeconomic deprived groups benefit from the interventions, the environmentally deprived areas are combined with the SIMD to determine areas with highest demand for CSGN actions. In consideration of CSGN visions, for this study environmental disadvantage is defined by the three themes *Green-/Bluespace*, *Environmental Health* and *Resilience*. As the themes are each represented by a range of different variables, a GIS-based Multi-Criteria Analysis (MCA) was applied.

2. Study Area and Spatial Unit

The CSGN activity area is located in the central belt of Scotland and encompasses 19 local authorities (Figure 1). Containing Scotland's largest cities Glasgow and Edinburgh, the area has 3.5 million residents which is more than 50% of Scotland's overall population (CSGN 2011). For the geographical evaluation of disadvantage inside the CSGN area this study uses 2011 data zones. This spatial unit was not only selected for its small size (500–1000 residents), but also because the zone construction considers environmental and cultural barriers.[1]

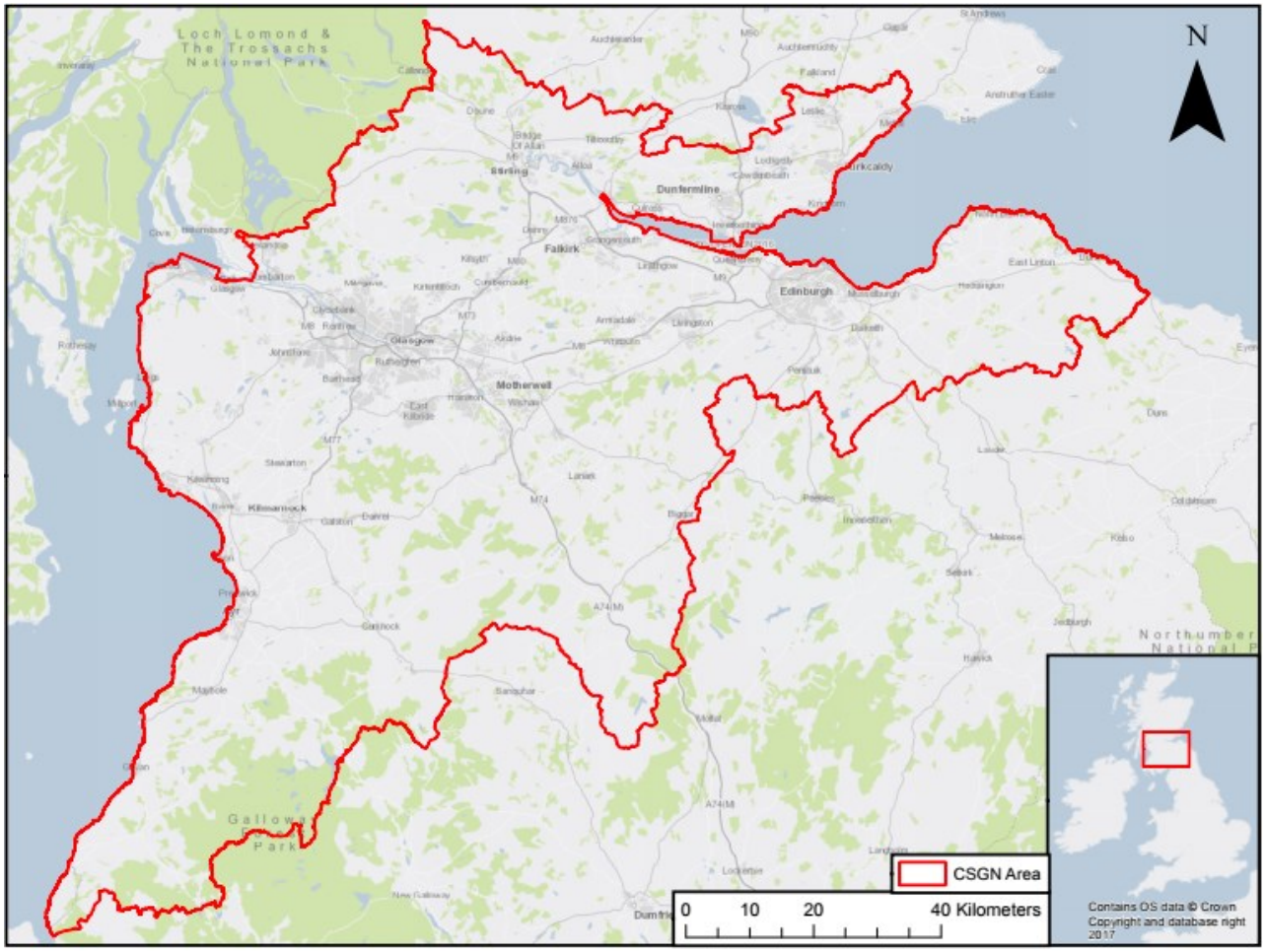

Figure 1: The CSGN activity area representing the study area.

[1] For an overview on the zone construction see Flowerdew *et al.* (2007).

3. Definition of Environmental Disadvantage for the SIED

Based on the vision of the CSGN (2011) the following broad definition of environmental disadvantage was developed.

> Environmental disadvantage relates to the process when the *environment* has a detrimental impact on health, wellbeing and overall quality of people's lives.
>
> *Environment* refers to the natural as well as the built-in environment that influences people's lives.

In consideration of the CSGN's themes and goals, three main services were defined that an environment should provide to ensure and enrich the quality of people's lives (see CSGN 2011).

1. **Greenspace and Bluespace:** Provision of access to high quality green- and bluespace
2. **Environmental Health:** Promotion of people's health and reduction of health inequalities
3. **Resilience:** Minimisation of risks and hazards and support of an adaptable resilient community

Areas where there is an overall lack in provision of these three services – hereinafter referred to as themes – were defined as being environmentally disadvantaged.

4. Definition of Variables and Data Assessment

The variables representing the three themes *Green-/Bluespace*, *Environmental Health* and *Resilience* were chosen based on (1) literature research and (2) data availability and quality. Environmental variables for the first two themes were justified through empirical findings, mainly from studies in the United Kingdom, that show a spatial pattern or correlation with socioeconomic or health deprivation. Variables for the last theme were chosen considering widely used environmental factors for indices measuring resilience and risk assessment of communities. Data availability for Scotland at a high spatial resolution and data quality narrowed the wished factors down two ten variables. The specific justifications for each of the ten variables can be viewed in Table 1 whilst Table 2 contains the datasets representing the factors.

The theme *Green-/Bluespace* consists of the factors (1) proximity to greenspace such as urban greenspaces, forests and grassland, (2) percentage of greenspace within a data zone and (3) proximity to bluespaces such as rivers, lakes and the sea. *Environmental Health* is represented by (1) air pollution through NO_2, NO_x, PM_{10} and $PM_{2.5,}$ (2) access to health care and proximity to (3) derelict land and (4) landfill sites. The evaluation of the last theme – *Resilience* – was performed by including the three criteria (1) vulnerability to climate change through flood risk, (2) access to basic services such as schools and food markets and (3) fire risk. The theme *Resilience* is the most constrained by data availability as no suitable data on commonly used factors to measure resilience – such as resource management, perception of environment and risks, sustainability and green networks – could be found (e.g. Food and Agriculture Organization of the United Nations 2016).

Justifications of Factors	
Factor(s)	**Justification / Empirical Evidence**
Access & Ratio to Greenspace	A body of empirical evidence from the United Kingdom and Scotland in particular shows that greenspace has positive economic, social and physical effects on a range of health and well-being variables (e.g. Urban Green Spaces Taskforce, 2002; SNH 2004, CABE Space 2004). A review of literature states the benefits of proximity to high quality greenspace, including prevention of illness, inclusion of healthy lifestyles and urban regeneration (Fairburn et al. 2005).
Access to Bluespace	Whilst a plethora of research on greenspace has been carried out in the United Kingdom the same cannot be said for bluespace (Miller et al. 2012). However, several studies find that high quality bluespace offers an even greater opportunity for restauration and support for psychological well-being than greenspace (Volker and Kistemann 2011, White et al 2010).
Air Pollution	The link between social social deprivation and air pollution is outlined in several studies for England and Scotland (e.g. Fairburn et al. 2015, Walker et al. 2003)
Access to Healthcare	Empirical studies show a correlation between declining geographical access to healthcare facilities and adverse health outcomes including length of stay in a hospital and survival rates (see Kelly et al. 2016 for a meta-study).
Proximity to a Derelict Site	Derelict land is often related to past industry. There's empirical evidence that contamined and derelict land has a detrimental impact on health due to air pollution (Environmental Agency 2002, Fairburn et al. 2005).
Proximity to Landfills	Several empirical studies show that proximity to landfill sites correlates with social deprivation (England by the Environment Agency 2002) and is often related to an increased risk of negative health outcomes including birth weights, cancer and heart disease (Malik 2004, Baibergenova et al. 2003, Elliot et al. 2001).
Vulnerability to Climate Change	The *UK Climate Change Risk Assessment 2017* defines flooding and coastal change risks as the top area of inter-related climate vulnerability for the UK (HM Government 2017).
Access to Basic Services	The resilience indices RIMA and RIMA II use Access to Basic Services (ABS) as a resilience pillar. Having ABS such as schools, health centres, water, electricity and nearby markets, are entitled as a fundamental aspect of resilience (Food and Agriculture Organization of the United Nations 2016). In addition, recent evidence supports the association between ABS and the ability to recover after a disaster (Khan 2014).
Fire Risk	Empirical research indicates a link between rates of fire and poverty or social deprivation such as unemployment. Furthermore, for fires in socially disadvantaged areas the mortality probability is found to be higher (for a meta study see Jennings 2013).

Table 1: Justification of the used factors/variables.

Datasets used for Factors/Variables					
Factor(s)	**Dataset Name**	**Year**	**Description**	**Spatial Unit**	**Supplier**
Access to Bluespace	OS Open Rivers	2017	Routes of rivers throughout Scotland, to be used for determining distance of data zones from major rivers.	Location-based Polylines	Ordnance Survey
Access & Ratio to Greenspace	OS Open Greenspace	2017	Contains geographic location of greenspace areas within urban areas of Scotland (places >500 population). Includes access points for greenspace areas and classifications of area	Location-based Polygons	Ordnance Survey
	Land Cover Map 2015	2015	Contains geographic location of greenspace areas within rural areas of Scotland.		Digimap
Air Pollution	Estimated Background Air Pollution Map (NO2, Scotland)	2015	Estimated levels of four air pollutants in Scottish air during the year 2015.	1 km Grid	UK Department of Environment, Food, and Rural Affairs
	Estimated Background Air Pollution Map (NOx, Scotland)				
	Estimated Background Air Pollution Map (PM10, Scotland)				
	Estimated Background Air Pollution Map (PM2.5, Scotland)				
Access to Healthcare	Travel Times to Key Services by Car or Public Transport	2015	Mean of travel minutes to reach healthcare institutions; divided into vehicular and public transport.	2011 Datazones	Statistics.gov.scot
Proximity to a Derelict Site	Population living in close proximity to a derelict site	2016	Ratio of population living within 500 metres of a derelict site.	2011 Datazones	Statistics.gov.scot
Proximity to Landfills	List of waste sites and capacities in Scotland	2015	Locations of waste sites within Scotland, to be used to determine datazones located within 4 km.	Location Points	SEPA
Vulnerability to Climate Change	Dwellings in flood risk areas	2006	Measures number of dwellings in flood risk areas as ratio (percentage of dwellings).	2001 Datazones	Statistics.gov.scot
Access to Basic Services	Travel Times to Key Services by Car or Public Transport	2015	Mean of travel minutes to reach basic services, including schools, food markets, and post offices; divided into vehicular and public transport.	2011 Datazones	Statistics.gov.scot
Fire Risk	Fire-Type of Incident	2016	Number of fires, by type of fire and whether accidental or not.	2011 Datazones	Statistics.gov.scot
SIMD	Scottish Index of Multiple Deprivation	2016	Sixteen indicators divided into seven areas of study (income, health, access, employment, education, crime, and housing) that provide information on socio-economic factors throughout Scotland.	2011 Datazones	Scottish Government

Table 2: Datasets used to represent factors within the themes.

5. Evaluation Methods

5.2 Evaluative Approach

For the calculation of the SIED, a GIS-based Multi-Criteria Analysis (MCA) was applied. This approach was suitable as environmental disadvantage consists of a complex set of different geographically located criteria with distinctive relative importance. To conduct the MCA, the weighted summation method was chosen as it is easy and transparent for implementations (Janssen 2001). Furthermore, it is the most commonly applied method in GIS-based MCA (Malczewski 2006). Figure 2 shows a diagram of the MCA workflow in this study.

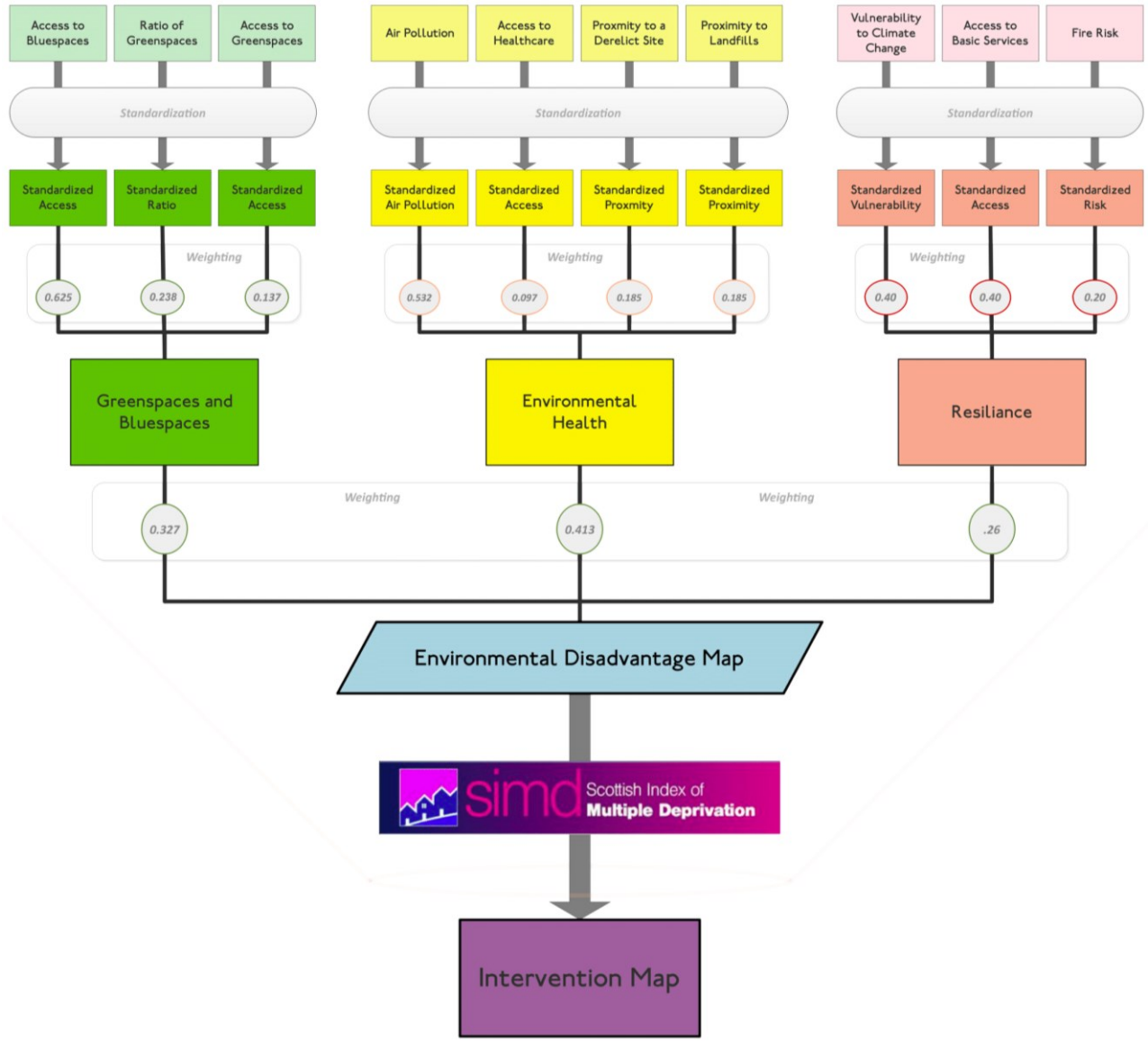

Figure 2: Complete workflow of the GIS-based Multi-Criteria Analysis.

5.2 Data Processing

As described above, data zones 2011 were used as a spatial evaluation unit. Data within distinct spatial units or references had to be aggregated or interpolated. For areal interpolation from the 2001 data zones to 2011 data zones, a *simple area weighting* method was used (for more information see ArcGIS 2013). Variables represented by proximity (access to greenspace, access to bluespace, proximity to landfill sites[2]) were calculated using mean euclidian distance[3] within each data zone (see ArcGIS 2016). In cases where the conversion from distinctive spatial units didn't cover each data zone (e.g. air pollution in 1 km grid) as well as for null values, interpolation from geographically surrounding data was performed.[4]

The use of continuous variables in the MCA model led to the demand for data normalisation.[5] To normalise the factors a score range procedure $x_i' = (x_i - x_{min}) / (x_{max} - x_{min})$ was applied.[6]

5.3 Weightings

To identify the weightings of themes and variables this study made use of the Analytic Hierarchy Process (AHP)[7], a mathematical technique for complex decision making that is frequently applied in MCA's (e.g. Wong & Li 2008, Madadian *et al.* 2013). The relative importance of factors inside the themes was identified through group decisions based on data quality and scientific knowledge. Policy priorities and aims determined the weightings of the three themes against each other.[8]

5.4 Evaluation of Intervention Areas

To ensure that interventions targeting environmental disadvantage benefit socioeconomic deprived groups the calculated Scottish Index of Environmental Disadvantage (SIED) was overlaid with the SIMD. Areas where the most disadvantaged quintile of both – the SIED and the SIMD – overlap were defined as areas with the highest need for interventions.

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[2] Following the suggestion of Palmer *et al.* (2005) 4000 meter was set as a threshold value from where further distance to landfill sites wouldn't be regarded as a higher advantage. This is based on the assumption that pollutant particles from landfill sites don't travel by air further than 4000 meter.

[3] Note that road network and public transport weren't considered for calculating proximity to green- and bluespace as empirical findings show that the majority of people get there by walking (e.g. Dunnett *et al.* 2002).

[4] This procedure is based on the principle of spatial autocorrelation (see Suriatini 2006).

[5] See van Til *et al.* (2014) for a comparison between standardisation techniques for multi-criteria decision support frameworks.

[6] Note that the given formula was applied when higher values resulted in higher disadvantage (e.g. for concentrations of air pollutants). For reversed values where higher values reflected lower disadvantage – such as proximity to waste sites – the formula $x_i' = (x_{max} - x_i) / (x_{max} - x_{min})$ was used.

[7] The AHP was developed in the 1980's by Thomas Saaty. It is a technique measuring pair-wise comparisons of factors and relies on the judgements of one or several experts. For a good explanation on calculation and use of the AHP see Saaty (2008).

[8] In a meta study within the Netherlands Janssen (2001) identifies this as the most common procedure for MCA's.

6 Results

This section presents the results for both, SIED and need for intervention. In Figure 3 the evaluation of each environmental theme is displayed. Access to *Green-/Bluespace* and *Environmental Health* are graded poorer in cities while *Resilience* – with some exceptions – does not show this pattern. The weighted summation of these three maps lead to the Scottish Index of Environmental Disadvantage (SIED) (Figure 4). The most disadvantaged areas are nearly equally distributed between rural and urban areas (see Figure 5). However, the areas where both – social deprivation (SIMD) and environmental disadvantage (SIED) – are the highest, tend to be located in urban areas, mostly in Glasgow (Figure 6). In total, 215 data zones were classified as areas with high demand for CSGN interventions (see Appendix 6).

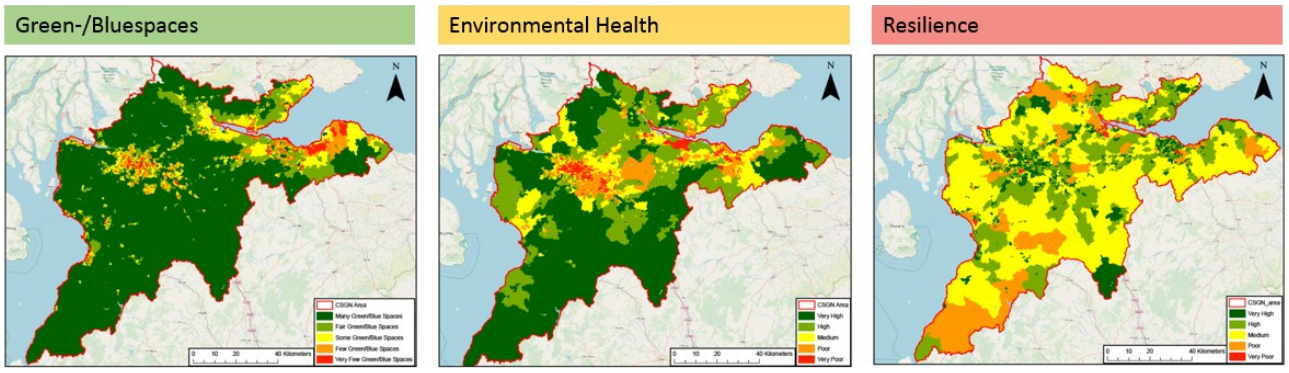

Figure 3: Evaluation of the three environmental themes Green-/Bluespace, Environmental Health and Resilience. Red colours display the most disadvantaged data zones within each theme while green colour represents the most advantaged areas.

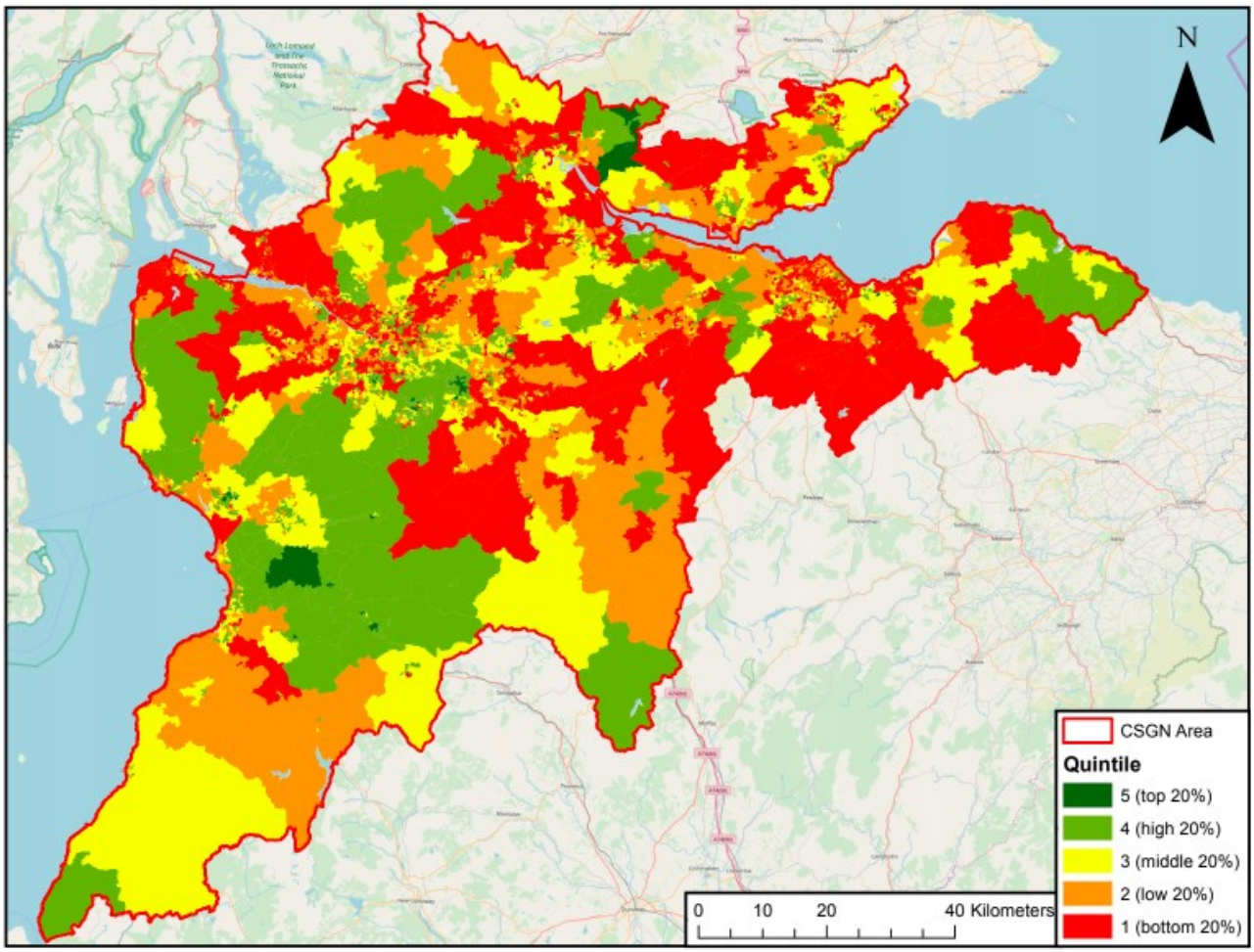

Figure 4: The Scottish Index of Environmental Disadvantage (SIED) displayed as quintiles, with the bottom quintile (red) as the most environmentally disadvantaged areas.

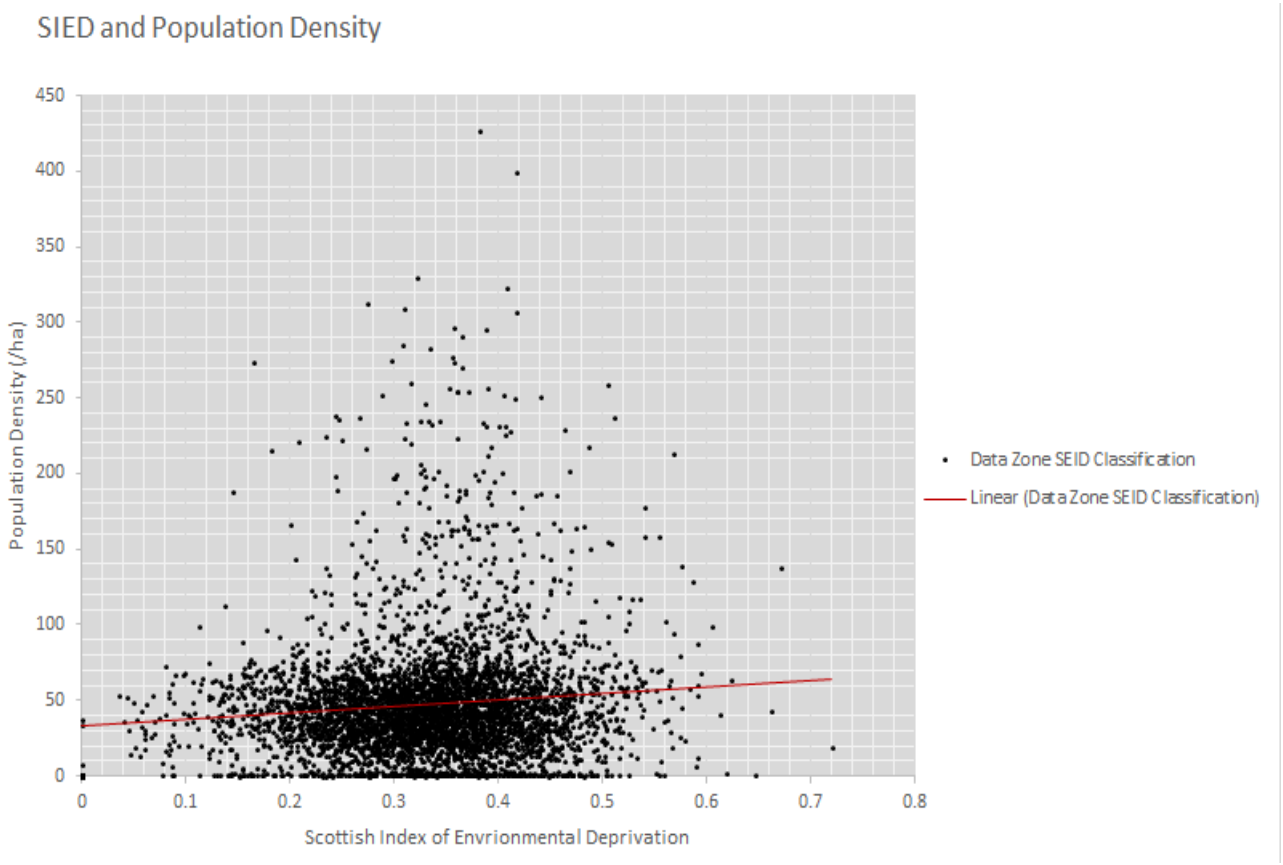

Figure 5: A plot of the SIED classification and the population density of data zones. A higher SIED indicates higher environmental disadvantage. The trend line shows that the classification is relatively well distributed amongst rural and urban areas with a weak trend that higher populated areas tend to be more environmentally disadvantaged.

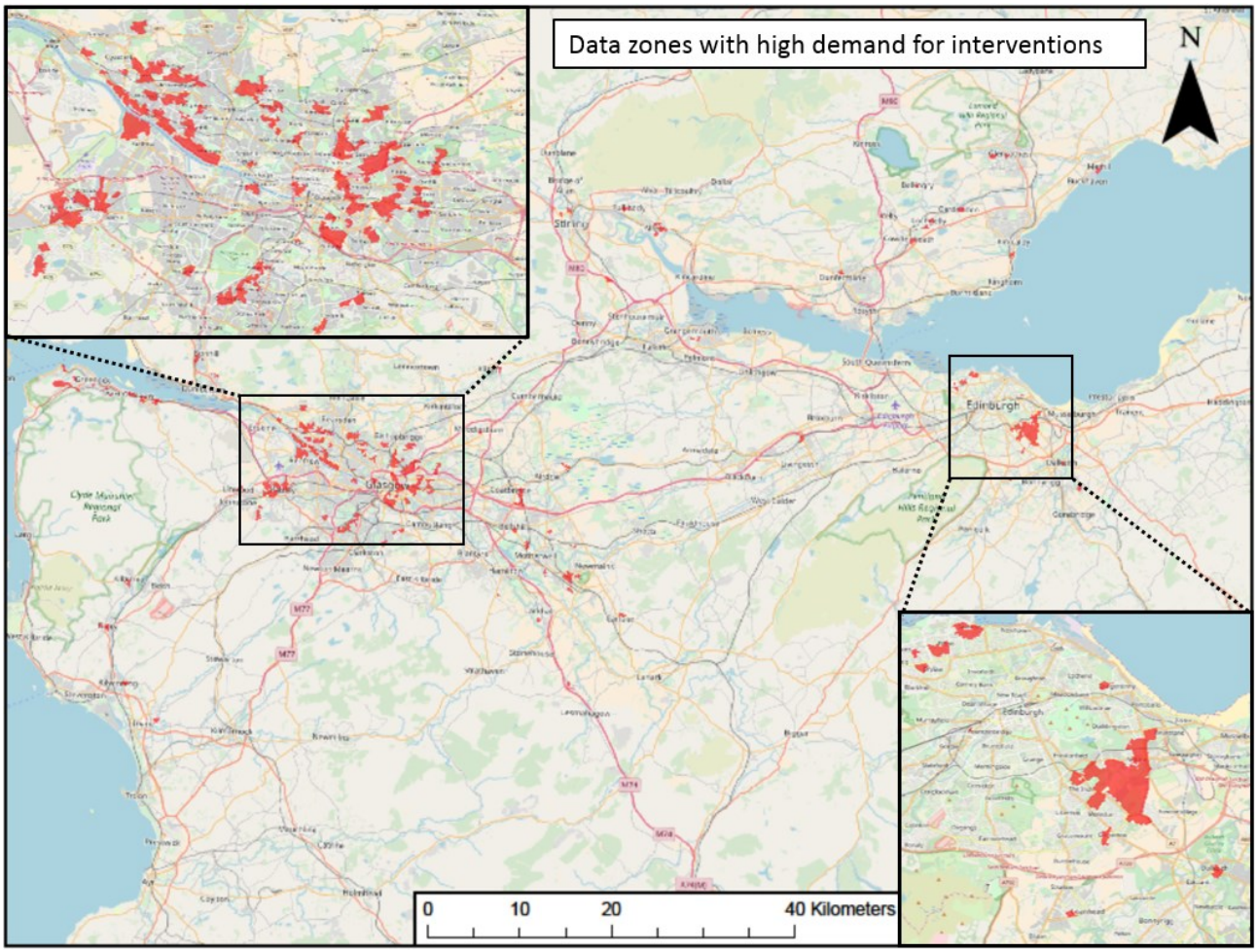

Figure 6: Areas with high desire for CSGN interventions. The map displays the areas that are in the most disadvantaged quintile in both indices, the SIMD and the SIED.

7 Discussion

7.1 Interventions

The CSGN proposes several interventions for environmentally disadvantaged areas such as repurposing derelict land, establishing active travelling and cycling, greening and implementation of sustainable urban drainage systems (CSGN 2011). As the settings in each data zone displayed in Figure 6 are unique, no general statement about specific interventions can be made. However, this section will analyse the data zone S01010223 in Glasgow (see Appendix 1) as an example and show how the results of the SIED can be used to make specific suggestions for interventions. Table 3 shows that the data zone is in the most disadvantaged quintiles for environmental health variables such as air pollution and proximity to derelict land and for greenspace variables. A potential CSGN intervention would be to convert derelict land to public greenspace. Such an intervention is efficient as it targets and improves several environmental factors at once.

Access to Green-/Bluspace	Air Pollution	Access to Health Care	Priximity to Landfills	Proximity to Derelict Land	Access to Basic Services	Fire Risk	Climate Change Vulnerability	SIED	SIMD	Intervention
1	1	4	1	1	4	5	5	1	1	1

Table 3: Classification of the specific theme factors for the S01010223 data zone within quintiles. With 1=most disadvantaged 20%; 2=most disadvantaged 40%; 3=most disadvantaged 60%; 4=most disadvantaged 80%; 5= most advantaged 20%.

7.2 Limitations

A major limitation of this study, is its reliance on availability of spatial data which also had a great impact on the definition of environmental disadvantage.[9] As mentioned above, the theme *Resilience* could not be appropriately represented by data. There is a high need for environmental data acquisition on a data zone level or other small scale units including resource management, perception of environment and risks, sustainability and green networks.

Another limitation is that the model provides only a snapshot of environmental disadvantage and does not include time. However, the evolution of certain areas can be crucial to determine areas in need for intervention (e.g. areas where environmental quality has the tendency to impair should be considered to have a higher priority for action).

Finally, it must be stated that the results of this research are not incontestable. Indeed, they should be considered as policy tool to support decision making and should always be used with contextual knowledge about the specific data zones.

[9] Fairburn *et al.* (2005) describe the same issue for environmental data in Scotland.

8. Conclusion

Conducting a GIS-based MCA, this study has located the most environmentally disadvantaged areas in the central belt of Scotland by introducing a Scottish Index of Environmental Disadvantage (SIED). To ensure that socially deprived groups benefit from the interventions targeting environmental inequalities, the results were combined with the SIMD. This resulted in a map displaying areas with the highest demand for CSGN actions. The results of this study were constrained by the scarcity of environmental data available in Scotland at a high spatial resolution. However, the results represent a robust decision making tool which can be used by policy makers.

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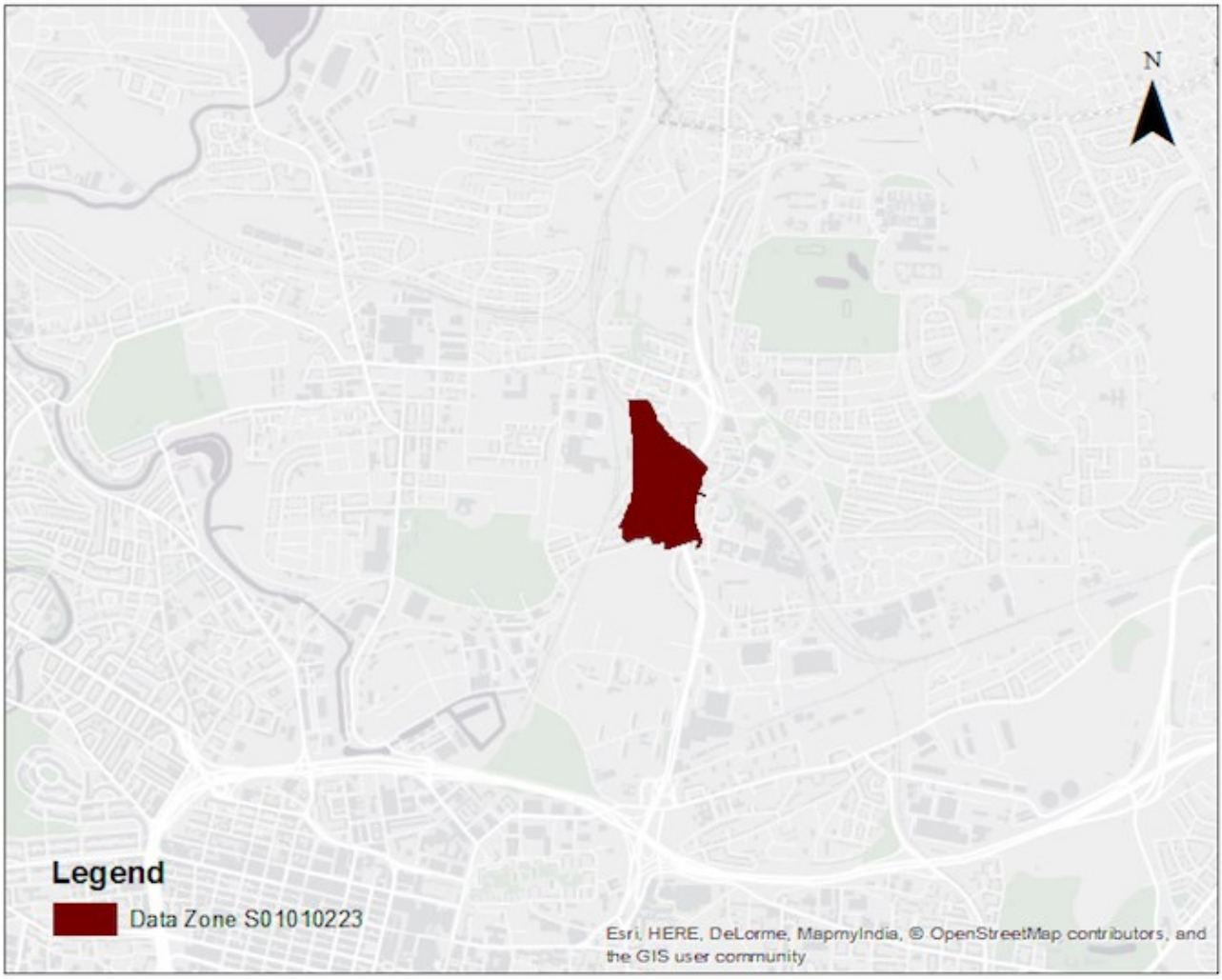
Appendices



Appendix 1: Map of the data zone S01010223 as an example of an area with high demand for CSGN action.

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons

	Category	Priority	Rank
1	Access to Greenspaces	62.5%	1
2	Ratio of Greenspaces	23.8%	2
3	Access to Blue Spaces	13.7%	3

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix

	1	2	3
1	1	3.00	4.00
2	0.33	1	2.00
3	0.25	0.50	1

Appendix 2: Resulting weights using the AHP for the theme Green-/Bluespace.

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons

	Category	Priority	Rank
1	Fire Risk	20.0%	3
2	Vulnerability to Climate change (flood risk)	40.0%	1
3	Access to basic services	40.0%	1

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix

	1	2	3
1	1	0.50	0.50
2	2.00	1	1.00
3	2.00	1.00	1

Appendix 3: Resulting weights using the AHP for the theme Resilience.

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons

	Category	Priority	Rank
1	Air pollution	53.2%	1
2	Access to health care	9.7%	4
3	Derelict sites	18.5%	2
4	Landfill	18.5%	2

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix

	1	2	3	4
1	1	5.00	3.00	3.00
2	0.20	1	0.50	0.50
3	0.33	2.00	1	1.00
4	0.33	2.00	1.00	1

Appendix 4: Resulting weights using the AHP for the theme Environmental Health.

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons

	Category	Priority	Rank
1	Environmental Health	41.3%	1
2	Green- and Bluespaces	32.7%	2
3	Resilience	26.0%	3

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix

	1	2	3
1	1	1.00	2.00
2	1.00	1	1.00
3	0.50	1.00	1

Appendix 5: Resulting weights using the AHP between themes.

S01007410	S01008905	S01009560	S01010026	S01010198	S01010354	S01010450	S01010896	S01011395
S01007411	S01008906	S01009561	S01010029	S01010205	S01010357	S01010451	S01010900	S01011398
S01007461	S01008907	S01009571	S01010044	S01010208	S01010358	S01010453	S01010910	S01011399
S01007463	S01008916	S01009631	S01010048	S01010216	S01010359	S01010455	S01010911	S01011449
S01007465	S01008917	S01009787	S01010051	S01010217	S01010360	S01010458	S01010916	S01011457
S01007905	S01008918	S01009859	S01010052	S01010218	S01010386	S01010461	S01010920	S01011492
S01008500	S01008921	S01009907	S01010055	S01010222	S01010423	S01010478	S01010965	S01011521
S01008562	S01008933	S01009933	S01010132	S01010223	S01010424	S01010488	S01011010	S01011602
S01008704	S01009232	S01009935	S01010141	S01010228	S01010425	S01010489	S01011027	S01011675
S01008705	S01009234	S01009938	S01010142	S01010229	S01010426	S01010500	S01011029	S01011711
S01008708	S01009240	S01009940	S01010146	S01010239	S01010427	S01010501	S01011196	S01011795
S01008709	S01009301	S01009942	S01010148	S01010254	S01010430	S01010842	S01011290	S01011796
S01008710	S01009420	S01009943	S01010153	S01010256	S01010434	S01010848	S01011302	S01011801
S01008711	S01009435	S01009945	S01010154	S01010262	S01010436	S01010849	S01011304	S01012065
S01008712	S01009439	S01009948	S01010158	S01010272	S01010438	S01010850	S01011343	S01012066
S01008713	S01009446	S01009971	S01010167	S01010314	S01010439	S01010851	S01011360	S01012067
S01008714	S01009450	S01009982	S01010169	S01010320	S01010440	S01010856	S01011371	S01012068
S01008752	S01009451	S01009992	S01010179	S01010332	S01010442	S01010859	S01011373	S01012070
S01008787	S01009474	S01010022	S01010184	S01010347	S01010444	S01010880	S01011389	S01012071
S01008899	S01009489	S01010024	S01010197	S01010352	S01010447	S01010887	S01011390	S01012072
S01013205	S01013153	S01013132	S01013130	S01012674	S01012187	S01012083	S01012080	S01013075
S01013208	S01013156	S01013135	S01013122	S01012704	S01012219	S01012086	S01013361	S01012673
S01013222	S01013157	S01013138	S01013126	S01013027	S01012610	S01012148	S01013184	S01012155
S01013336	S01013169	S01013139	S01013127	S01013072	S01012651	S01012153	S01013140	S01013128

Appendix 6: Data zones classified as areas with high demand for CSGN interventions.