Master of Urban Climate and Sustainability (MUrCS)

Vulnerability and Glasgow Greendex

A Framework to Optimise the Impact of Green Infrastructure in Improving Socio-Environmental Vulnerability

Megi Zala

August 2020

Vulnerability and Glasgow Greendex

A Framework to Optimise the Impact of Green Infrastructure in Improving Socio-Environmental Vulnerability

Submitted in partial fulfilment for the requirements of Master of Urban Climate & Sustainability (MUrCS) by:

Megi Zala
S1839395

Glasgow Caledonian University, UK;
LAB University of Applied Sciences, Finland;
University of Huelva, Spain

Supervisors: Dr C Gallagher & Prof R Emmanuel

August 2020

Declaration

This dissertation is my own original work and has not been submitted elsewhere in fulfilment of the requirements of this or any other award.

Megi Zala

August 2020

Abstract

The aim of this dissertation is to investigate the socio-environmental vulnerability blended with the potential of GI in Glasgow to demonstrate how two different aspects such as social and environmental aspects that often are treated separately in relation to green infrastructure can be combined to archive a better comprehensive approach for the planning sector. Using the case study of Greater Glasgow, a development of a Greendex planning tool is proposed to investigate through simulation software to what extend it can be beneficial for the city.

The results demonstrate that GI depending of the urban structure has the potential to provide Glasgow with the diverse socio-environmental benefits and ecosystem services essential in combatting climate change and archive climate justice while preserving biodiversity. Nevertheless, the study has effectively communicated the potential and objectives where further research can be conducted.

This approach can be beneficial to prioritise decision-making by giving power to decisions based on evidences, with the focus where vulnerability and potentials are high. Given the versatile nature of this methodology, it can be replicated and adapted further for other case studies.

I dedicate this dissertation work to my beloved mother Afërdita and my aunt Mira. A special feeling of gratitude for all the sacrifices and the unconditional support throughout the years and for teaching me to always believe in myself and follow my dreams.

You have been my best examples in life.

Acknowledgements

Firstly, I would like to thank the ***MUrCS Consortium*** for believing in me and making this amazing experience possible. Nothing would have been possible without you.

To my supervisors, ***Dr Caroline Gallagher*** *and* ***Prof. Rohinton Emmanuel*** for their invaluable advice and assistance on this dissertation.

To ***Benjamin Fisher*** for his time and guidance on the spatial analysis techniques.

To ***Glasgow City Council*** for their assistance.

A special thanks to all the ***MUrCS family*** and this wonderful life and learning experience beyond expectations.

To my ***Dearests*** and our special friendship.

To my dear friends ***Kleona***, for always finding time to listen to me and reminding me how lucky I was; and ***Kiran***, who has always been there in guiding and grounding me with his valuable knowledge.

Thank you all

Contents

Declaration i

Abstract ii

Dedication iv

Acknowledgements iv

1 Introduction 6

1.1 Rationale 6

1.2 Research questions 7

1.3 Aim and Objectives 7

1.4 Disposition 8

2 Literature Review 9

2.1 Green infrastructure 9

2.1.1 The definitions and importance of GI for the planning process 9

2.1.2 Ecosystem services and benefits of GI 11

2.2 Case studies on the application of Green Infrastructure Index 13

2.2.1 Biotope Area Factor Berlin 14

2.2.2 Malmö Green Space Factor (GSF) 16

2.2.3 Seattle Green Factor (SGF) 16

2.2.4 Stockholm's Green Area Factor (GAF) 16

2.2.5 Southampton's Green Space Factor 17

2.2.6 London Urban Greening Factor (UGF) 17

3 Glasgow Study Area Profile 20

3.1 Presenting the Environmental Conditions 22

3.1.1 Urban Heat island 22

3.1.2 Flooding 23

3.1.3 Inequality distribution, accessibility and standard of green spaces 26

4 Research Method 29

4.1 Introduction 29

4.1.1 Research approach 31

4.1.2 Research strategy: CASE STUDY 31

4.1.3 Data collection 32

4.1.4 Data analysis 32

4.1.5 Introduction of the case study 32

4.2 Vulnerability Assessment 33

4.2.1 Social Vulnerability Analysis 37

4.2.2 Environmental Vulnerability Analysis 39

4.3 Potential of mitigation ***41***
4.3.2 Hotspot identification and site selection 42
4.3.3 Site analysis 43
5 Results 45
5.1 Introduction 46
5.2 Section 1 47
5.2.1 Social Vulnerability results 47
5.2.2 The Environmental Vulnerability results 52
5.2.3 Environmental Vulnerability summary 54
5.2.4 Socio-Environmental Vulnerability 56
5.3 Section 2 58
5.3.1 The adaptive capacity analysis 58
5.3.2 Hotspot Analysis of prior interventions 60
5.4 Section 3 60
5.4.1 Site selection and analysis 60
5.4.2 Results from ENVI-met simulations 62
5.4.3 Preliminary analysis of the Greendex 66
6 Discussion 69
6.1 Evaluation of the research method 69
6.2 Research findings 70
6.3 Limitations 71
7 Conclusions and recommendations for future studies 72
7.1 Conclusions 72
7.2 Recommendations 73
7.2.1 Recommendation for Glasgow City Council 73
7.2.2 Recommendation for further studies 73
8 Bibliography 75
9. Appendix 1 87
9.1 Specification on the simulation settings in ENVI- Met used for both the scenarios. 87

List of Figures

Figure 2.1. *Map of Berlin showing the distribution: (a) Per capita UGS provision, (b) population density by sub-district* ***15***
Figure 2.2. *SWOT analysis of a Green Infrastructure Index.* ***19***
Figure 3.1. *Glasgow City Green Infrastructure.* ***20***
Figure 3.2. *Percentage of full GI policy coverage by LDP and supplementary guidance for each local authority.* ***21***
Figure 3.3. *Annual Average Damages by flood source.* ***23***
Figure 3.4 *Glasgow has the highest number of zones classified as having above average social vulnerability to flooding.* ***24***
Figure 3.5 *Glasgow has one of the highest percentages of residential properties in local authorities exposed to surface water flooding.* ***24***
Figure 3.6 *Number of extremely or acutely flood disadvantaged neighbourhoods with respect to surface water flooding (%)* ***25***
Figure 3.8.*Networks for People Outputs, showing connectivity to Greenspace.* ***26***
Figure 3.9. *Glasgow Data Zones in Lowest (Worst) 15% of SIMD.* ***28***
Figure 4.1. *"The Research Onion" (Saunders et al., 2016).* ***29***
Figure 4.2. *VSD diagram.* ***33***
Figure 4.3. *Conceptual framework of vulnerability.* ***34***
Figure 4.4. *Flow chart of the methodology followed for site analysis.* ***43***
Figure 5.1. *Local Climate Zone Analysis for Greater Glasgow.* ***46***
Figure 5.2.*Distribution of green spaces per capita at datazone level.* ***47***
Figure 5.3. *Distribution of Income rate (a) and Employment rate per datazone (b).* ***48***
Figure 5.4 *Distribution of the health rate per datazone by indicators: CIF (a), Disability rate (b), Depression rate (c).* ***49***
Figure 5.5. *Distribution of Crime rate (a) and Sensitive population per datazone (b).* ***49***
Figure 5.6. *Map of network analysis and accessibility of green spaces Distribution (a) and Map of distribution of GS Service area per datazone (b).* ***50***
Figure 5.7. *Distribution of Social Vulnerability at datazone level.* ***51***
Figure 5.8.*Social vulnerability Pie Chart.* ***52***
Figure 5.9 *Distribution of NDVI for Greater Glasgow.* ***53***
Figure 5.10. *Distribution of land surface temperature for Greater Glasgow.* ***53***
Figure 5.11 *Distribution of flood vulnerability per datazone.* ***54***
Figure 5.12. *Distribution of the availability of green spaces per datazone.* ***54***
Figure 5.13. *Distribution of Environmental Vulnerability at datazone level.* ***55***
Figure 5.14. *Environmental Vulnerability Pie Chart.* ***56***
Figure 5.15.*Distribution of Socio-Environmental Vulnerability at datazone level.* ***57***
Figure 5.16. *Socio-Environmental Vulnerability Pie Chart.* ***57***
Figure 5.17. *Potential Distribution of GI (Cooling and flood mitigation).* ***58***
Figure 5.18. Distribution of vacant/derelict land by ownership. ***59***
Figure 5.19*. Hotspot analysis Map for prior interventions.* ***60***
Figure 5.20.*Spatial distribution of MRT (a,b),and PAT (c,d)at 15:00 for SITE 1 (a,b)* ***62***
Figure 5.21.*Spatial distribution of the difference of MRT (a) , and PAT (b) at 15:00 between the two scenarios.* ***63***
Figure 5.22. *Spatial distribution of MRT (a,b),and PAT (c,d)at 15:00 for SITE 2 (a,b).* ***64***
Figure 5.23. *Spatial distribution of the difference of MRT (left) , and PAT (right)at 15:00 between the two scenarios (Site2)* ***64***
Figure 5.24. *Profile of air temperature over time. Site 1: NST over time (a) / MRT over time (b) / PAT over time (c).* ***65***
Figure 5.25.*Profile of air temperature over time. Site 2: NST over time (a) / MRT over time (b) / PAT over time (c).* ***65***
Figure 5.26 *Profile of air temperature over time for green roofs. Site 1: / MRT over time (a) / PAT over time (b).* ***66***
Figure 5.27. *Profile of air temperature over time for green roofs. Site 2: / MRT over time (a) / PAT over time (b).* ***66***

List of Tables

Table 2.1. *Definitions of green infrastructure.* **9**
Table 2.2.*Classification of ecosystem services based on the Millennium Ecosystem Assessment.* **11**
Table 2.3. *A summarise of ecosystem services (ES) provide by green infrastructure (GI).* **13**
Table 2.4.*Summary of key differences of the GF applications.* **18**
Table 2.5. *Comparison of the factors attributed to individual GF .* **18**
Table 3.1. *Percentages of greenspace types in Glasgow .* **27**
Table 4.1.*Characteristics of a Positivism and Constructivist/Interpretive Paradigm.* **30**
Table 4.2. *Indicators, data collection and source.* **35**
Table 4.3.*The influence of selected Indicators on vulnerability.* **37**
Table 4.4. *The weightage of Indicators for Social Vulnerability for the overlaid maps.* **39**
Table 4.5. *The weights of the environmental indicators for the overlaid maps.* **40**
Table 4.6. *Classification of vacant land.* **41**
Table 4.7. *The Green Infrastructure Scoring system proposed for the city of Glasgow.* **42**
Table 5.1 *Social Vulnerability distribution across classes.* **51**
Table 5.2. *Environmental Vulnerability distribution across classes.* **55**
Table 5.3. *Socio - Environmental Vulnerability distribution across classes.* **58**
Table 5.4. *The Classification of vacant land by ownership.* **59**
Table 5.5.*Specifications of the site selected and details of the simulation model in ENVI-met.* **61**
Table 5.6. *The Greendex Scoring analysis for Site 1.* **67**
Table 5.7. *The Greendex Scoring analysis for Site 2.* **68**

Abbreviations:

BAF – Biotope Area Factor

ES – Ecosystem service

GCC – Glasgow City Council

GI – Green Infrastructure

GF – Green Factor

IUA – Inner Urban Area

LCZ – Local Climate Zone

LEZ – Low Emissions Zone

LST – Land Surface Temperature

MEA – Millennium Ecosystem Assessment Report

MRT – Mean Radiant Temperature

NDVI – Normalised difference vegetation index

NFRA – The National Flood Risk Assessment

NPF3 – National Planning Framework 3

OSS – Open Space Strategy

OUA – Outer Urban Area

PAN – Planning Advice Note

PAT – Potential Air Temperature

SAT – Surface Air Temperature

SEPA – Scottish Environment Protection Agency

SIMD – Scottish Index of Multiple Deprivation

UHI – Urban Heat Island

UGS – Urban Green Space

1 Introduction

Today 60% of the European population lives in cities. Urban growth and the increasing density in urban structures are putting green infrastructure under pressure by bringing to a reduction in the amount of vegetation and sometimes their loss, by causing extreme weather event *(European Commision,2017).*
Cities are taking important initiatives to mitigate and adapt to climate change, including the improvement and addition of green infrastructure. However, this being considered a relatively new concept for the planning sector have demonstrated uncertainties in the application that can lead to inequalities.
Using the case study of Greater Glasgow, this dissertation investigates the exposure, sensitivity and adaptivity to climate change in relation to GI and explore how a GI tool can be beneficial for city planners and its inhabitants.
With a working experience as a city planner, and being able to realise everyday's challenges in decision-making, this research has a particular importance to help city planners and as a variables for future research.

1.1 Rationale

In the last years, the city of Glasgow has taken significant initiatives in developing policies and strategies for climate mitigation and adaptation and has recognised the importance of green infrastructure on this matter. Only the last year, the city introduced the first Low Emissions Zone (LEZ) in the whole of Scotland and declared the ambitious target to become Carbon Neutral by 2030. Besides, other strategies were reviews lately and putting new standards for the city.

Nevertheless, despite all the achievement and progress of the city in the last decades in improving air quality and the livability, the effect of climate change is evident. Severe climate events are becoming more frequent and are affecting the quality of life and health of the residents.

Following this, Glasgow demonstrates to have an inequality distribution and accessibility of green spaces, where only 10% of Glasgow is classified as Public Park or Garden, only 1% of green spaces is located in city centre area and 17% in Inner Urban Area (IUA) *(Greenspace Scotland, 2018).* Other studies highlight s that the most deprived neighbourhoods reflect to have often a lack of green spaces or relatively poor access to green spaces (*Hislop et al., 2019).*

Therefore, in support of the current strategies, it is needed a new multi-dimension approach that can measure and quantify the benefits and focus in maximising the potentials by archiving a climate justice at the same time.

1.2 Research questions

This study concerns three research questions, with the focus on the Glasgow study area:

Research question 1: What is the pattern of socio-environmental vulnerability and mitigation potential for Greater Glasgow in relation to GI?

Research question 2: How socio-environmental vulnerability analysis can be seen as complementary in the planning process of implementing and investing on GI?

Research question 3: What is the role of a Greendex in the Glasgow context and how it can be beneficial to incorporate into the policies and initiatives toward climate change?

1.3 Aim and Objectives

This research aims to facilitate decision-making by identifying at datazone level the potential and vulnerability of implementing GI and further, to regulate and quantify the benefits with the use of a Greendex for Glasgow.

It has six main objectives as follow:

Objective 1: To explore the importance and benefits of Green Infrastructures and analyse the application of similar GI index through literature review.

This objective will be archived through a detailed literature review offering an understanding of the strengths and weaknesses on the integration of this planning tool summarised in a SWOT analysis.

Objective 2: Spatial analysis of the Environmental and Social Vulnerability pattern for Grater Glasgow at datazone level by taking in consideration a set of indicators.

Objective 3: Mapping the potential of Green Infrastructure by taking in consideration three indicators: land availability, cooling and flood mitigation potential within Greater Glasgow limits.

Objective 4: To integrate the potential of GI and socio-environmental vulnerability in creating a hotspot map that can help in decision making.

Objective 5: Establishing a classification of green infrastructure and developing a scoring system part of the new GI Index tool.

The objectives 2-5 will be archived based on the literature review and analysis of secondary data.

Objective 6: Evaluate the GI Index through microclimate program simulations (ENVI-met and ArcGIS) for two different scenarios: (a) Compact mid-rise; (b), Open low-rise area by taking in consideration the influence of vegetation.

The last objectives seek to establish standards based on finding from the previous objectives, playing an important role in decision making and as an initiative for further studies.

1.4 Disposition

This dissertation is structured into 7 chapters as follow:

Chapter 1 introduces a brief overview of the topic to understand the identified problems, outlines the aim, objectives and defines the scope of the study.

Chapter 2, provides the literature review by presenting an overview of the interdisciplinary GI concept, following with the benefits and ecosystem services provided by it and introducing the GI index concept illustrated with case studies applications. Further, a comparison of these applications is presented and summarised with a SWOT analysis and identifying the gaps of this urban planning approach.

Chapter 3 offers a comprehensive review of the Glasgow context by presenting the chronology of the initiative to incorporate GI concept into their policy and initiatives toward climate change. Further, the chapter presents the social and environmental conditions and the inequality distribution, accessibility and standard of green spaces based on literature and reports.

Chapter 4 outlines the proposed methodological framework (adopted from literature), to investigate the socio-environmental vulnerability and the adaptive capacity. This chapter explains the development of the new GI Index and the methodology used for the site selections and simulation models.

Chapter 5 encompasses the analysis and results presented in different sections. Twelve indicators are analysed through a spatial distribution analysis in ArcGIS. In addition, this chapter offers a comparative analysis of the two simulations occurred for the site selected.

Chapter 6 offers a discussion of the results and comparison with previous studies and similar implementations by summarising key findings and outline limitation*s.*

Chapter 7, consists in summarising the conclusions, followed by recommendations for GCC and potential future studies.

2 Literature Review

The focus of this chapter is to explore the definitions and importance of Green Infrastructure in spatial planning, its benefits and its implementation. In addition, it presents a background of the city of Glasgow, policies, progresses, and socio-environmental challenges in relation to green spaces.

Le Corbusier, a pioneer of modernism in architecture, design and urbanism called for bringing nature into cities, but still in today's world, the essence of humankind is to use nature for his own needs. Therefore, the essence of a harmonious city is to have a symbiosis relation with nature and emphasis on that. Today, it is argued that solutions to many of the contemporary urban challenges can be found in nature *(European Commission 2015).*

2.1 Green infrastructure

2.1.1 *The definitions and importance of GI for the planning process*

The concept of Green Infrastructure started developing in the United States in the 90' as a need from a growing concern of uncontrolled urban sprawl described as an extensive system of greenways 'an entirely new infrastructure category' *(Little, 1990).* The concept gained further attention in the context of sustainable development when there was an ungraded from "urban green space" to "green infrastructure" as part of the urban structure.

The concept of GI itself consists of two fundamental connotations, green which is associated with the environment and infrastructure as a structure of technical operation *(Mell, 2013).* There are several definitions of GI *(Table 2.1),* however the most used in the academic literature is from Benedict & McMahon (2006) that refers GI as a concept to manage networks of green spaces and their ecosystem services and can be viewed as a process that encourages land-use practices that benefits nature, people and ecosystems *(Benedict & McMahon, 2006).*

Table 2.1. Definitions of green infrastructure

Author/s	Definition
Kambite And Owen (2006)	'Connected networks of multifunctional, predominantly unbuilt, space that supports both ecological and social activities and processes' .

Tzoulas et al. (2007)	‘All natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales’.
Naumann et al. (2011)	‘The network of natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas‘.
European Commission (2013)	‘Strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings’.
Ely and Pitman (2014)	‘The network of green places and water systems that delivers multiple environmental, social and economic values and services to urban communities’ .
Mell (2017)	‘An effective climate-change mitigation measure that provides a wide range of ecosystem services, as well as social, environmental and economic benefits’.

Green infrastructure is considered as a network and is characterised by four characteristics: *multifunctionality*, *integration, connectivity and multi-scale* from regional to building level *(Hansen et al., 2014)*. Multifunctionality represents the ability of green infrastructure to provide a wide range of ecosystem services such as ecological, economic and socio-cultural benefits. Integration is the ability of GI to coordinate and integrate with other urban infrastructures in terms of physical and functional relations such as the built-up structure, transport infrastructure or water management system. Connectivity is presented as a planning principle *(Rouse & Bunster-Ossa, 2013*) and as a link for the green infrastructure system to work *(Benedict & McMahon, 2002).* A good example of these links are green corridors, greenbelts or greenways.

Green infrastructure has recently become a popular concept in planning. With a holistic approach, green infrastructure planning is considered strategic planning that aims to enhances and synergises benefits provided by nature, to promote ecosystem health and resilience, contribute to biodiversity conservation, enhance ecosystem services and create multifunctional networks from regional to the city to neighbourhood level *(Naumann et al., 2011, Hansen et al., 2019).* In contrast to the traditional planning, GI planning is considered more effective in handling the complexity of cities and open spaces *(Kambites and Owen 2006)* and more suited for urban areas characterised with social and ecological dynamic *(Pickett et al., 2011).*

From 2010 it has been observed an increase of awareness on the importance of including GI in national guidance, regional development plans, strategic documents and investments. In May 2013, the European Commission came with a strategy in promoting green infrastructure for the cities and regions. The strategy was focused on the potential of green spaces as the main contribution to sustainable development by highlighting the importance of Green Infrastructure for the cities in adapting to climate change and supporting the economy. This strategy provided advice and support on how to plan and develop Urban Green Infrastructure for cities. Today 10% of the EU budget is dedicated to GI policies and its implementations.

In addition to the concept of green spaces, GI is not only considered as a network of green features but as a planning delivery mechanism of interventions for specific fusions and benefits *(Hislop et al., 2019).*

2.1.2 *Ecosystem services and benefits of GI*

To create and archive a sustainable and resilient urban environment, green infrastructure is considered to be one of the most efficient strategic planning tools to prevent and mitigate the urban stress impacts, improving microclimate, improving ecosystem services and conserving biodiversity, supporting green economy and social interaction through the use of vegetated systems while providing public green spaces *(Green Surge,2017)*. The benefits of GI are widely recognised in the literature and originates in the 1970's, when ecosystem functions beneficial to humans were termed as "services" in order to raise awareness. Further, the concept started rising at the end of 1990's in publications *(Gomez-Baggethun et al. 2010)*.
The Millennium Ecosystem Assessment Report (MEA) from United Nations in 2001 presented a significant milestone to the policymakers, as it represented the first global assessment of ecosystem services. MEA stated that the risk of habitat and biodiversity reduction places the ecosystem services and human well-being in cities at risk *(Millennium Ecosystem Assessment, 2005).*
The term of GI refers to vegetation such as parks and gardens, natural and semi-natural urban green spaces, green corridors, amenity green spaces, blue infrastructure, soils and bio-engineered systems provide ecological services *(see Table 2.2).*
The MEA divides ecosystem services into four broad categories: Provisioning, Regulating, Supporting and Cultural that can be categorised on a larger number of ecosystem services. *Table 2.2* presents a summarise based on the Millennium Ecosystem Assessment *(Elmqvist et al., 2013, Ramyar et al., 2020).*

Table 2.2.Classification of ecosystem services based on the Millennium Ecosystem Assessment (derived from (Elmqvist et al., 2013, Ramyar et al., 2020).

	Type of ecosystem services
● *Supporting*	Ecological functions underlaying the production of ecosystem services.
● *Provisioning*	Goods obtained from ecosystems.
● *Regulating*	Benefits obtained from ecosystem processes.
● *Cultural*	Intangible benefits from ecosystems.
	Ecological services
● *Carbon storage*	Slow the accumulation of atmospheric carbon in urban areas. Depending on type of vegetation, soil type, and environmental conditions.

● *Noise pollution mitigation*	Reflect, refract, and disperse the sound energy by branches and trees. Depending on types of trees and leaves and their distance from and position in relation to the source of the noise.
● *Cooling*	Reduce temperature through shading and evapotranspiration. Depending on trees' position, their canopy size, the volume of irrigation (Pataki et al., 2011), their position in the streets (Ramyar et al., 2019), and their density (Xie et al., 2013).
● *Air purification*	Improve air quality by removing pollutants from the atmosphere. Depending on plants' characteristics, their position relative to the source of pollution, and the concentration of pollution (Derkzen et al., 2015).
● *Run-off infiltration*	Reduce run-off and increase underground water supplies through infiltration Depending on tree types, canopy types (including seasonal variations), the slope of the land, and soil types.
● *Food production*	Provide food security, especially during crises. Depending on types of trees, agricultural lands, and gardens.
● *Habitat provision*	Provide habitat for species affected by urban land-use changes. Depending on the health of the trees, patch sizes and the connections between patches (Naumann et al., 2011).
	Social-cultural services
● *Accessibility and recreation*	Provide manifold possibilities for recreation, and enhance human health and well-being.

Ecosystem services were originally defined as “the conditions and processes through which natural ecosystems and the species that make them up, sustain and fulfil human life” *(Daily, 1997).*

TEEB defines ES as direct or indirect services provided by nature that benefit the environment and humans *(TEEB,2011).* As stated by Oke, Urban Ecosystems are formed by the biological population of organisms (vegetation, people, animals) and the abiotic environment of cities. Having said that, urban ecosystems are the habitat of the majority of humanity, and they are created and reshaped in the process of urban transformation and development *(Oke et al.,2017).*

Further, the promotion of GI is considered as one of the most important climate change adaptation approaches that are capable to provide ecosystem services that can mitigate climate change *(Emmanuel & Loconsole, 2015)*. The benefits of green infrastructure and its ecosystem services are increasingly known from academics and planners. It can be grouped in three categories: environment, social and economic benefits for city residents *(Nature Scotland, 2014).*From the *environmental* aspect, GI has been shown to reduce air pollution including ozone and particulate matter *(Pugh, Mackenzie, Whyatt, & Hewitt, 2012),* increase carbon storage *(Strohbach & Haase, 2012*), stabilise climate through air filtration *(Jim & Chen, 2008)* and has a cooling potential on the local environment by reducing the urban heat island effect (UHI) *(O'Neill et al., 2009).* A study conducted by Gill et al. highlights that by adding 10% green space in high-density urban areas will maintain current summer temperature levels up to 2080 *(Gill et al., 2007).* Moreover, Bolund & Hunhammer highlight that grass surfacing reduces noise levels by up to 3 decibels compared to concrete paving *(Bolund & Hunhammer, 1999).*

Green infrastructure such as green roofs, rain gardens, swales etc, can reduce the water run-off through infiltration process and improve the quality of water through purification and manage flood risk *(Bolund & Hunhammar, 1999, Gill et al., 2007*). Surfaces covered by grass can absorb more than 2.54cm of rainwater without run-off *(Whiting et al., 2005)* and the increasing of greenspace could reduce run-off in residential areas by 5% *(Gill et al., 2007).* It provides habitat for different species, prevents fragmentation of different habitats and promotes biodiversity *(Forestry Commission, 2010).*

In economic terms, GI attracts businesses, increases inward investment and property values due to proximity to greenspace *(Gensler et al., 2011),* provides jobs for the natural environment *sector (Nature Scotland, 2014)*, and reduces energy consumption *(Simpson, 200*2). According to a study in 2008, the natural environment sector provided 2.7% of all jobs in Scotland *(RPA & Cambridge Econometrics, 2008).*

Further, GI has been linked to numerous social, community and well-being benefits, such as improving quality of life through the provision of recreational benefits (active and passive), increasing social capital, improving mental well-being by providing access to nature and food growing *(Byrne & Wolch, 2009, Nature Scotland, 2014, Coutts & Hahn, 2015).*

Table 2.3. A summarise of ecosystem services (ES) provide by green infrastructure (GI).

Regulating services: ○ Local climate and air quality ○ Carbon sequestration and storage ○ Moderation of extreme events ○ Water-waste treatment ○ Land regeneration	***Provisioning services:*** ○ Fresh water ○ Raw materials ○ Food ○ Medicinal resources
Cultural services: ○ Health and well-being ○ Stronger communities ○ Recreation ○ Tourism ○ Physical and mental health ○ Aesthetic appreciation and inspiration for culture ○ Spiritual experience and sense of place	***Habitat and supporting services:*** ○ Habitats for species ○ Maintenance of genetic diversity

2.2 Case studies on the application of Green Infrastructure Index

Green Infrastructure Index or differently called Green Factor is seen to be an important indicator in the planning process that serves as a guide to balance the ratio between the built and non-built environment. Depending on city's regulation and priorities, the GI Index can have a different focus in emphasising

specific ecosystem services as a parameter for urban qualities. This tool gives a weighted scoring system to green features according to their ecological value, and it is mostly used for new developments.
The concept of this strategic planning tool originates in Berlin and later on, has been adapted and applied in other cities. The following sections present similar implementations of this tool on different cities and give an overall picture of the achievements, uncertainties and comparison between the case studies. Some of the case studies give the opportunity to co
Some of the case studies, in complementary to the GI Index have created a Green Points System giving a checklist for more combinations of blue and green infrastructure, to help developers in archiving the minimum target.

2.2.1 *Biotope Area Factor Berlin*

The first initiator in creating a green factor tool was the City of Berlin. The tool was called "Biotope Area Factor" (BAF) and started its implementation in 1997. This tool established a new standard in the urban environment by requiring green infrastructure enhancements on private properties, a proportion of the area to be left as a green space and expresses the ratio of the ecologically effective surface area to the total land area.

BAF = Ecologically Effective Surface Areas/Total Land Area

The instrument includes three components: a set of ratings, a set of targets and the final ratio determined for each parcel, where the first two are established by municipal planners by determining the scope of the metric system and the third Is generated by the developers of the parcel in order to meet the standards *(Keeley, 2011).*

As an urban site sustainability metric, BAF's target is variable and depend on the specific uses of an area. Public and residential areas need to archive a higher target of 0.6 meanwhile administrative, commercial and business need to archive a lower target of 0.3. Different surface covers have a different attribution score depends on its permeability, evapotranspiration capacity, the possibility to store rainwater, type of soil and habitat for plants and animals *(Becker & Mohren, 1990).*

Although Berlin's Senate Department of Urban Development declared Berlin as one of the greenest cities in Europe with approximately 33% of green areas, they acknowledge that GI provision is not equally distributed over the total city area *(Senatsverwaltung für Stadtentwicklung und Umwelt, 2013).* In 2013, the city administration of Berlin defined two targets addressing the accessibility of green spaces: with a minimum 6 m2 of green space per inhabitant and a maximum walking distance of 15 min to the nearest green space *(BSDUDE, 2013).*

Most of the sub-districts areas in Berlin meet the threshold value of 6 m2 of green spaces per inhabitant, but studies highlight a negative relationship between the provision of GI and population density. Thus inner-city districts have a smaller provision of GI per capita *(Coppel & Wüstemann, 2017, Kabisch & Haase, 2014).*

Researchers suggest that from a distributive perspective, planners should consider who is using the green spaces including who lives in a walking distance not only to the park but to park entrances and therefore more likely to use it *(Coppel & Wüstemann, 2017).*

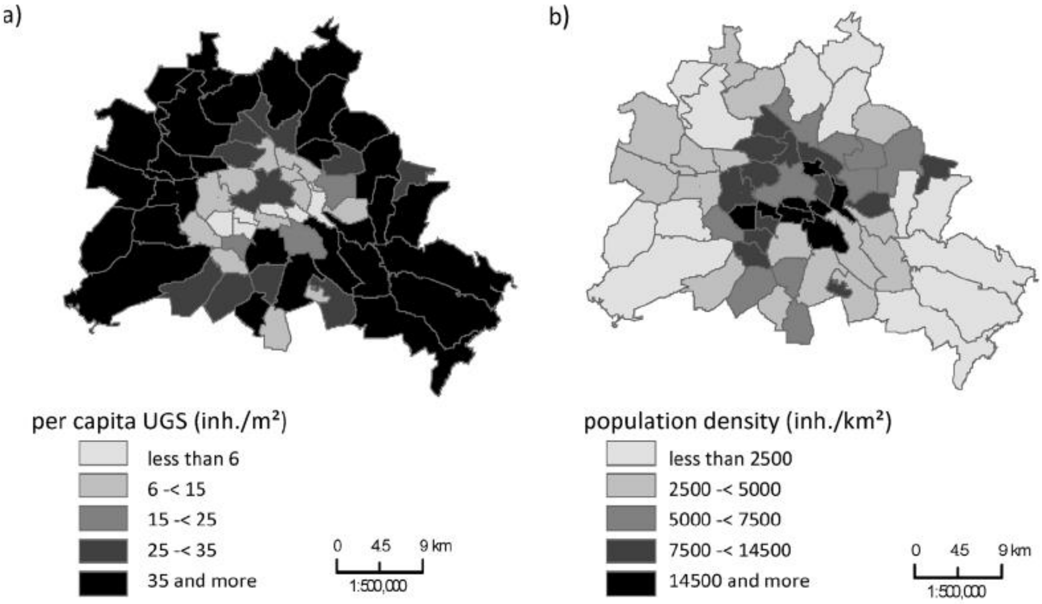


Figure 2.1. Map of Berlin showing the distribution: (a) Per capita UGS provision, (b) population density by sub-district (Kabisch & Haase, 2014).

A study from Kabisch & Haase *(2014)* highlighted the lack of green spaces on sub-districts where there was a high concentration of immigrants and high population density. In the context of Berlin, accessibility and availability of green spaces are seen to be more important than the size itself.

However, it is importance to acknowledge the positive impact on the development of green spaces in the city for the last two decades with the implementation of BAF, where numerous brownfield areas have been converted in green spaces (*Senatsverwaltung für Stadtentwicklung und Umwelt, 2013*) and the solutions on the way that the natural environments of cities provide against climate change-induced heat stress *(Kabisch, 2015).*

2.2.2 *Malmö Green Space Factor (GSF)*

Malmo GSF started implemented in 2001, similar to the Berlin Factor but developed to make it applicable in the conditions of Southern Sweden. Malmo initially has developed a specific Green Space Factor called Bo01 for a specific ecological residential area in Western Harbour and began developing the Green Points System, in order to mainstream biodiversity concerns into urban planning, reduce the run-off and enhance the greenness of dense developments *(Kruuse,2015).* After GSF was tested for this site that intends to be finalised by 2030, it became mandatory for the whole city. Malmo, being a post-industrial city, aims to use this factor not only for the new development but also to enhance regeneration projects and refurbishments. From a list of 35 features, developers are obligated to consider and combine a minimum of 10 features to reach the minimum target required. A minimum target of 0.6 was necessary to secure for residential and schools, while 0.5 was needed for commercial/office.

2.2.3 *Seattle Green Factor (SGF)*

Seattle was the first US city to adopt the GI Index since 2006. Like other tools, it is also a score-based code that aims to improve the quality of landscaping in new development, with the main focus on manage stormwater run-off, aesthetically enhance neighbourhoods, and improve biodiversity. In Seattle, exceeding the minimum targets set for land use classification makes it possible to negotiate on the permitted building volume for the lot so that more area per floor can be built on a private lot (commercial or residential) if the amount of green surfaces in the area increases accordingly *(Urban Land Institute, 2015).*

The implementation phase for the city of Seattle went into different stages. When it was firstly introduced in 2006, it was a mandatory process only for new development under the Commercial and Neighbourhood-Commercial zones. Further, in 2009 it was introduced to Mid Rise and High-Rise zones and lately to Low Rise Multifamily zones, South Downtown Planning Area, and Urban Centre. The Scoring system required is different for every zone, where residential zones need to archive a higher target compared to commercial or industrial areas. Overall, the minimum target to be archived is 0.3, similar to the case of Berlin.

The SGF reflects that higher priority score was given to GI that has higher retention potential and extra bonus credits to developers that use irrigation systems with harvested rainwater.

2.2.4 Stockholm's Green Area Factor (GAF)

With the increase of urban density, the city of Stockholm started promoting green spaces and ecosystem services to improve urban quality by developing its own version of Green Area Factor (GAF) with more ambitious targets. Similar to Berlin (BAF), the GAF has a minimum score of 0.6, but in addition to it the tool includes more than 50 elements that affect green factor score. It has integrated a wider detailed list of possible features, offering wider possible combinations by giving additional scores and features emphasising more on the climate impact, landscape ecology, biodiversity and social aspect. The tool was implemented on specific development projects, such as the Royal Urban Seaport, an existing industrial site that would redevelop as an environmentally sustainable neighbourhood.

(GAF) has made it mandatory for new developers in Stockholm to integrate GI into the project since the very beginning and as a first step of the planning documents. Further, this planning tool is calculated per district, making it obligatory in many cases for developers to collaborate in attaining the minimum required per district on common ground. In contrast with other Green factors, the case of Stockholm presents an integrated collaborative approach between different actors through an innovative business model.

2.2.5 Southampton's Green Space Factor

Southampton was the first city in the UK to adopt the Green Space Factor from 2015 in support of Green Space Strategy. It aimed to maximise the opportunities offered by new development in creating new GI with a main focus in the city Centre and encouraging initiatives within the city administrative area.

The purpose of the tool was to easily quantify the improvement of green spaces and comes as part of a Sustainability checklist with no minimum score required. Rather than a strict score, the tool serves as a mediator by bringing discussion between the council and developers to set specific targets as part of the application process.

2.2.6 *London Urban Greening Factor (UGF)*

London is one of the latest cities adopting the Urban Greening Factor. The strategy was incorporated in the urban policy with the aim to unsure better-planned greening under the pressure of a growing city. Similar to other tools, the London UGF helps to evaluate and quantify urban greening and decide the appropriate greening for new developments. According to their policies, the tool will have a multi-dimensional focus in improving air/water quality, cooling the urban environment, flood mitigation, enhance biodiversity, improve health living standard and encourage walking. Boroughs can develop individual targets where a minimum target 0.4 is recommended for residential developments and 0.3 for predominantly commercial developments. Different from other case studies, the city of London has created a Green Infrastructure Focus Map as a complementary tool of which 29 environmental and health indicators are considered to identify where investment and focus should be addressed and what kind of investment are mostly needed to a particular area.

Table 2.4 summarises the key differences between the GF presented in this chapter *(derived and adapted from Vartholomaios et.al 2013)*.

Table 2.4.Summary of key differences of the GF applications (derived from (Vartholomaios et.al 2013).

	Case studies					
	Berlin	**Malmo**	**Seattle**	**Stockholm**	**Southampton**	**London**
Name of the tool	*Biotope Area Factor*	*Green Space Factor*	*SeattleGreen Factor*	*Green Space Factor*	*Green Space Factor*	*Urban Greening Factor*
Area of application	Mandatory only for areas with Landscape Plan. Voluntary for the rest of Berlin.	Mandatory for new devellopment and regeneration projects	Mandatory for new comercial and multi-family developments.	Mandatory for new development. District score - Necesary the collaboration between developers	Mandatory for new comercial and multi-family developments.	Mandatory for new development.
Minimum target	0.3 - commercial 0.6 - residencial	0.6	0.3 - commercial / city centre 0.5-0.6 - multifamily development	0.6	No minimum specified	Boroughs can develop individual targets. 0.3 -commercial 0.4 - residencial
Layering	no	yes	yes	yes	yes	yes
Green points	no	yes	no	no	yes	no

The same study from Vartholomaios et.al (2013) presented a summarise where it has been compared in a simplified way the factors given to different individual features on the application of Green Factor in different cities adapted in *Table 2.5.*

Table 2.5. Comparison of the factors attributed to individual GF (adapted from (Vartholomaios et. al., 2013).

Surface cover type	Case studies					
	Berlin	**Malmo**	**Seattle**	**Stockholm**	**Southampton**	**London**
Vegetation on shallow unconnected soil	0.5	0.7	0..1	0.3	0.4	0.4
Vegetation on deep unconnected soil	0.7	0.9	0.6	1.2	0.6	1
Vetetation on connected soil	1	1		0.2	1	0.8
Water surface	N/A	1	0.7	N/A	1	1
Collection/ retantion of storm water	0.2	0.2	1			0.7
Permeable pavemeent and partially-sealed are (no vegetaion)	0.3	0.2	0.2 / 0.5		0.2	0.1
Area covered with gravel or sand		0.4			0.4	0.1
Green pavers	0.5	N/A			N/A	0.5
Structural soil system	N/A	N/A	0.2		N/A	N/A
Shrub	N/A	0.2	0.3	0.2	0.3	0.6
Tree - small		1	0.3	1	0.4 per m2 of canopy cover	0.6-0.8
Tree - medium		1.5	0.4	1.5		
Tree - large		2	0.4	2.4		
Tree - poretedted / exeptional		N/A	0.8	3		
Green roofs	0.7	0.6	0.4 / 0.7	0.1 / 0.4	0.7	0.3-0.7
Vegetation on vertical surfaces	0.5	0.7	0.7	0.4	0.6	0.6
Bonuses for specific vegetation qualities	no	no	yes	yes	no	no

Although it can be clearly observed that the tools are relatively similar by having a similar ecological aim, there is a difference in prioritising the ecosystem services. For instance, cities with higher vulnerability to flooding have prioritised permeable pavements, retention of stormwater and blue infrastructure by giving a higher scoring. In the other hand, other cities with the primary focus in improving urban life and biodiversity, have given a particular focus to soil vegetation and trees. In most the cases green walls and green roofs have given similar scoring taking into consideration the projection of 5-year coverage.

All the studies reflect similarities following the approach adopted in Berlin. Most of the case studies reflect how the scoring system and their policies have involved throughout the years, proving that the initial implementation was not entirely successful and at the same time, gives a good example of the learning process.

To conclude, a lack of policy action based on scientific findings can lead to various uncertainties because of missing knowledge or weak implementation processes *(Wilkinson et al., 2013).*

A summerise of this concept giving a general panorama from different literature is presented and summarised in the form of a SWOT analysis by identifying the strength, weaknesses, opportunities and threats of a Green Infrastructure Index tool.

Figure 2.2. SWOT analysis of a Green Infrastructure Index

3 Glasgow Study Area Profile

The Scottish government has recognised the importance of green infrastructure and greenspaces across the country with the publication and adaptation of a wide range of policies and strategies in climate adaptation, planning and placemaking. Policies such as Climate Change Scotland Act (2009), the National Planning Framework (NPF3) or Green Infrastructure- Design and Placemaking, Planning Advice Note (PAN), Central Scotland Green Network, Regeneration Strategy, National Walking Strategy, Good Places, Better Health, Scotland's Biodiversity Strategy, and The Community Empowerment Act give a special attention to it by setting it as a main agenda and by generating new requirements for local authorities in enhancing and promoting green space and green infrastructure, improving the quality of life and encourage new investments and developments to contribute in the economy.

Glasgow City Council has already started implementing the Local Development Plan, Glasgow Open Space Strategy (PAN65) *(Figure 3.1),* Glasgow and Clyde Valley Green Network Partnership (GCVGN), Surface Water Management Strategies, City Centre Strategy, Action Plan and Supplementary Guidance (SG6) by prioritising the integration of greenspace and GI.

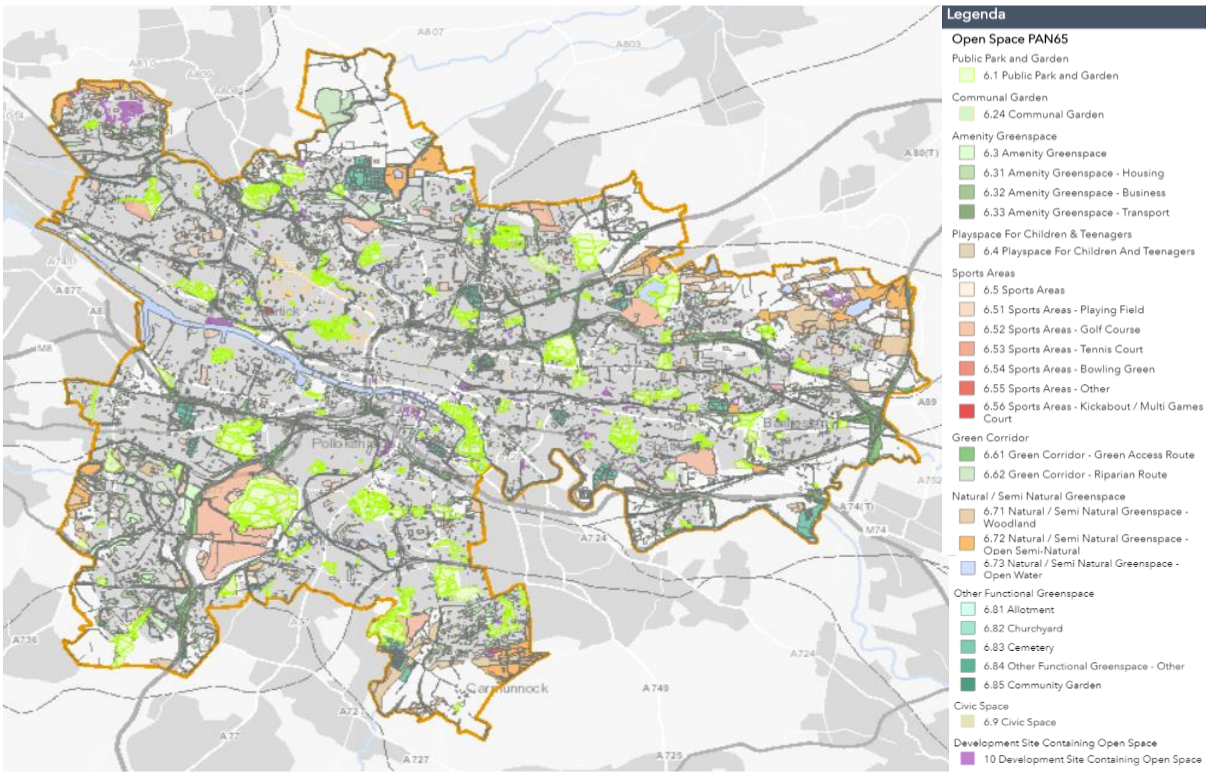


Figure 3.1. Glasgow City Green Infrastructure (Open Space PAN65)

With the publication of the Planning Advice Note 65, was a recognition of the importance of creating successful places and promotes effective links between the planning, design and management of open spaces. This document explained the values and importance of open spaces and created a classification of them and raised the requirement of a greenspace approach for a strategy that protects and enhances these spaces extending and linking them where feasible *(Planning Advice Note 65, 2008).* This document identified 10 categories of open spaces as protected: public parks and gardens, communal private gardens, amenity space, play space for children and teenagers, green corridors, natural/semi-natural greenspace, civic space, sports areas, allotments & community gardens, other functional greenspaces (including churchyards and cemeteries).

In December 2018 Glasgow was the first city in Scotland introducing Low Emissions Zone (LEZ) for the city centre to local bus services and in in May 2019, Glasgow City Council declared a climate and ecological emergency for the city recognising once again the challenges and impact of climate change for the city, people and nature by revising strategies and current targets. Furthermore, in September 2019 the city declared the ambitious target to become Carbon Neutral by 2030.

In February 2020, the revised Open Space Strategy was published with the aim to achieve a network of good quality, multi-functional, and well distributed GI, that will contribute in improving liveability, health and wellbeing and strength resilience by 2050.

Currently, GCC is working on several projects for the Glasgow City Centre 2050 Program, City Centre Strategic Development Framework and City Centre Living Strategy, Vision 2035. At Policy level the City of Glasgow is considered to have the highest coverage level of GI policies in Scotland with a total full coverage of 87% , from which 40% coverage in the Local Development Plan (LDP) and 47% of coverage in the Supplementary Guidance (SG) *(Figure 3.2) (Hislop et al., 2019)*.

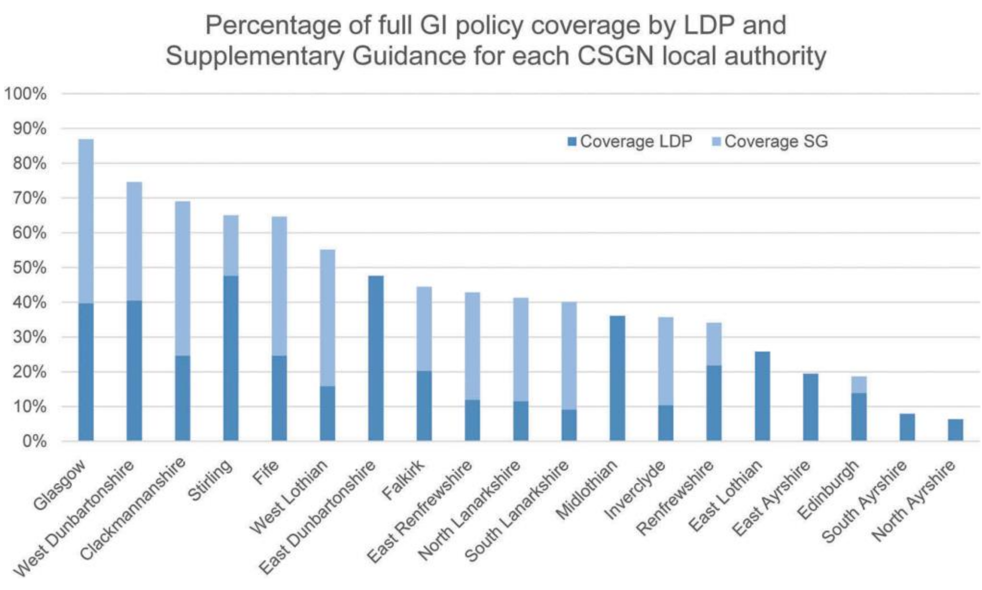


Figure 3.2. Percentage of full GI policy coverage by LDP and supplementary guidance for each local authority.(Source: Hislop et al., 2019, Hislop & Corbett, 2018, p. 24)

Nevertheless, there are still gaps at the policy level with the local authority in managing GI and in prioritising decisions in which research can be extended *(Gray & Barford, 2018).*

3.1 Presenting the Environmental Conditions

3.1.1 *Urban Heat island*

While a warmer climate for Glasgow can be considered as beneficial for the lifestyle and consequently more outdoor activities, the current housing infrastructure is not prepared to perform efficiently under heat stress. In Glasgow, it has been observed an increase of temperature by 1oC between 1961 and 2004 and a higher rise it is expected by 2050 *(Adaptation Scotland, 2017).*

Urban Heat Island effect was originally defined as the phenomenon whereby air and surface temperatures in towns and cities are elevated in relation to surrounding rural areas *(Oke, 1982).* Studies have found a relation between the UHI effect and air pollutions, where twelve per cent (12%) of air pollution in urban areas is attributed to the urban heat island effect, due to formation of pollutants volatile organic compounds (VOCs) and ozone as a temperature-dependent *(Beckett et al.,1998).*

Further, Heidt and Neif have identified two main factors that cause the UHI: lack of vegetation in urban areas and the absorption of direct solar radiation by buildings and other man-made surfaces (Heidt & Neif, 2008). UK Climate Projections (UKCP09) predicts that climate change may lead to warmer and drier summers. Reports highlight that for the city of Glasgow there was an increase of approximately 200 Ha of impermeable surfaces between 2008 – 2015 in the city and likely a negative effect from Urban Heat Island (UHI) due to trapping of solar radiation from the urban form, wasted heat and air pollutions *(ClimateXChange, 2016).*

The intensity of UHI in Glasgow can reach up to 4°C under certain atmospheric conditions, but yet there are uncertainties on determining the factors for explaining the local UHI *(Kruger, Drach and Emmanuel, 2018).*

A study of the cooling effects of GI conducted by Emmanuel and Loconsole has identified that a third to a half of the expected extra UHI effect in Glasgow can be eliminated by increasing the green cover of the city by approximately 20% over the present level by 2050 and can reduce the surface temperature by up to 2oC *(Emmanuel & Loconsole, 2015).*

Moreover, studies highlight that interventions are important in key areas where they can have the greatest equitable impact, areas that can be able to mitigate climate risks *(Emmanuel et al.,2014).* Glasgow City Council in collaboration with Greenspace Scotland have been working for "The Five Streets project" in implanting and retrofitting green spaces into existing urban areas, with a mainly focus in the city centre in order to reduce UHI, by beginning with Sauchiehall Street.

3.1.2 *Flooding*

In the last decade, severe weather events are becoming more frequent. For Scotland, the average rainfall of the last decade (2009- 2018) was 15% wetter compared with the average on 1961-1990 with winters 25% wetter *(Kendon, et al., 2017).* A total number of 161 weather events were reported in Glasgow between 1991 and 2009 *(GCC,2010).*

The National Flood Risk Assessment (NFRA) for Scotland, published by SEPA in 2011, highlights that 1 in 22 of all residential properties in Scotland is at risk of flooding from any source (sea, river and surface water), considering the 1 in 200 years return period *(SEPA,2011).*

The city of Glasgow has a long history of surface water-related floods with the position of river Clyde flowing throw the main city. With the increase of sea level, climate projections highlight a rise by approximately 70cm by 2070, posing more risk the city.*(Adaptation Scotland, 2017).*

With river Clyde presented as a risk, the Clyde and Loch Lomond Local Plan District and SEPA report that 68% of the average annual damages are caused by surface water flooding and 32% from coastal flooding *(Figure 3.3) (SEPA,2015).*

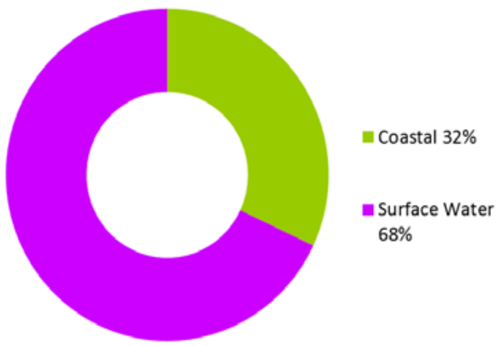
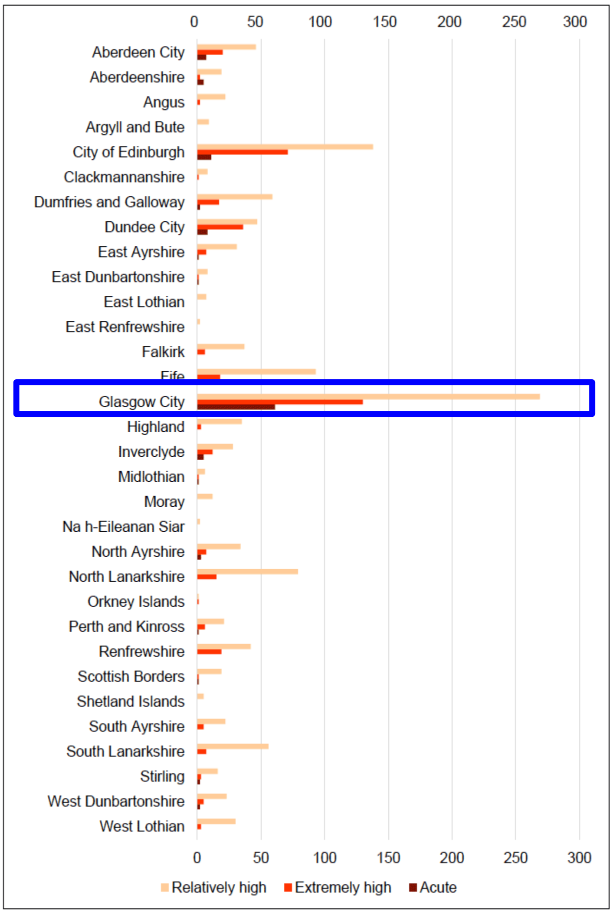


Figure 3.3. Annual Average Damages by flood source (SEPA,2015).

According to a report published in 2015 from Scottish Government "Mapping flood disadvantage in Scotland 2015" where flood types have been classified by return period, more than 250 zones are classified as relatively high risk of flooding, more than 120 as extremely high and more than 50 zones as acute (*Figure 3.4 – Figure 3.5)*.



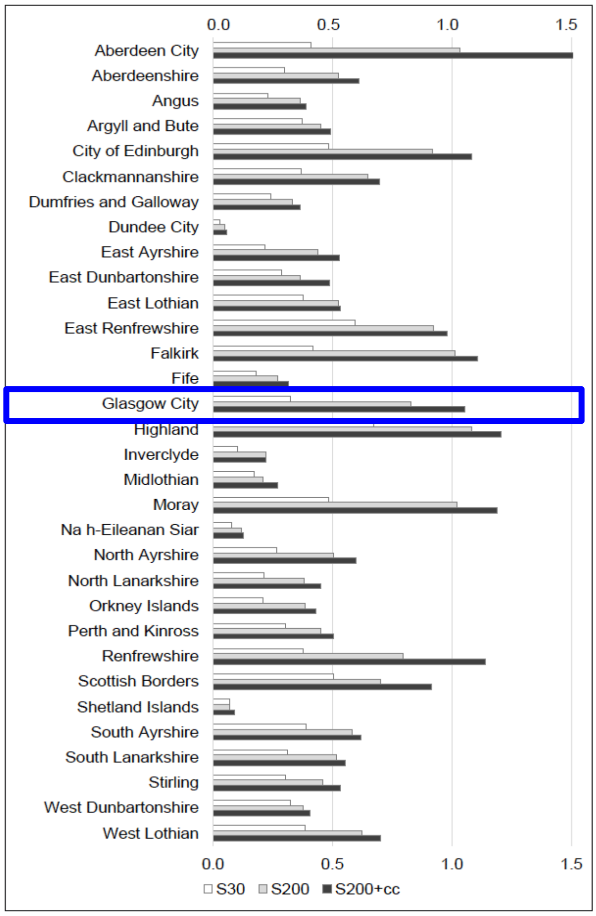
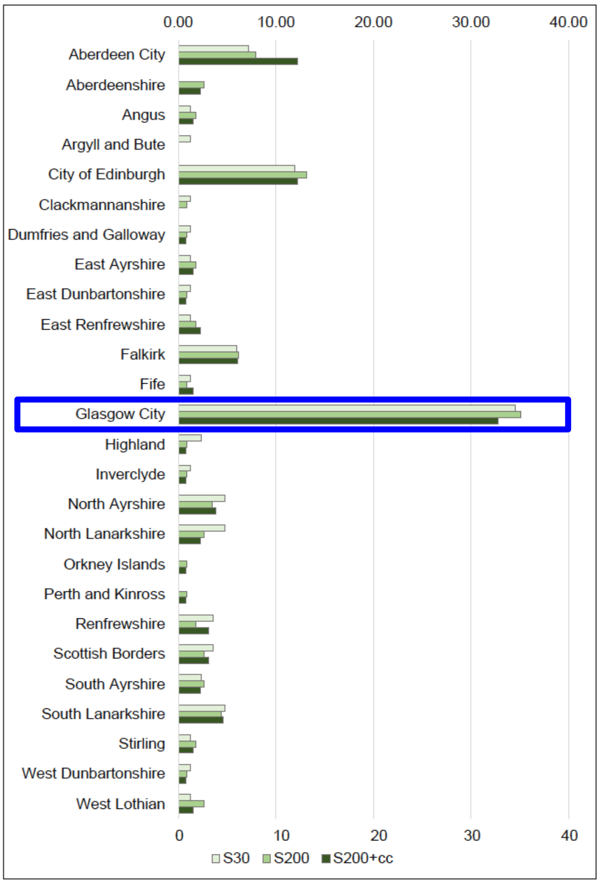


Figure 3.4 Glasgow has the highest number of zones classified as having above average social vulnerability to flooding (Kazmierczak, et al., for Scottish Government,2015).

Figure 3.5 Glasgow has one of the highest percentages of residential properties in local authorities exposed to surface water flooding(Kazmierczak, et al., for Scottish Government,2015).

Further, Glasgow has a total number of 191 zones classified as extremely high or acute vulnerability to flooding, which demonstrates one-third of the total zones in Scotland and presents the highest concentration of surface water flood disadvantage*(Figure 3.6 - Figure 3.)* (*SEPA, 2015).*



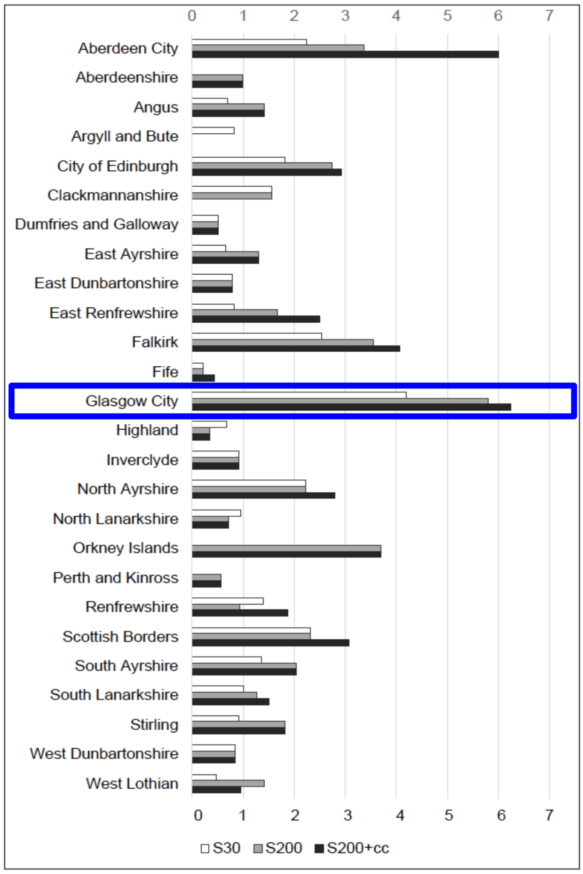


Figure 3.6.Percentage of extremely and acutely flood disadvantaged neighbourhoods with respect to surface water flooding in local authorities (Kazmierczak, et al., for Scottish Government, 2015).

Figure 3.7 Number of extremely or acutely flood disadvantaged neighbourhoods (from the named local authority) with respect to surface water flooding (%) (Kazmierczak, et al., for Scottish Government,2015).

Having said that, cities today suffer from the impact of impermeable urban grounds that bring more than 90 percent of rainfall into run-off and urban sewage collected in the system. Urban green spaces and GI can serve as a system that can reduce the flow by increasing the permeability (*Gill, Handley, Ennos, & Pauleit, 2007*). A study made by Bonan, states that urban landscapes with coverage between 50-90% of green spaces have a potential of infiltrating 40-83%of run-off *(Bonan, 2015).*

Vulnerability studies and infrastructure investment on flooding have been a priority in the last years for both central and local government. Various agencies and stakeholders such as the Scottish Environmental Protection Agency (SEPA), Scottish Water and The Metropolitan Glasgow Strategic Drainage Partnership (MGSDP) have taken several studies in identifying and mapping potential flood surface areas, taking actions in preparing flood plan such as Surface Water Management Plans (SWMPs) and flood kit, adopting policies in order to include the provision of new green infrastructure and maintaining water courses and public sewer network in order to cope with existing flood risk and a changing climate.

The new adapted Open Space Strategy (OSS) for Glasgow, published in February 2020 highlights the importance of integrating the multi-functional Green Infrastructure approach wherever investment is delivering new flood management infrastructure with a main focus on The Metropolitan Glasgow Strategic Drainage Partnership (MGSDP) *(GCC,2020).*

3.1.3 *Inequality distribution, accessibility and standard of green spaces*

The city of Glasgow has a significant inequality mostly associated with economic decline, high vulnerability to flooding and lately climate change as a higher risk on increasing further this inequality. The negative impacts of climate change are likely to be felt by the most already vulnerable groups *(OSS,2020).* Therefore, studies pointed out that this should bring new mechanisms and tools in order to reduce vulnerability in a more effective way *(SNIFFER, 2017).*

The city demonstrates an inequality distribution of green spaces where only 1% of green spaces is located in city centre area, 17% in Inner Urban Area (IUA) and 82% in the Outer Urban Area (OUA) (*Figure 3.) (OSS, 2020).* Further, proximity to green spaces has been considered as a determining factor in its use and with the increase in the elderly population will become a stronger indicator of use *(De Oliveira & Mell, 2019).*

Therefore, the supplementary Guidance SG6 (2017) in support of the City Development Plan and Open

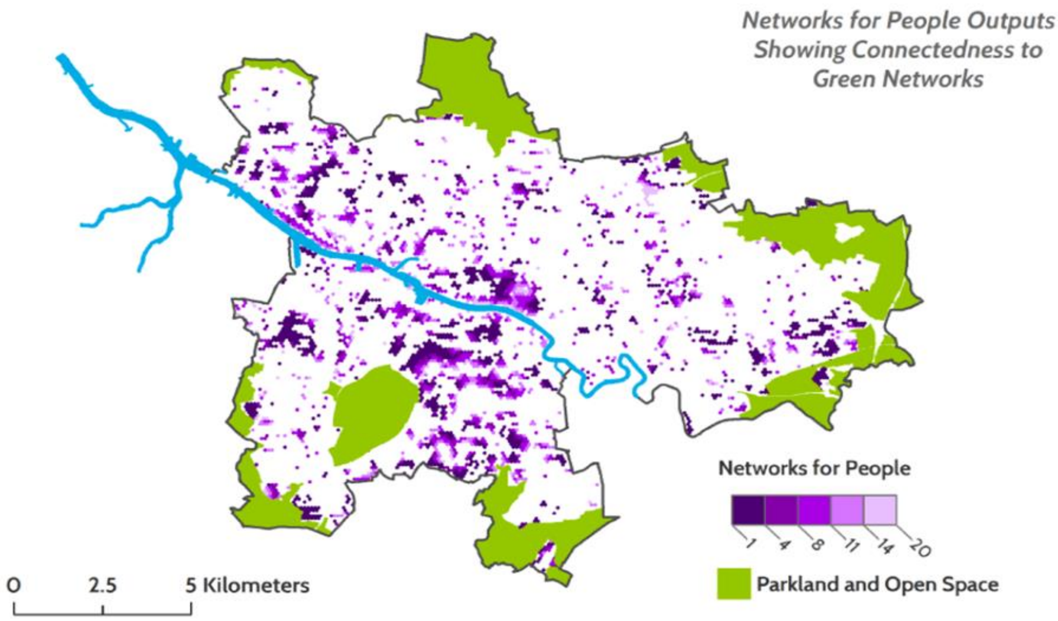


Figure 3.8.Networks for People Outputs, showing connectivity to Greenspace. The lower the NfP score, the more disconnected that 100 m cell is from the Green Network (model output of green network). Data Sources: U.K. Ordnance Survey (basemap layers); Glasgow and Clyde.

Space Strategy (OSS,2020) has set new quality, quantity and accessibility standards for open spaces for the planning process. SG6 highlights the importance of *accessibility* and recommends that “homes (including purpose-built student accommodation), out with the City Centre, should be within a 400m actual walking distance of a good quality, publicly usable open space of 0.3 ha or more” (SG6,2017). Studies conducted by Mell outlines that the promotion and accessibility of green spaces is a major objective for GI planning *(Mell, 2013).*

Researchers have observed that in different cities, multiple deprived neighbourhoods with health challenges have often a lack of green spaces, relatively poor access to green spaces or lack of maintenance (*Hislop et al., 2019)*. Based on the Third State of Scotland’s Greenspace Report 2018, 40% of Scots say that the quality of their local greenspace has reduced in the past 5 years. 90% of urban Scots say it is important to have green space in their local area and 43% wants to get involved in activities to improve their local greenspace *(Greenspace Scotland,2018).* Further, this report states that only 10% of Glasgow is classified as Public Park or Garden, and 30% is considered Private Garden *(Table 3.1) (Greenspace Scotland, 2018).*

Table 3.1. Percentages of greenspace types in Glasgow (Greenspace Scotland, 2018).

Local Authority	Public Park Or Garden	Private Garden	School Grounds	Institutional Grounds	Amenity	Play Space	Playing Field	Golf Course	Tennis Court	Bowling Green	Other Sports Facility
Glasgow City	10%	30%	3%	2%	39%	<1%	2%	4%	<1%	<1%	2%

Glasgow being a post-industrial city still faces consequences such as having the largest area of the city authorities of a derelict and vacant land consistently for the past years (2012-2018). Reports confirm that Glasgow has 9% of the Scotland total derelict land of 1,005 hectares and the most urban vacant land in Scotland with 425 hectares, 35.6% of the total in Scotland. In Glasgow it is estimated that 60.1% of the population live within 500 metres of a derelict site *(Greenspace Scotland,2018)*. One of the recommendations from Climate Emergency working group include utilising the City open space and vacant and derelict land to help deliver carbon savings and and improve Green spaces and accessibility *(OSS,2020).*

The quality and quantity standard set by the supplementary Guidance SG6 promote and state that “there should be 1.9Ha of publicly usable open space per 1000 people in the Inner Urban Area and 5.5ha of publicly usable open space per 1000 people in the Outer Urban Area” and “Community Spaces, whether existing or proposed, should, when considered against the Quality Assessment Matrix, achieve a minimum overall score of 75% of the total possible score".

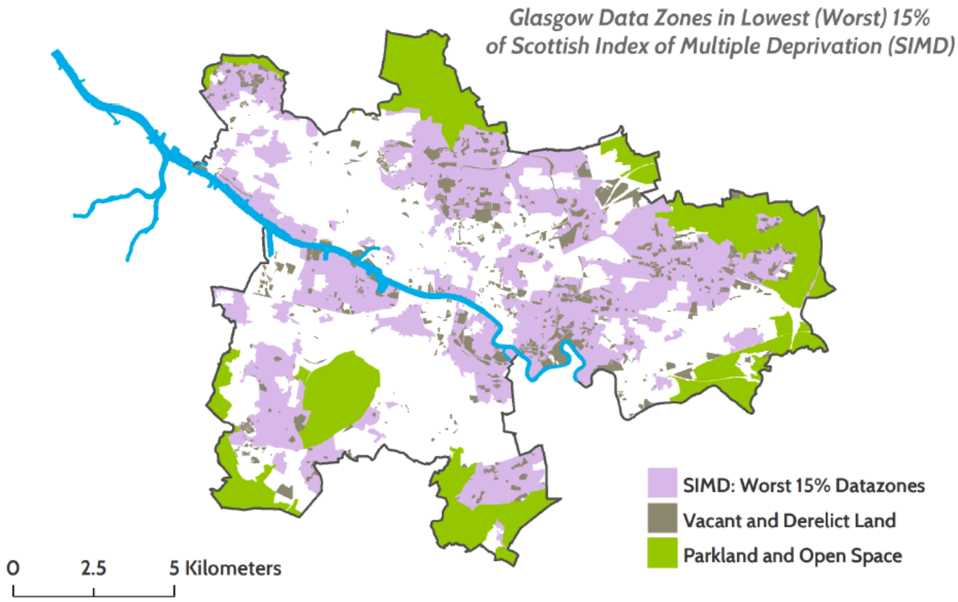


Figure 3.9. Glasgow Data Zones in Lowest (Worst) 15% of SIMD. (Vacant and Derelict Land Survey, Scottish Government, 2012; Scottish Index of Multiple Deprivation, General Report and Technical Report,2012)

To conclude, Glasgow presents complex socio-environmental conditions, where it is demonstrated a lack of public green spaces, high availability of vacant land, high vulnerability to flooding and risk of heat stress. Intensive progress is made from local and central authorities to address these problems at policy level. However, there are still gaps that require more attention such as policies that can help in supporting the actual policies on GI and help in decision-making.

An example of these can be the Green Infrastructure Index that can embed and support these policies and/or archived on the ground. The contribution of Green spaces/green infrastructure in environmental and sustainability benefits is not equal. Therefore, the weighting system of an index gives a relative environmental performance to the different type of green covers (*Emmanuel & Loconsole, 2015).* Recognising these, the GI Index for a city like Glasgow, will not solve all the climate and environmental problems of the city, but the scoring system has the importance of prioritising decision making, assisting developers and planners and tackle Socio- Environmental needs based on vulnerability and demand to archive it on the ground level and to assist developers and planners in the process.

4 Research Method

4.1 Introduction

This chapter presents the research methodology, philosophical approach and the set of data used for the study. A multi-approach method was used, taking in consideration different methods and data sources to help build and analyse the subject in the context of Glasgow.

The research for this dissertation consists of three sections:

- **The first section** includes a detailed *review of the literature* carried out in chapter 2, which included review and comparison of existing applications of GI.Index, supported by a literature review on the benefits of GI and Ecosystem Services and a background of Glasgow's policies on climate change and vulnerability reports.
- **The second section** includes the development of conceptual Vulnerability Assessment through dataset analysis and mapping technics.
- **The third section** establishes a classification to develop a GI. Index and test the tool through microclimate program simulations to quantify the benefits of GI in the urban environment.

This chapter covers in detail the methodology used for the second and third section under the objectives 2-6 of this study.

A detailed approach of the stages involved in the development of this research are presented in the sections below following the "Research onion" developed by *Saunders et al., (2007).* As noted by Saunders et al. (2016), as a first necessary step for researchers is to work through each layer of the research onion before developing the methodology to proceed with more clarity during the process.

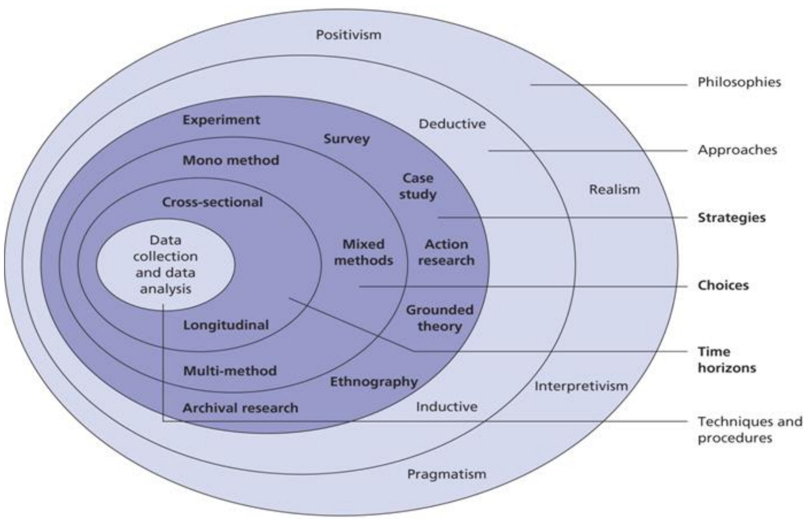


Figure 4.1. "The Research Onion". (Saunders et al., 2016)

For the purpose of this research, a mixed-method approach was conducted in order to combine both qualitative and quantitative data into the study *(Table 4.1).*

Due to the complex nature of planning Green Infrastructure and taking into consideration the multi-criteria nature of the study, **positivism** has been deemed more appropriate for describing the philosophy that covers the first two sections of this research. This approach reflects the theoretical developments made previously at similar case studies and the vulnerability assessment technique characterised by a quantitative and qualitative approach.

As defined by Patel (2015), the definition *epistemology for positivism describes that the reality can be measured and hence the focus is on reliable and valid tools to obtain that, characterised by a quantitative approach that might include sampling, measurement and scaling, statistical analysis, etc (Patel, 2015).*

In the other hand, *Interpretivism* has been deemed to fit best for describing the philosophy of the third part of methodology that includes the development of the GI. Index and the testing process through simulations.
Further, Patel (2015) defines *the epistemology for interpretivism / constructivism describes that the reality needs to be interpreted. It is used to discover the underlying meaning of event and activities. This paradigm usually is characterised by a qualitative approach that might include a case study analysis interviews, observations, etc. (Patel, 2015).*

Table 4.1.Characteristics of a Positivism and Constructivist/Interpretive Paradigm (Patel, 2015).

Paradigm	**Ontology** *What is reality?*	**Epistemology** *How can I know reality?*	**Theoretical Perspective** *Which approach do you use to know something?*	**Methodology** *How do you go about finding out?*	**Method** *What techniques do you use to find out?*
Positivism	There is a single reality or truth (more realist).	Reality can be measured and hence the focus is on reliable and valid tools to obtain that.	Positivism Post-positivism	Experimental research Survey research	Usually quantitative, could include: Sampling Measurement and scaling Statistical analysis Questionnaire Focus group Interview
Constructivist / Interpretive	There is no single reality or truth. Reality is created by individuals in groups (less realist).	Therefore, reality needs to be interpreted. It is used to discover the underlying meaning of events and activities.	Interpretivism (reality needs to be interpreted) • Phenomenology • Symbolic interactionism • Hermeneutics Critical Inquiry Feminism	Ethnography Grounded Theory Phenomenological research Heuristic inquiry Action Research Discourse Analysis Femenist Standpoint research etc	Usually qualitative, could include: Qualitative interview Observation Participant Non participant Case study Life history Narrative Theme identification etc

4.1.1 *Research approach*

The approach followed to develop the theory of this research can be considered abductive, seen best as a mixture of deductive and inductive approaches *(Saunders et al., 2016).* Being an approach that has the flexibility to move between induction and deduction was more relevant to the nature of the study. Starting with observations on the theory of GI and similar Index applications, this research tests existing theories and at the same time establishes new insights and theories derived from different variables through analysis and simulation processes in order to find the most likely explanation. The research takes place in a specific context and place and will result in building a new policy.

4.1.2 *Research strategy: CASE STUDY*

For this research, a case study method was conducted to examine Socio-environmental vulnerability for Grater Glasgow in relation to green infrastructure and to bring a new Assessment and GI. Index that can help in the decision-making process.

A case study approach is defined that "*illuminates a decision or set of decisions, why these were taken, how they were implemented, and with what results" (Schramm, 1971; Yin, 1994).* Other defines it as an empirical inquiry that investigates a contemporary phenomenon within its context with unclear evident boundaries between the phenomenon and its context (Gillham 2000; Johansson 2003; Zainal, 2007; Yin, *2009)*. Yin highlights that what makes a case study research distinct from experimental studies it is the examination of that specific context in its real-world setting *(Yin,2014).*
Usually, this method is characterised by a qualitative approach. However, there are cases that it can be characterised by qualitative data which through a categorise process can be converted in quantitative data and analysed through statistical models *(Lincoln et al., 2011, Harrison et al.,2017).*

Therefore, The multi-method used determines a combination of both qualitative and quantitative but different from the mixed method, is used when the research is divided into segments, by producing specific data set *(Saunders et al.,2016).*

The qualitative method is used to explore literature, urban policies and existing implementations of green infrastructure and similar tools and analysing climate and environmental patterns through various programs *(ArcGIS and ENVI-met).*

The quantitative method is especially suited for this research in order to quantify the complexity of socio-environmental vulnerability. Statistical data at datazone level, microclimate simulations and data analysis produce and describe pattern and trends needed in developing the assessment, to create the new GI. Index tool and to quantify the benefits of GI in the urban environment.

4.1.3 *Data collection*

The data collection process aimed to gather all the data required to create the key indicators for the vulnerability assessment and the GI. Index. For the purpose of the research, sets of secondary data were collected from different sources in the form of publications, books, imagery, geospatial data, Census data summarised in Table 4.2*(section 4.2).* Secondary data was decided to suit best to the research, taking in consideration the scope and giving the greater volume that can be analysed.

4.1.4 *Data analysis*

The data were analysed by using different software. The vulnerability assessment was built by using the geographic information system *(ArcGIS ver.10.6)* in order to quantify and qualify each indicator at the data zone (neighbourhood) level. This technique was seen to suit best given the ability of this software to integrate and display information based on its location and giving a visualisation of the data analysed in the desirable scale (data zone).

Further, after identifying the potentials zones with-in medium to high socio-environmental vulnerable areas, a selection process of two sites was conducted in order to create a hypothetical proposal and test to what extend the GI Index can be beneficial in the contextual cases.

These have been possible with the help of different software such as ENVI-met *(ver. 4.4.5)* for microclimate analysis on temperature differences, and thermal comfort, GIS for identifying the new service are provided, and I-tree for the flood mitigation potential.

4.1.5 *Introduction of the case study*

The present study was carried out in Glasgow. Greater Glasgow has a total area 368.5 km2 and an approximate population of 600,000 inhabitants, positioned 55.86 ° North longitude and 4.25° West latitude and characterised by a climate type 5C (cool, marine1) with an average annual precipitation of 1318.4mm *(MET Office,2018).* The annual high temperature is 12.4 °C, the annual low temperature 5.5°C with a mean temperature in the warmest season lower than 20 ° and the daily temperature is over 10 °C *(M.ET Office, 2018; Kruger, Drach and Emmanuel, 2018).*

4.2 Vulnerability Assessment

The methodology followed to scope the Vulnerability Assessment started by scaling the indicators into the Vulnerability Scoping Diagram that it is considered an advanced vulnerability framework. This concept is well know in literature and has been adapted in a large number of research papers *(McCarthy et al., 2001;Turner et al., 2003;Polsky, at al, 2007; IPCC,2007).* It includes three dimensions: exposure, sensitivity, and adaptive capacity. The adapted VSD for the case study presented in (*Table 4.2*).

The Adaptation of Vulnerability Scoping Diagram (VSD)used for measuring vulnerability

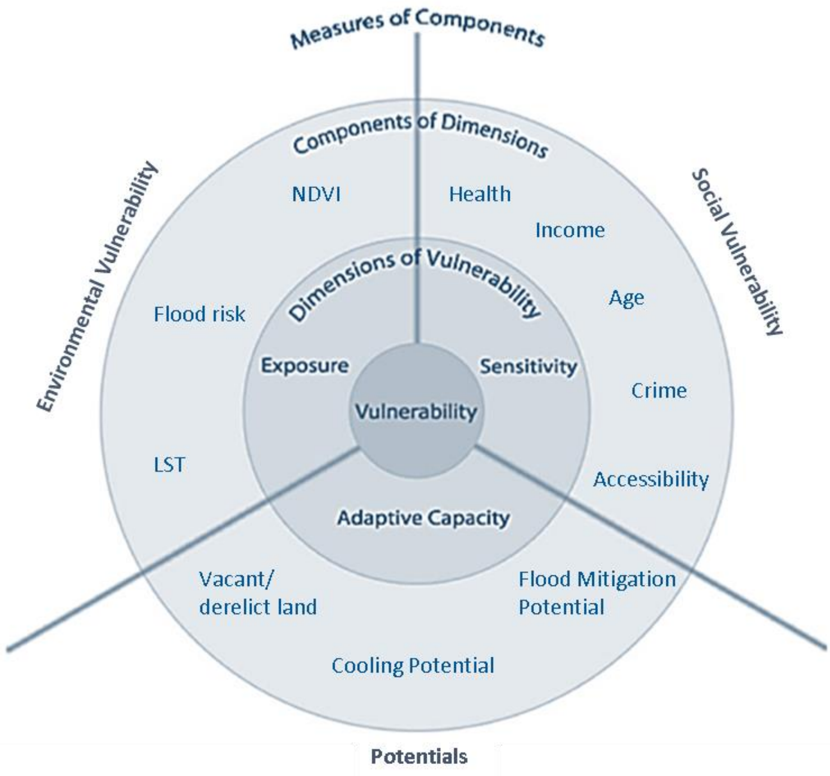


Figure 4.2. VSD diagram adapted from: (Adger and Kelly, 1999; McCarthy et al., 2001; Turner et al., 2003; Janssen et al., 2006)

Taking in consideration the context-specific nature of a vulnerability assessment, indicators have been chosen carefully to analyse the Vulnerability for Greater Glasgow in relation to Green Infrastructure. Figure 4.3 presents more in detail the vulnerability flow chart adapted from the Conceptual Framework of Vulnerability (AR4) IPCC 2007.

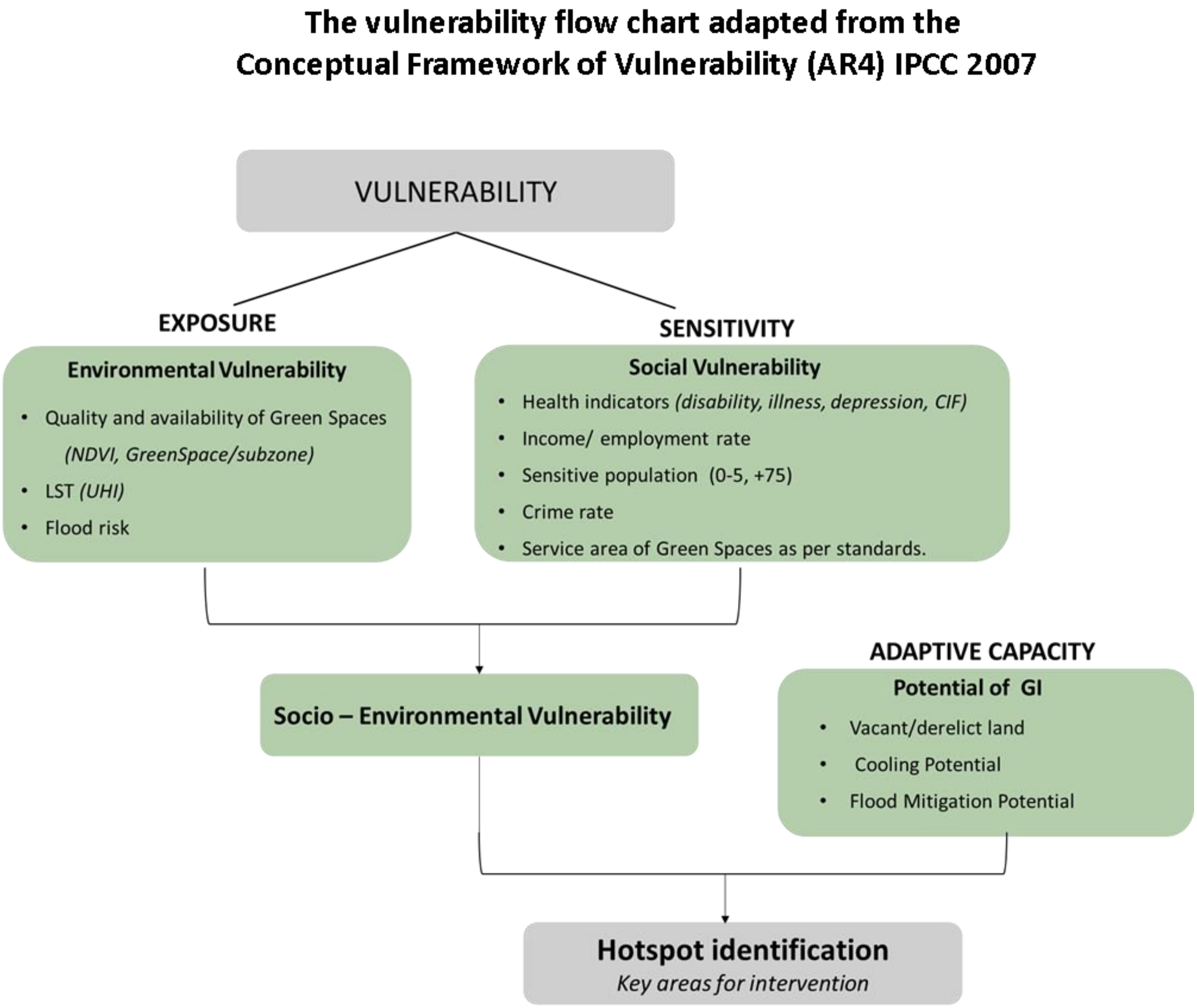


Figure 4.3. Conceptual framework of vulnerability adapted from (IPCC,2007; GIZ,2011 based on OEDC Policy Guidance)

Exposure reflects "the nature and degree to which a system is exposed to significant climatic variations" *(IPCC, 2001).* For this assessment, the exposure analysed for the Environmental vulnerability includes four indicators: Quality and availability of Green Spaces (NDVI, GreenSpace/subzone), LST (UHI) and flood risk.

The sensitivity of a system is described as "the degree to which a system is affected, either adversely or beneficially, by climate variability or change and it reflects the responsiveness ability of a system to climatic events (*IPCC, 2007).* The dimension of sensitivity was adapted to observe and map the most vulnerable part of society that has the less adaptive capacity to climate changes. Eight indicators were considered for this process:

Health indicators (disability, illness, depression, CIF), Income/ employment rate, sensitive population (age 0-5, +75), Crime rate and Service area of Green Spaces as per Accessibility Standards.

The adaptive capacity is defined by IPCC (2007) as the ability of a system to adjust successfully to climate change to moderate potential damages, to take advantage of opportunities; and/ to cope with the consequences *(IPCC, 2007).*

Thus, it was important to identify adaptive capacity, taking in consideration that Glasgow is a city with the largest area of vacant/derelict land in Scotland *(Chapter 2).* Therefore, three indicators were taken into consideration: vacant/derelict land under the Public ownership of the Local Authority, Housing Association and Urban Regeneration Company, Cooling Potential and Flood Mitigation Potential.

The analysis was built combining ArcGIS following the Multicriteria Decision Analysis (MCDA) model, which are widely discussed in the literature. This method serves in transforming and combining geographic data and preferences (value judgments) to obtain information for decision making *(Malczewski & Rinner, 2015).* Malczewski & Rinner (2015) highlight that three main concepts are involved in tackling spatial multi-criteria problems: value scaling, criterion weighting, and combination.

Table 4.2 summarises the datasets used for each indicator, format and sources needed for the study.

Table 4.2. Indicators, data collection and source.

	Indicator description	Format data	Source and provider	Date	Indicator processing details
Social Vulnerability	**Disability / people in ill-health (% people whose day- to-day activities are limited)**	Excel (xls)	Census, ONS	2011	Census table KS301. The number of people whose day to day activities are limited a lot + number of people whose day to day activities limited a little, divided by the total population and multiplied by 100. *Converted in normalised data (0-1)*
	Depression (% of population who are depressed)	Excel (xls)	SIMD2020	2017	The proportion of population being prescribed drugs for anxiety, depression or psychosis. *Converted in normalised data (0-1)*
	Comparative Illness Factor: standardised ratio	Excel (xls)	SIMD2020	2017	The CIF is a combined count of the total number of people receiving one or more of Disabled Living Allowance (DLA), Attendance Allowance, Incapacity Benefit (not receiving DLA), Employment Support Allowance and Severe Disablement Allowance. Converted in normalised data (0-1)
	Number of populations	Excel (xls)	NRS	2017	NRS 2017 small area population estimates
	Sensitive population % (young children under 5 years elder people over 75 years)	Excel (xls)	Census, ONS	2011	Census table 102. The number of people divided by the population and multiplied by 100. Converted in normalised data (0-1)
	Income deprived rate %	Excel (xls)	SIMD2020	2020	Percentage of people who are income deprived. *Converted in normalised data (0-1)*

	Employment deprived rate %	Excel (xls)	SIMD2020	2020	Percentage of people who are employment deprived. Converted in normalised data (0-1)
	Crime rate %	Excel (xls)	SIMD 2020	2020	Recorded crimes of violence, sexual offences, domestic housebreaking, vandalism, drugs offences, and common assault per 10,000 people. *Converted in normalised data (0-1)*
	Service area of green spaces / datazone	Vector	*Generated from a combination of indicators*		
	-Green Open Spaces	Vector	PAN65 Data	20017	PAN65 refers to 'open space' as any greenspace consisting of any vegetated land or structure, water, path or geological feature within settlements, civic space, market, paved or hard landscaped areas with a civic function
	- Road map and access point (entrance)	Vector	Digimap, Ordnance Survey	2019	Total service area under each datazone was obtained using the criteria of greenspaces >0.3 ha and 400m walking distance from access points obtained from Ordinance
Environmental Vulnerability	**Normalised difference vegetation index (NDVI)**	Raster	Sentinel-2 satellite image. Spatial resolution of 10m	June 2019	The NDVI map was generated from Image analysis process in ArcGIS. NDVI is used to analyse the state of vegetation (quality) and as a proxy indicator for Biodiversity (Bawa et al.,2002).
	Availability of Green Space/ subzone	Vector	PAN65 Data	2008	PAN65 - open space with the criteria of >0.3 ha
		Vector	Digimap, Ordnance Survey	2020	Subzone shapefile obtained from Ordnance Survey
	Land surface temperature (LST)	Raster	LANDSAT 8 - spatial resolution of 30 meters	28-06-2019 11:15	LST is the radiative skin temperature of the land derived from solar radiation (Copernicus,2018). The satellite images processed in ArcGIS for the LST map has a cloud cover lower than 20% and with a high estimation solar radiance.
	Flood risk map	JPG	SEPA	2020	The data were created as a raster file refereeing to the interactive Map generated from SEPA official website http://map.sepa.org.uk/floodmap/map.html
Potential	**Floor mitigation potential**	Vector	(Majekodunmi, Emmanuel & Jafry, 2020)	2020	The map obtained by adapting a method from the TR55 model of the i-Tree tool. Soild cover data and the extent of grass cover (PAN65) classification were used to assign a weighted to the flood prevention capability. The result obtained estimates the flood mitigation in 3 categories (low-medium-high)
	Cooling potential	Vector	(Majekodunmi, Emmanuel & Jafry, 2020)	2020	The study adopts a methodology established by Zardo et al., (2017), together with the methodology used by Keeley (2011) in which the cooling provided depends from the type of GI and the extend of GI. A weighted score of GI was then merged to produce a cooling potential map.

	Vacant land	Vector	Digimap, Ordnance Survey	2019	The Scottish Vacant and Derelict Land Survey is a national data collection undertaken to establish the extent and state of vacant and derelict land in Scotland. For the purpose of the study, the distribution of vacant/derelict land was reclassified by ownership by prioritising only the ones under public the ownership of Public Authorities.

Following the UNDP Guidance for vulnerability assessment tools (2017), *Table 4.3* presents the influence on vulnerability for the selected indicators for this study, taking into consideration the context-dependent (*UNDP,2017*).

Table 4.3.The influence of selected Indicators on vulnerability

Group	**Indicators**	**Influence on vulnerability** **Increases** ↑ **Decreases** ↓
Social	Disability / people in ill- health	↑
	Depresion (% of population who are depressed)	↑
	Comparative Illness Factor: standardised ratio	↑
	Income rate (% who are income deprived)	↑
	Employment rate (% who are employment deprived)	↑
	Sensitive population % (0-5, +75)	↑
	Crime rate %	↑
	Service area of Green Spaces	↓
Enviromental	Normalized difference vegetation index (NDVI)	↓
	Land surface temperature (LST)	↑
	Flood risk	↑
	Green space/ subzone	↓
Potential	Vacant/derelict land	↓
	Cooling Potential	↓
	Flood Mitigation Potential	↓

The criteria and the weighted system of each dimension are explained in the following sections.

4.2.1 *Social Vulnerability Analysis*

Social vulnerability is defined by Dow (1992) and UNDP (2017)as "the differential capacity of groups and individuals to deal with hazards, based on their positions within physical and social worlds" *(Dow, 1992;UNDP,2017),* The development of indicators for the social Vulnerability analysis follows the guidance of UNDP (2017) on Social Vulnerability Assessment tools for Climate Change and DRR Programming. The preliminary list of indicators was considered suitable for the local context, considering the availability of data. Depending from the approach, the Vulnerability assessment can be flexible in adding or removing indicators according to the context applied.

To identify the social vulnerability, seven datasets of population indicators such as sensitive population (older than 75 and 0-5), health, income and crime rate were collected at datazone level from Census data and SIMD2020 *(Table 4.2).* Data zones are the key geography for the dissemination of small area statistics in Scotland from the 2011 Census and designed to have a population of 500-1000 habitants *(Scottish Government, 2011).* For the city of Glasgow, there are in total of 746 statistical zones.

The advantage of these secondary data is that the statistical zone is accurate enough to present a detailed analysis and pattern in order to identify clusters and understand the dynamic. Hence, the population distribution can be spatially presented with the help on ArcGIS program.

Different from the Scottish Index of Multiple Deprivation 2020 approach, we have used some of their indicators to establish a relation between social and environmental vulnerabilities and green spaces.

To obtain accuracy in the analysis, it was necessary to convert all the indicators into the same system through a normalised data process in order to standardise the data before the use of the MCDA (Lu et al., 2012). Normalisation is the linear transformation of data in a scale (0-1), and it is obtained by applying the formula below (I) *(Sneath & Sokal, 1973; Doherty, Adams & Davey, 2007).*

$$z = \frac{x - \min(x)}{\max(x) - \min(x)} \qquad \text{(I)}$$

In addition to these indicators, an accessibility analysis took place in order to identify the service area of open green space under each datazone through access points/ entrance using the data from the Ordnance Survey vector file. The analysis was processed by applying the criteria of Accessibility Standards established under Guidance SG6 (2017) in which it is highlighted the importance of accessibility and good quality standard can be considered greenspaces >0.3 ha and within 400m walking distance from access points (see literature review section 3.1.3).

The network analysis function was used to give a more accurate analysis by taking into consideration the actual routes, compared to the simple buffering method.

All the indicators were reclassified in five classes (very low- very high) with the standard deviation method. Afterwards, the weighted overlay was conducted to combine the reclassified datasets, assigning a percentage of influence to each indicator and therefore establishing a hierarchy *(Table 4.4).*

The weighting process is considered to be the most sensitive step in a vulnerability study, and it is highly discussed in the literature *(UNDP,2017)* .

Table 4.4. The weightage of Indicators for Social Vulnerability for the overlaid maps

Social Vulnerability			
Group of indicators	**No**	**Indicators**	**Weighted score (%)**
HEALTH 37.5%	1	Disability / people in ill- health	12.5
	2	Depression (% of the population who are depressed)	12.5
	3	Comparative Illness Factor: standardised ratio	12.5
INCOME 25%	4	Income rate (% who are income deprived)	12.5
	5	Employment rate (% who are employment deprived)	12.5
AGE/POPULATION 12.5%	6	Sensitive population % (0-5, +75)	12.5
CRIME 12.5%	7	Crime rate %	12.5
ACCESSIBILITY 12.5%	8	Service area of Green Spaces	12.5

For each indicator, a representative map has been produced and presented in the results Chapter.

Studies highlight that "equal weights" or known as "unweighted indexes" is considered the most common approach in vulnerability studies. In a comparison of 106 studies conducted by Papathoma-Köhle et.al (2019) 41.5% of them used the equal weights system (*Papathoma-Köhle, Cristofari, Wenk & Fuchs, 2019).*

Following this approach, an equal percentage of influence was assigned to each indicator, which at the same time, creates a hierarchy at a group level. This approach gives equal importance to variables, making them independent at the same time *(Table.10).*

4.2.2 *Environmental Vulnerability Analysis*

The literature review was used in developing the indicators for the Environmental Vulnerability analysis taking in consideration available data. The four indicators are explained in the sections below in this Chapter.

The weighted criteria assigned to each indicator is based on the literature review of Glasgow's strategy and studies in section 3.1 *(Mell, 2013; Emmanuel & Loconsole, 2015; Adaptation Scotland, 2017; CDP, 2017; Greenspace Scotland,2018; Kruger, Drach and Emmanuel, 2018; OSS,2020)* and shows a rational approach in giving a score of 40% to the quality and availability of Green spaces, presented by two indicators which have a direct relation in affecting the two other environmental indicators that have been considered (LST and Flood Risk). A weightage of 30% each was given to LST and Flood Risk *(Table 4.5).*

Table 4.5. The weights of the environmental indicators for the overlaid maps

Evinronmental Vulnerability			
Indicators	**No**	**Indicators**	**Weighted score (%)**
Green space *(quality and availability)*	1	Normalised difference vegetation index (NDVI)*	20
	2	Green space/ subzone	20
UHI	3	Land surface temperature (LST)	30
Flood	4	Flood risk	30

For each indicator, a representative map has been produced and presented in the results Chapter.

4.2.2.1 Normalised Difference Vegetation Index (NDVI)

The NDVI map was generated from the Image analysis process in ArcGIS using the metadata of the Sentinel-2 Satellite image with a spatial resolution of 10m, to obtain a good accuracy of results.

NDVI is used to analyse the state of vegetation (quality) and as a proxy indicator for Biodiversity *(Bawa et.al.,2002).* It identifies the state of vegetation; therefore, a higher NDVI means healthier vegetation which implies the possibility of healthy habitats for biodiversity. Thus, due to limited data for biodiversity, this approach was followed.

Different studies conducted on the analysis of large areas that required the use of remote sensing imagery have concluded that NDVI can be used as a proxy indicator for biodiversity to identify the pattern, but detailed work should be followed on ground level for more precise and further studies *(Bawa et al.,2002; Culbert et al., 2012; Wood, Pidgeon, Radeloff & Keuler, 2013).*

Due to the ability of chlorophyll to reflect near-infrared radiation (NIR), and absorb red light, a combination of NIR and R band was possible to identify NDVI using the formula below *(Cracknell, 1997; Goward et al., 1985):*

$$\text{NDVI} = \frac{(\text{NIR - Red})}{(\text{NIR + Red})} \qquad \text{(II)}$$

The value of NDVI ranges from -1 to +1, and where negative values show the presence of water, values closer to 0 present no presence of vegetation (barren areas of rock, sand, snow cover or urban area) and values closer to +1 present a healthy vegetation (dense green leaves).

4.2.2.2 Availability of Green Space/ datazone

Quantifying the available green space for each datazone, was very important in the specific-context of Glasgow taking in consideration that only 10% of Glasgow is classified as Public Park or Garden. For this analysis the PAN65 classification was used with the criteria of green spaces >0.3 ha established from SG6 (2017) and OSS (2020) with the help different functions in ArcGIS (Zonal statistics, Majority function).

4.2.2.3 Land Surface Temperature

Land Surface Temperature (LST) it is considered essential to be identified to understand the anomalous of high temperatures in urban areas and to implement further mitigation measures against UHI formation *(Streutker, 2002).*

As a limitation of the study, the LST was not analysed throughout the year but for a particular date selected (28 July 2019 at 11:15) with cloud cover lower than 20% and with a high estimation of solar radiance. This was intentionally selected to understand the analysis with a high possibility of LST scenario. The methodology used to generate the LST map was adapted from Malakar et al. *(2018).*

4.2.2.4 Flood risk map

Flood risk map was obtained from the public data available from SEPA website, recreated as a raster file in ArcGIS and used accordingly with the classification provided. To quantify the risk at datazone level the Zonal statistics function (Majority) was used in ArcGIS.

4.3 Potential of mitigation

To investigate the potential of mitigating the vulnerability, three key indicators were taking in consideration: Vacant/derelict land, Flood mitigation and cooling potential. Vacant land vector data were obtained from the Digimap portal (Ordnance Survey), and classification was needed to prioritise the potential of Public land under Category 1 *(Table 4.6)* and exclude the private land as a potential since it is not under the administration of any public authority.

Table 4.6. Classification of vacant land

Classification	Ownership	Priority scoring
Public Land 1	Local Authority	2
	Urban Regeneration Company	
	Housing Association	
Public Land 2	Scottish Enterprise	1
	Other non-Crown	
	Health Boards	
	British Waterways	
Private	Ownership unknown	0
	Network Rail/ Rail Franchise Holder	
	Other	

Flood mitigation and cooling potential maps were obtained from a study conducted from *Majekodunmi, Emmanuel & Jafry (2020),* in which the potential depends from the type of GI and the assigned weight was in function of the capacity.

The final potential Map was generated as a result of these indicators by prioritising the classes with the highest potential and using Raster calculator (addition function) in ArcGIS.

To conclude, the Socio-Environmental Vulnerability map was obtained following the Conceptual Vulnerability Framework and with the help on ArcGIS by using Raster Calculator function (Multiplication) as an accurate method to not assign a biased weightage.

4.3.1.1 Green Infrastructure index for Glasgow

Based on the case studies and comparison presented for the implementation of the GI Index in Chapter 2, this research chose to follow the approach of the tools that have a similar ecological aim, similar scope on a specific ecosystem service such as the run-off infiltration, cooling potential, and improve health and wellbeing.

Therefore, the methodology applied in other UK cities (London, Southampton) and Berlin helped in developing the indicators and scoring factors for Glasgow *(Table 4.7).* Emphasis is given to elements that provided the specific ecosystem service to regulate the urban microclimate and with a high capacity of absorbing such as trees in natural soil, vegetation on deep soil, rain gardens, intensive green roofs and green pavers. Less scoring it is assigned to vegetation in shallow soil, extensive green roofs and green walls, giving the context-specific climate. Different from green roofs, a lower score was given to the green façade, based on different critical studies that highlight the uncertainties of the performance of green/living walls, long-term / high-cost maintenance and the irrigation required that can directly affect the life and quality of performance *(Riley, 2017).*

Table 4.7. The Green Infrastructure Scoring system proposed for the city of Glasgow

No.	Surface cover type	Factor
1	Semi natural vegetation / wetland / water surface	1
2	Large trees in natural soil (per m2 of canopy cover)	1
3	Medium-small trees in natural soil (per m2 of canopy cover)	0.8
5	Vegetation on deep soil	0.6
6	Vegetation on shallow soil	0.4
7	Rain Garden / vegetation	0.7
8	Intensive green roof (vegetation over structure) min depth 150mm	0.6
9	Extensive green roof (vegetation over structure) 60-150mm	0.3
10	Green walls / vertical vegetation	0.3
11	Green pavers	0.4
12	Permeable paving	0.2
13	Concreate/ asphalt / impermeable materials	0

4.3.2 *Hotspot identification and site selection*

Based on the evaluation of the vulnerability assessment and the potential areas of intervention, the hotspot map of interventions generated can help in decision making and fulfils two criteria: to fall under high-medium vulnerability and at the same time have a high-medium mitigation potential.

Following this approach, two sites were identified to test the scoring system of the GI Index proposed. The hypothetic scenario were created with the help of simulations through Envi- Met Software to identify the differences in the microclimate of the sites between the real and proposed scenario.

To determine the size of the sites, limitations have been taken into consideration, such as the processing capacity of the engine and the simulation time. The sites present two different urban structures in order to understand the behaviour and potential of GI in different locality of the city. This will help to evaluate and identify the gaps and microclimate changes.

4.3.3 *Site analysis*

To analyse the influence of the vegetation for the hypothetical scenarios, an analysis have been conducted in order to identify: Cooling potential, flood mitigation and the service area of new GI proposed explained in the flow chart below *(Figure 4.4).* The hypothetical scenario was created, taking in consideration the maximum addition of GI elements for each specific site and an evaluation of the scoring system proposed was necessary.

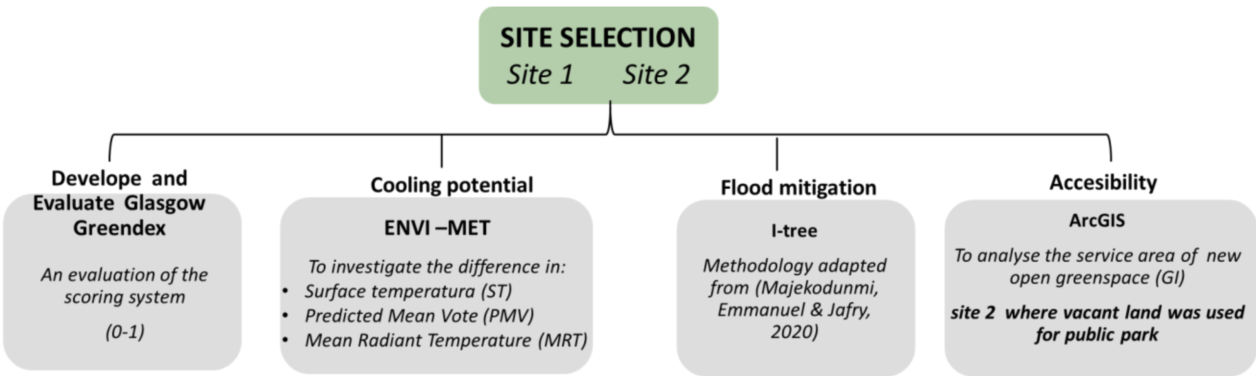


Figure 4.4. Flow chart of the methodology followed for site analysis

The cooling potential has been analysed with the help of simulations in ENVI- Met (4.4.5). The program helped in comparing Near Surface Temperature (NST), Potential Air Temperature (PAT) and Mean Radiant Temperature (MRT) between the current scenario and the hypothetical scenario proposed. A summerise of the base case models are presented in Results Chapter.

NST and PAT served to identify the presence of the UHI effect and its potential mitigation. MRT was used as a proxy indicator to analyse the human thermal comfort.

In order to validate ENVI-met simulations, simple forcing was used to simulate the humidity and temperature. The atmospherical data used were estimated, referring to the GCU weather station data of 2018 to create the hypothetical scenario. This was considered a reasonable decision, taking into consideration the limitations created from the pandemic and capacity of the engine used. The simulation process takes place in median summer peak and most of the analysis was conducted at the pedestrian's height.

To conclude, giving the scope of the GI Index, an evaluation of the scoring system was needed to understand the potential for each site and create space for discussion on its application.

5 Results

The following Chapter presents the analysis and results supported by the methodology presented in Chapter four.

The chapter answers to two of the research questions: to understand through spatial analysis the pattern of socio-environmental vulnerability and mitigation potential for Greater Glasgow to GI; and partially how socio-environmental vulnerability analysis can be seen as complementary in the planning process of implementing and investing on GI.

Further, the chapter addresses and fulfils to present the objectives 2,3,4,6 as follow:

Objective 2: Spatial analysis of the Environmental and Social Vulnerability pattern for Grater Glasgow at datazone level by taking in consideration a set of indicators.

Objective 3: Mapping the potential of Green Infrastructure by taking in consideration three indicators: land availability, cooling and flood mitigation potential within Greater Glasgow limits.

Objective 4: To integrate the potential of GI and socio-environmental vulnerability in creating a hotspot map that can help in decision making.

Objective 6: Evaluate the GI Index through microclimate program simulations (ENVI-met and ArcGIS) for two different scenarios: (a) Compact mid-rise; (b), Open low-rise area by taking in consideration the influence of vegetation.

This Chapter is structured in three sections and support:

- *Section one*: Results of the Socio-Environmental Vulnerability analysis presented at datazone level.
- *Section two:* Results of the adaptive capacity that includes flood mitigation, cooling potential and vacant/derelict land.
- *Section three:* Microclimate simulations to quantify the benefits of GI in the urban environment and preliminary analysis of the new Greendex proposed.

5.1 Introduction

Each section presents the result of the overarching research questions examine through data analysis, spatial visualisation, and simulation process.

Before presenting the vulnerability analysis, it was important to present and analyse the Local Climate Zone *(Figure 5.1)* and the distribution of Green spaces per capita *(Figure 5.2).*

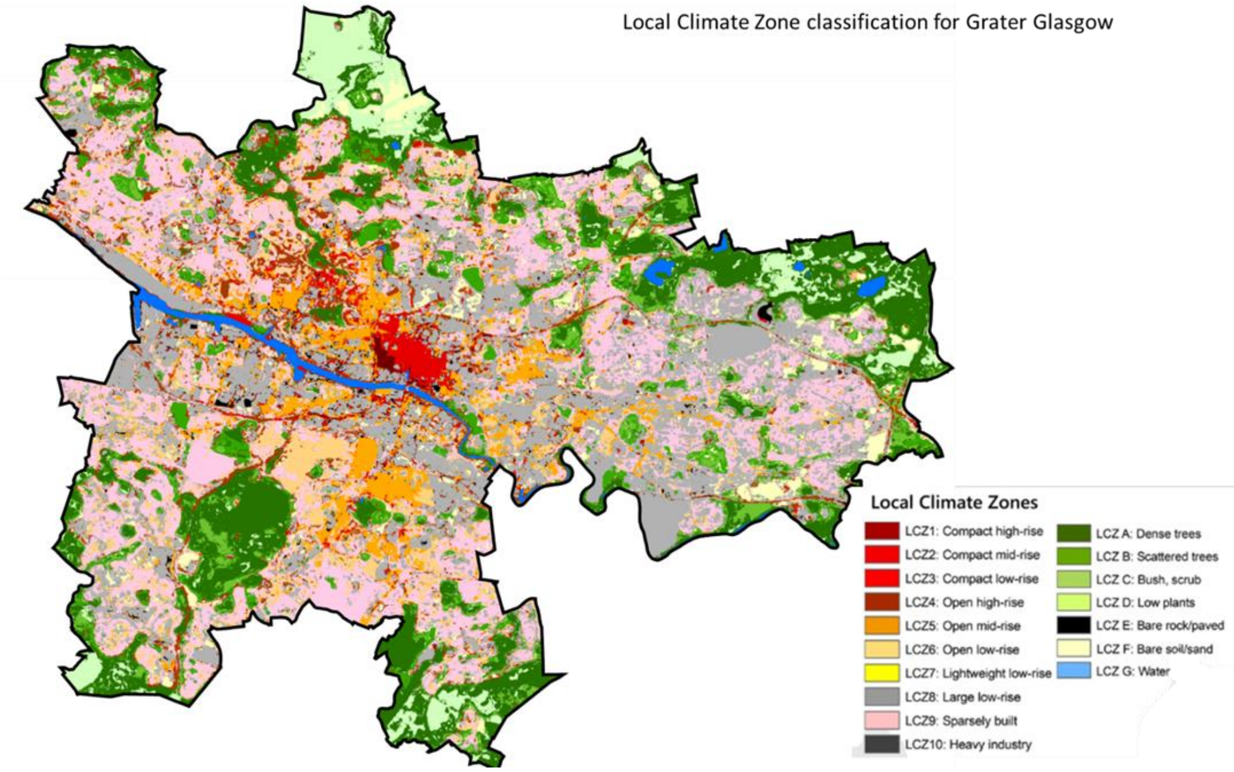


Figure 5.1. Local Climate Zone Analysis for Greater Glasgow

The LCZ was produces using the WUDAPT protocol, and it is widely considered and used in urban studies due to its ability to analyse a big range of parameters. In this context, it has been adapted to present the climate sensitivity for Greater Glasgow. Overall, the map reflects a higher climate sensitivity in the compact and open mid-rise zones and lower climate sensitivity distributed in the Outer city that falls under the low-rise zone and under green areas.

Further, the map of the distribution of green spaces per capita at datazone level was important to understand the greenspace in relation to its users.

The analysis of GI provision for Greater Glasgow uses a threshold value of 6 m² per person (as in the case of Berlin) is used to understand where residents have access to sufficient GI. This threshold value is evident in some clusters particularly presented in the city Centre, Glasgow East, Glasgow West, and central-South.

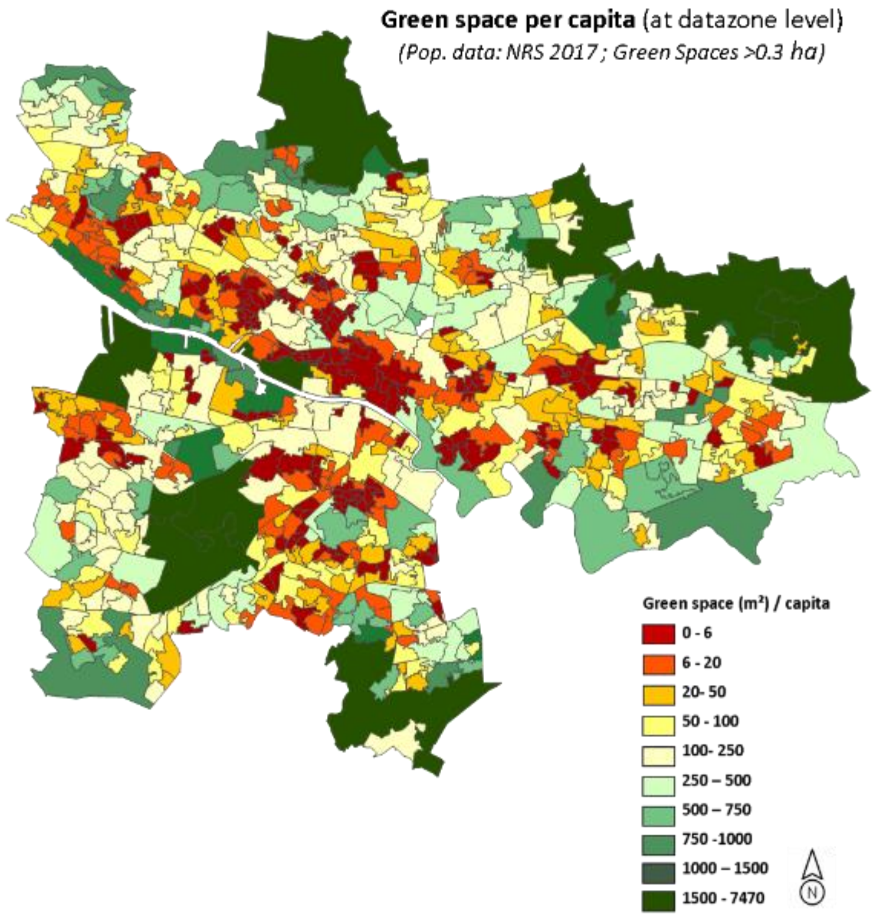


Figure 5.2.Distribution of green spaces per capita at datazone level.

5.2 Section 1

5.2.1 *Social Vulnerability results*

Social Vulnerability was conducted to analyse the most sensitive population with less adapted capacity. For each of the eight indicators, a map is produced in ArcGIS to identify the spatial dynamic presented in Figure 5.3- 5.6. The classification is illustrated with a colour scale from green to red (very low- very high) according to the vulnerability influence.

5.2.1.1 Income and employment

The distribution of income (a) and employment rate (b) follows almost the same pattern and have a clear cluster, where it can be observed that the highest rate is present in City Centre, Glasgow West, Sumerstone (canal), Garrowhill, Baillieston, Pollokshields and Langside.

Further, the North and East of Glasgow present to have lowest income/employment followed by Drumchapel West and Govan, Glenwood and Gorbals in the South.

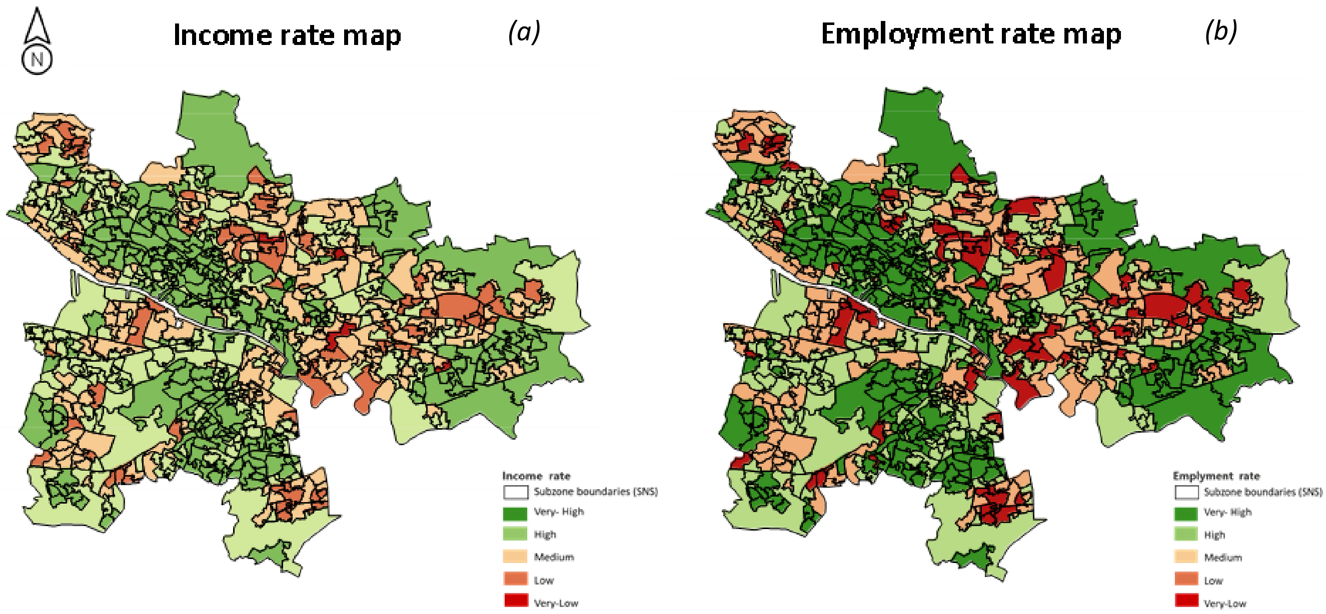


Figure 5.3. Distribution of Income rate (a) and Employment rate per datazone (b).

5.2.1.2 Indicators of health

In the other hand the three indicators of health: CIF (a), depression rate (b) and disability rate (c) present a similar pattern with each other in which the City Centre, Glasgow West and the central-South show to have a high health rate, compared to other zones *(Figure 5.4).* Therefore, it can be argued that the data zones with high income/employment rate have also a good indicator of health.

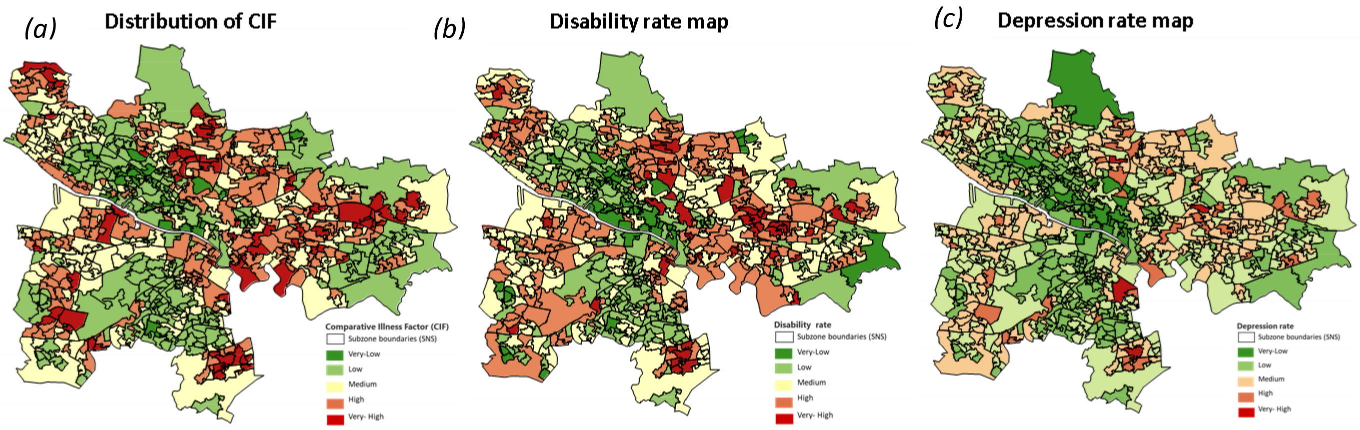


Figure 5.4 Distribution of the health rate per datazone by indicators: CIF (a), Disability rate (b), Depression rate (c).

In contrast with the other indicators that was possible to find a relation, the distribution of crime *(Figure 5.4c)* is mostly concentrated in the City Centre and Drumoyne- Shieldhall *(Figure 5.4a)* .

5.2.1.3 Crime and sensitivity population

Figure 5.5b illustrates the distribution of the sensitive population (age 0-5 and +75). Results demonstrate that City Centre, Glasgow West and the central-South has the lowest sensitive population per datazone. If compared to other output maps, it can be argued and relate that the datazones with highest income/employment rate, have the lowest sensitive population and better health rate.

The datazones with higher sensitive population fall mostly under the outer urban area or at the edges of the study area.

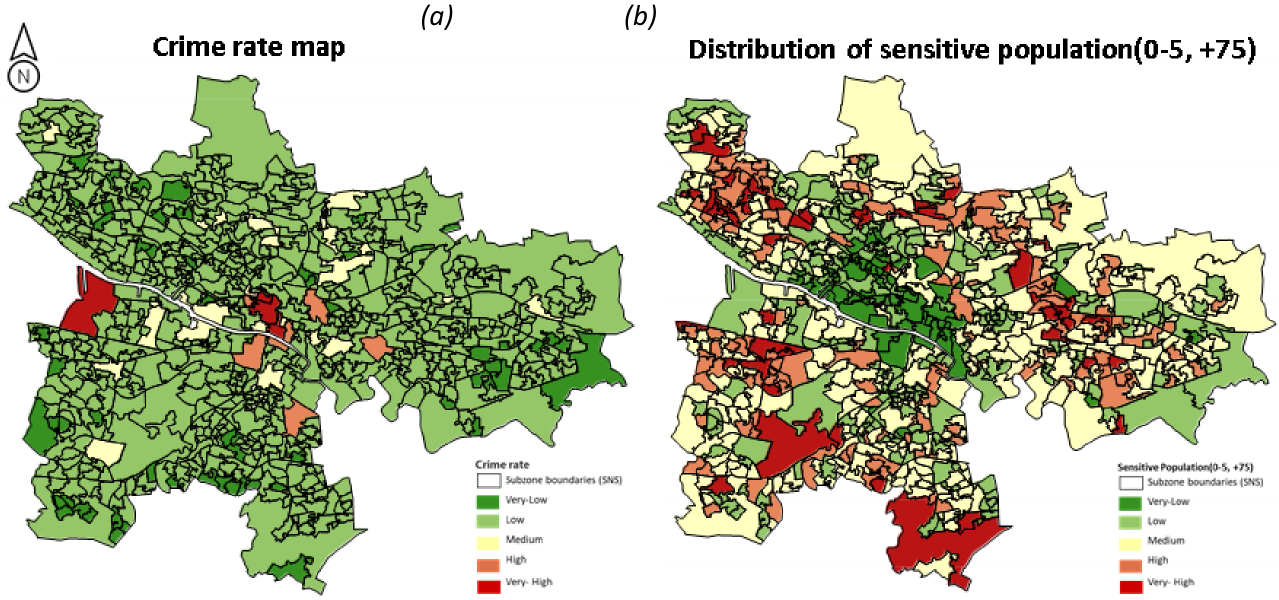


Figure 5.5. Distribution of Crime rate (a) and Sensitive population per datazone (b).

5.2.1.4 GS service area

To identify the distribution of GS service area / datazone, a two-steps process was required. Initially, a network analysis was conducted in order to identify the accessibility of (public) green spaces as per Accessibility and Quantity Standards established under Guidance SG6 (2017) presented in the Map *(Figure 5.6a).*

This output helped in producing the service area of green spaces per datazone by using Zonal Statistics function in ArcGIS *(Figure. 5.6b).* The Map demonstrates a low distribution of green-space service area in the North, North-West, East and the inner-city including City centre and some clusters in the central-South.

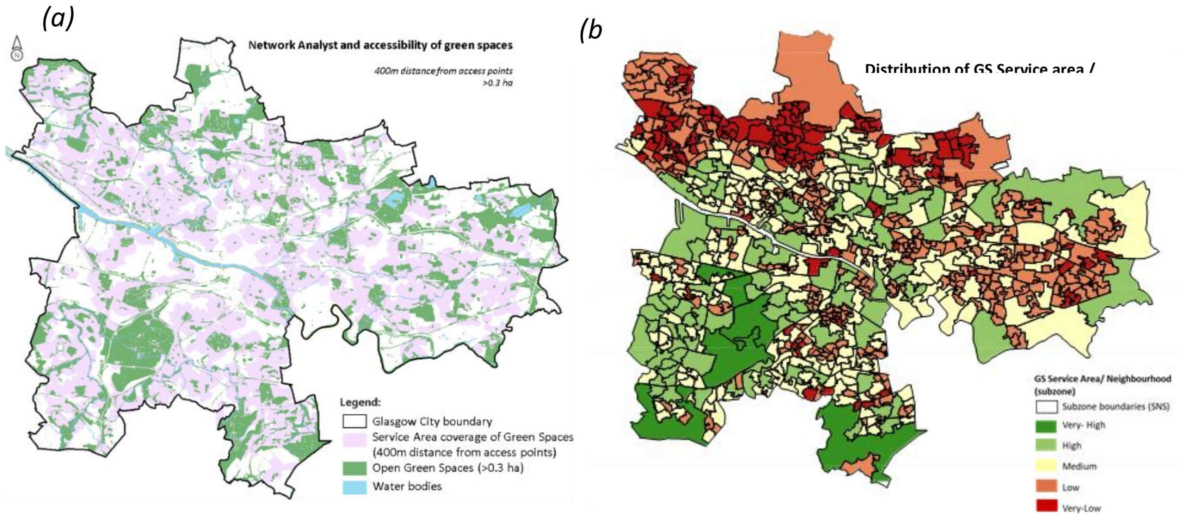


Figure 5.6. Map of network analysis and accessibility of green spaces Distribution (a) and Map of distribution of GS Service area per datazone (b).

Overall, the MCDA conducted in ArcGIS for the social vulnerability took into consideration the eight indicators analysed previously, and a vulnerability map was produced *(Figure 5.7).* The results indicate that 16% of Greater Glasgow has a high social vulnerability, and 47% has a medium vulnerability *(Figure 5.8).* From the total number of 756 datazones, 118 fall under high vulnerability and 354 datazones under medium vulnerability *(Table 5.7).* The resulting Map indicates that communities with the highest vulnerability are mainly located in the North and East of the study area, zones that are well recognised as fragile since the post-industrial period *(Figure 5.8).* These subzones are the most exposed to social vulnerability and therefore are the ones that have the least adaptive capacity in adapting to climate change.

In the other hand, only 2 datazones (0.27%) are classified as very-low in social vulnerability and 272 (37%) as low vulnerability. The classification of SV was intentionally generated in four classes giving the accuracy and readability of the results.

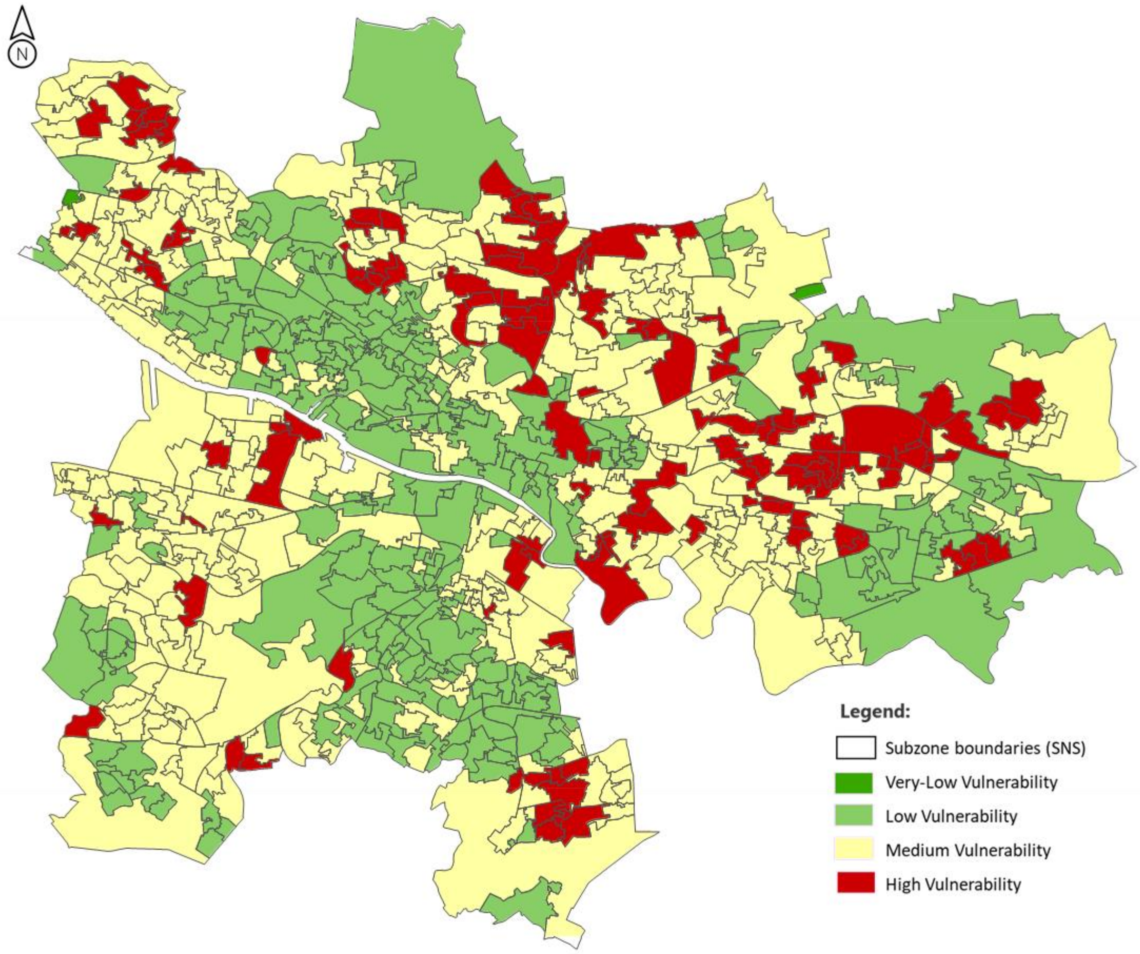


Figure 5.7. Distribution of Social Vulnerability at datazone level.

Table 5.1 Social Vulnerability distribution across classes

No. of Classes	Vulnerability Classes	No. of Subzones	Percantage(%)
1	Very-Low Vulnerability	2	0.27
2	Low Vulnerability	272	36.46
3	Medium Vulnerability	354	47.45
4	High Vulnerability	118	15.82

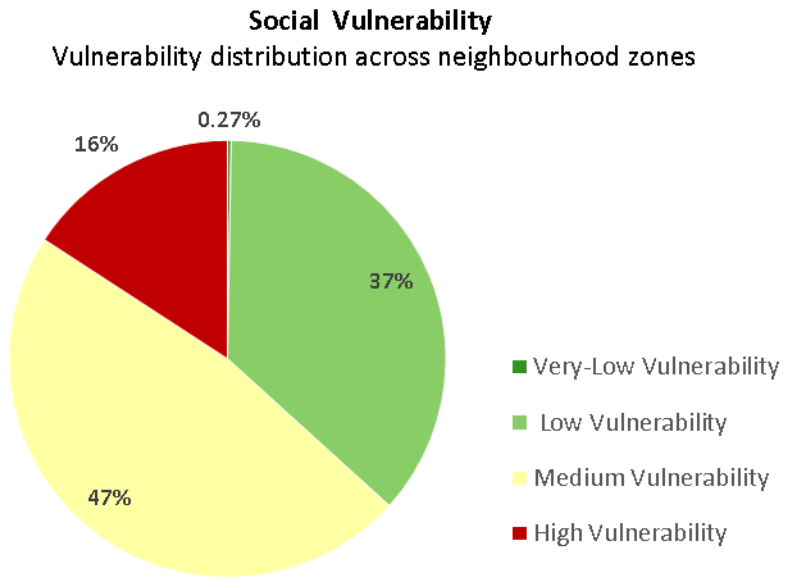


Figure 5.8.Social vulnerability Pie Chart.

5.2.2 *The Environmental Vulnerability results*

Environmental vulnerability was conducted analysing four indicators: NDVI, LST, flood risk and distribution of GS/ datazone. For each indicator, a map is presented as an output of several analysis in ArcGIS to identify the spatial dynamic.

5.2.2.1 NDVI

The NDVI analysis of Greater Glasgow was computed using Sentinel-2 satellite image with a spatial resolution of 10m on June 2019 and presents the photosynthetic activity or vegetation health. The higher NDVI values are illustrated where the dense vegetation cover is present and indicates higher environmental quality and mostly occur in the outer-city toward the edges of the study area. Inner-city is characterised from lack of vegetation, and therefore, lower NDVI is presented *(Figure 5.9).*

5.2.2.2 Land Surface Temperature

The LST of Greater Glasgow was computed using Landsat 8 satellite image with a spatial resolution of 30 meters on the date of 28 June 2019 around midday (11:15) and identified the LST distribution in the city. The Map illustrates LST classification into 5 classes from 14.5°C- 32°C (very low- very high). The highest temperature value class is presented in red and indicates the zone where higher LSTs are accumulated, and the lowest are presented in blue.

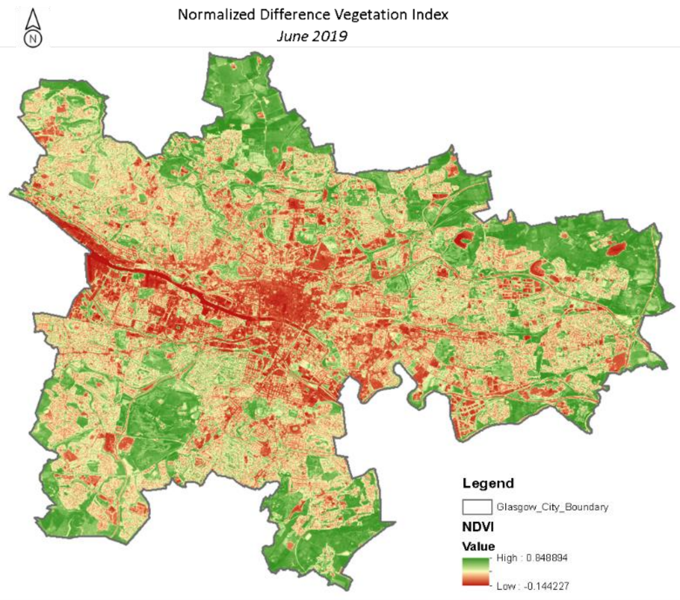


Figure 5.9 Distribution of NDVI for Greater Glasgow

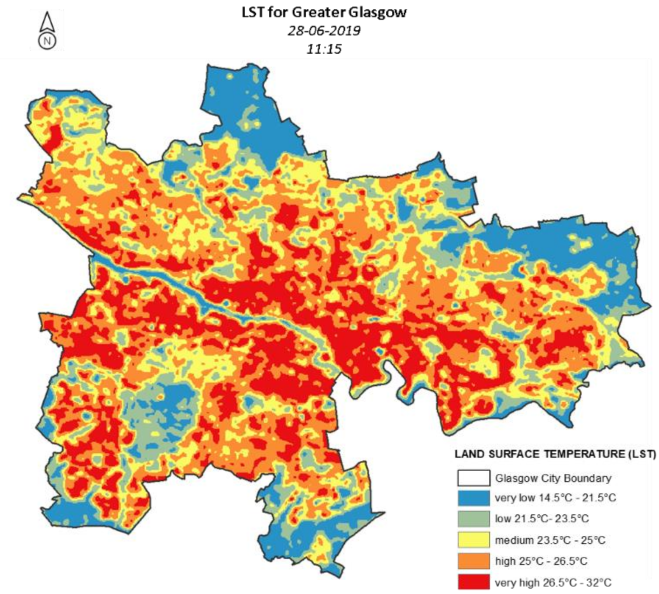


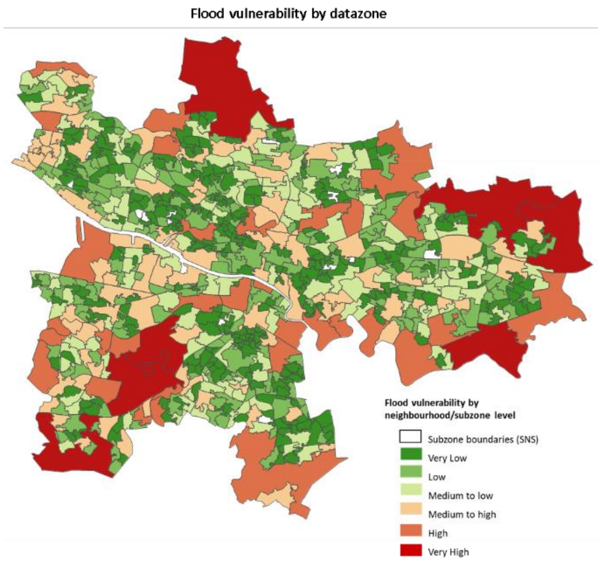
Figure 5.10. Distribution of land surface temperature for

Since vegetation cover plays a major role in LST and comparing with the NDVI map *(Figure 5.9).* It can be clearly observed the influence of vegetation in LST *(Figure 5.10)*. The urban areas with low NDVI present the highest LST temperature, and vegetation areas present the lowest. These explain the presence of UHI effect in the urban areas and its contribution to adverse environmental conditions.

5.2.2.3 Flood Risk

The following map *(Figure 5.11)* illustrates the distribution of flood vulnerability by datazone. It was produced by using the official data provided by SEPA and aim to quantify and qualify the risk for the spatial unit desirable (datazone) using "zonal statistic-majority" function in ArcGIS.

The produced Map demonstrates that exists a spatial disparity of flood vulnerability, with a higher vulnerability from fluvial flooding due to the presence of rivers mainly in the North, North-East, and South of the study area.



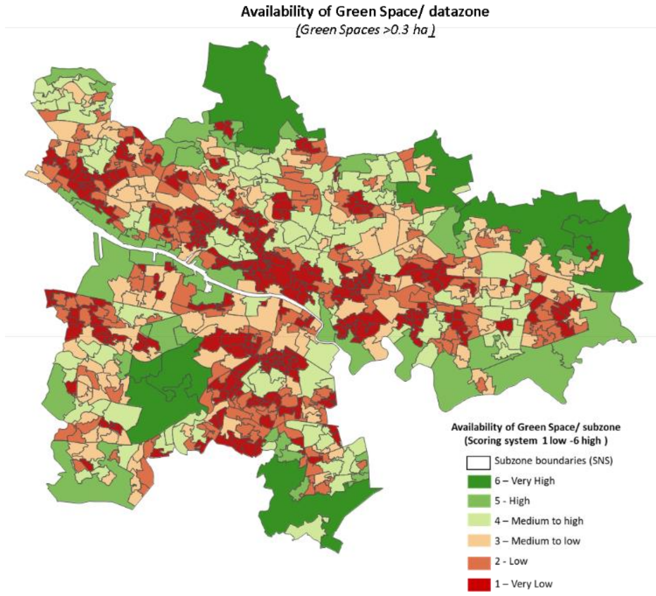


Figure 5.11 Distribution of flood vulnerability per datazone.

Figure 5.12. Distribution of the availability of green spaces per datazone.

5.2.2.4 Distribution of Green Spaces

The map presented in *Figure 5.12* illustrates the availability of green spaces per datazone using the criteria of Quantity Standards established under Guidance SG6 (2017), for GS >0.3 ha. The produced Map demonstrates that the inner-city / dense build up areas present the lowest availability of GS.

5.2.3 *Environmental Vulnerability summary*

The Map for Environmental Vulnerability was produced through overlay analysis and categorised into four classes *(Figure 5.13).* The result indicates that 3.62% of Greater Glasgow has a high environmental vulnerability and 60% has a medium vulnerability *(Figure 5.14).* From the total number of 756 datazones, 27 falls under high vulnerability and 452 datazones under medium vulnerability *(Table 5.2).* The resulting Map indicates that the highest vulnerability is mainly presented in the inner-city, including city Centre, Glasgow East and Central-South, zones that are well recognised as urban areas with lack of GI.

Further, 34% of Greater Glasgow is classified as low environment vulnerable that correspond in a total number of 252 datazones.

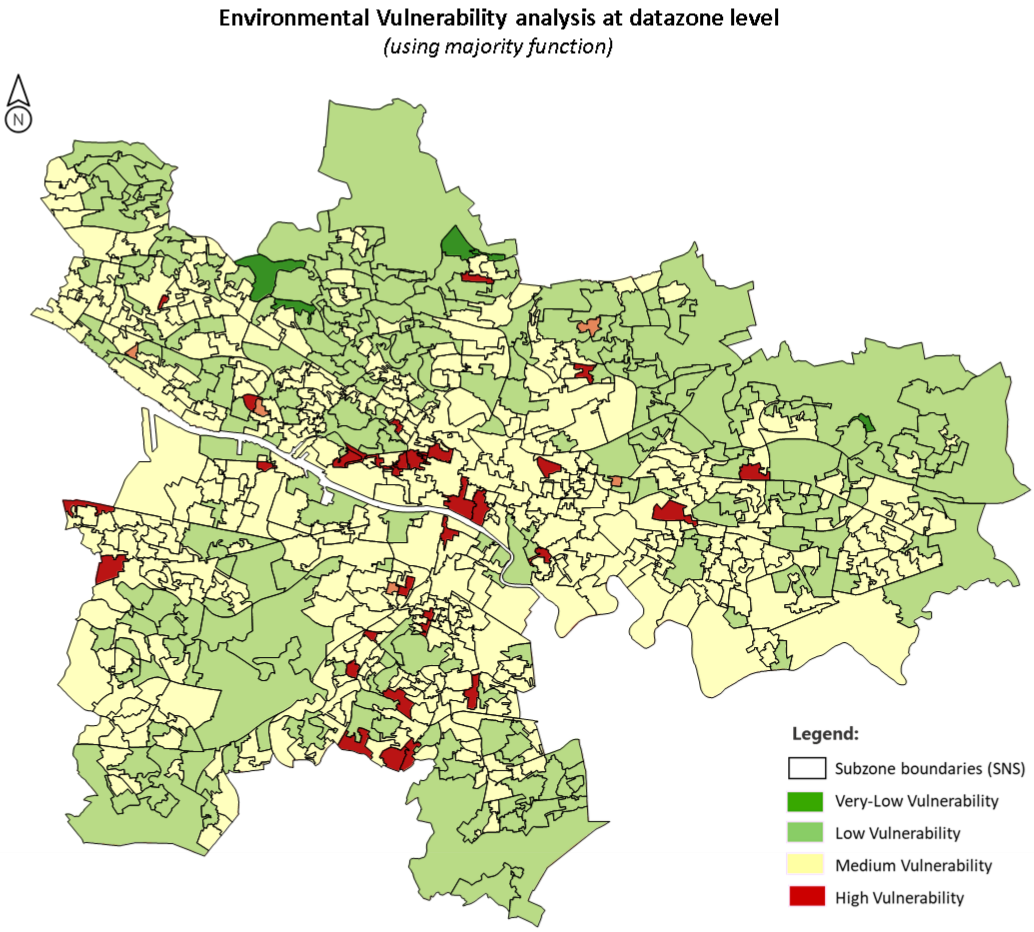


Figure 5.13. Distribution of Environmental Vulnerability at datazone level.

Table 5.2. Environmental Vulnerability distribution across classes

No. of Classes	Vulnerability Classes	No. of Subzones	Percantage(%)
1	No data	15	2.01
2	Very-Low Vulnerability	5	0.67
3	Low Vulnerability	247	33.11
4	Medium Vulnerability	452	60.59
5	High Vulnerability	27	3.62

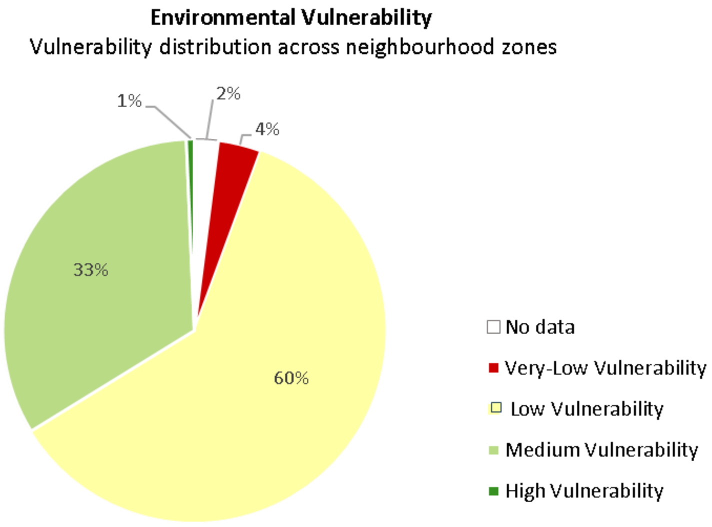


Figure 5.14. Environmental Vulnerability Pie Chart.

5.2.4 *Socio-Environmental Vulnerability*

The final output of Socio-Environmental Vulnerability presented in *Figure 5.15* illustrates the degree of vulnerability for each subzone ranked accordingly in five categories with a colour scale from red (most vulnerable areas) to green (less vulnerable). It is produced as a combination of all the indicators (raster calculator + zonal statistics), and it presents a non-homogenous vulnerability. The resulting Map highlights a higher vulnerability in the North and East part of the study area. The results indicate that 9% of Greater Glasgow is classified as very-high vulnerable, and 37% has a high vulnerable (Figure 5.16). From the total number of 756 datazones, 69 falls under very- high vulnerability and 278 datazones under high vulnerability *(Table 5.3).* Further, a medium vulnerability is presented in 140 subzones that correspond to 23.6% of the study area.

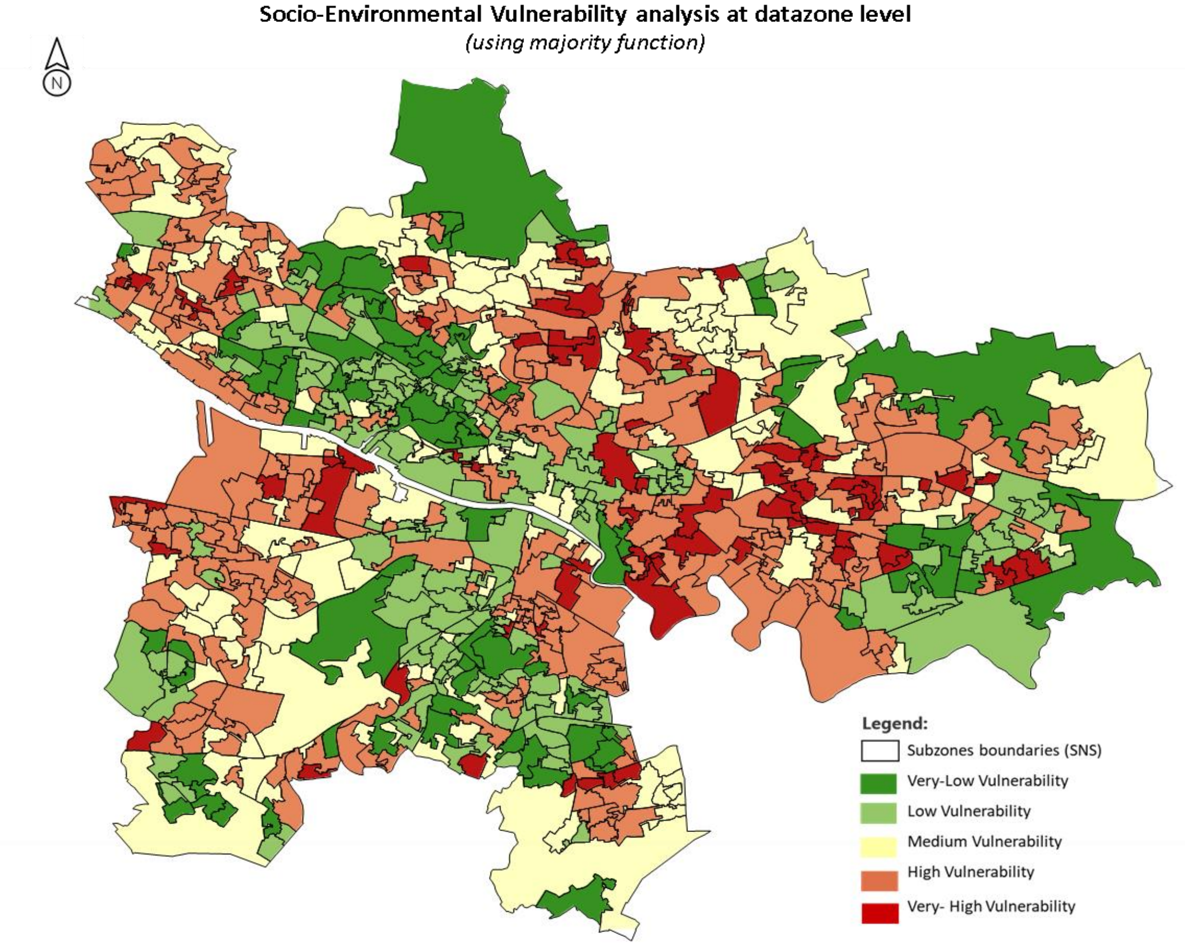


Figure 5.15.Distribution of Socio-Environmental Vulnerability at datazone level

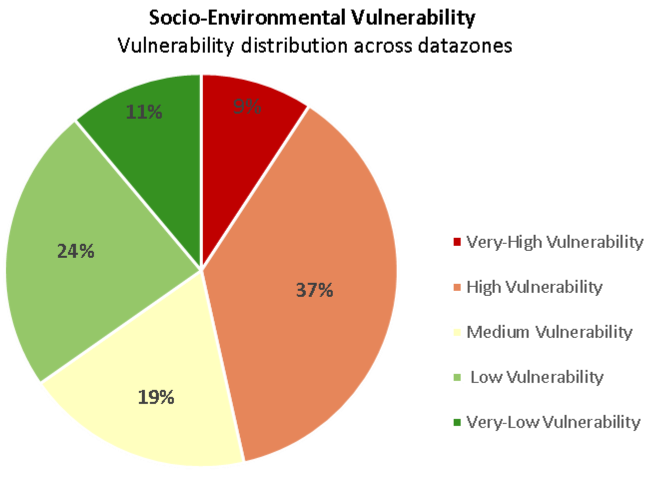


Figure 5.16. Socio-Environmental Vulnerability Pie Chart

Table 5.3. Socio - Environmental Vulnerability distribution across classes

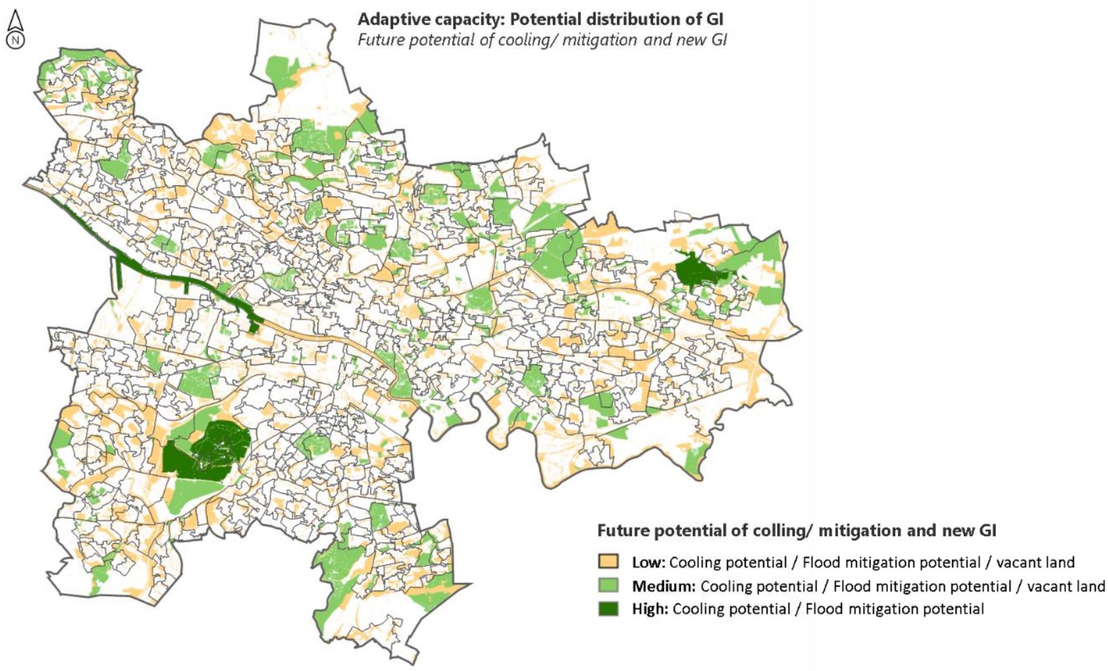
No. of Classes	Vulnerability Classes	No. of Subzones	Percantage(%)
1	Very-Low Vulnerability	83	11.13
2	Low Vulnerability	176	23.59
3	Medium Vulnerability	140	18.77
4	High Vulnerability	278	37.27
5	Very-High Vulnerability	69	9.25

5.3 Section 2

5.3.1 *The adaptive capacity analysis*

This section presents the results of the adaptive capacity to mitigate the effect of climate change and it is obtained through a spatial analysis of three indicators: flood mitigation, cooling potential and vacant/derelict land.

The first two indicators were combined in one output map following the approach from a study conducted by Majekodunmi, Emmanuel & Jafry (2020) *(Figure 5.17*). The Map presents the highest potential according to the type of GI and its capacity and function of mitigation. The distribution of potential is less present in the city Centre, Cental-south and Glasgow Est where there is a lack of GI or there is a lower mitigation potential.



Fig*ure 5.17. Potential Distribution of GI (Cooling and flood mitigation).*

The following map (*Figure 5.18*) illustrates the distribution of vacant land classified by ownership. For the purpose of the study, vacant/derelict land was categorised into three classes *(Table 5.4).* A higher priority was given to the class "Public land 1" under the ownership of Local Authority, Urban Regeneration Company and Housing Association (presented in Chapter 4). These cover 53,6% of the total vacant land available for Greater Glasgow. Public land under category 2 shows to have the least coverage with 4.95% compared private land with 41.56%.

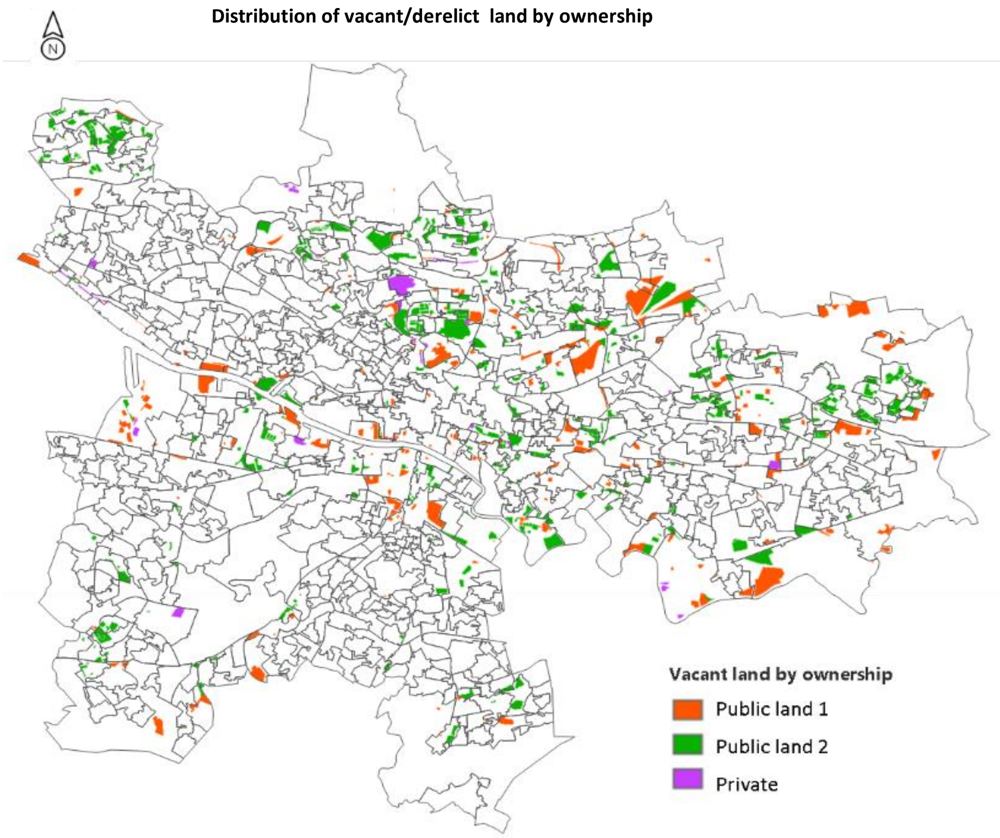


Figure 5.18. Distribution of vacant/derelict land by ownership

Table 5.4. The Classification of vacant land by ownership

Classification	Ownership	Size (ha)	Percantage (%)
Public Land 1	Local Authority Urban Regeneration Company Housing Association	538.76	53.59%
Public Land 2	Scottish Enterprise Other non-Crown Health Boards British Waterways	49.73	4.95%
Private	Ownership unknown Network Rail/ Rail Franchise Holder Other	416.82	41.46%

5.3.2 *Hotspot Analysis of prior interventions*

In order to prioritise decision-making, a combination of previous output was required to generate a hotspot map. *Figure 5.19* presents the Hotspot map that identifies the most vulnerable datazone (high to medium vulnerability) combined with the potential of GI integration. The map offers the major areas that need an immediate intervention of the application and improvement of GI. The east of Glasgow despite being highly vulnerable illustrates to have a good potential to be improved, compared to West side, that reflects less adaptive capacity. Overall, Glasgow presents an equal distribution of the adaptive capacity.

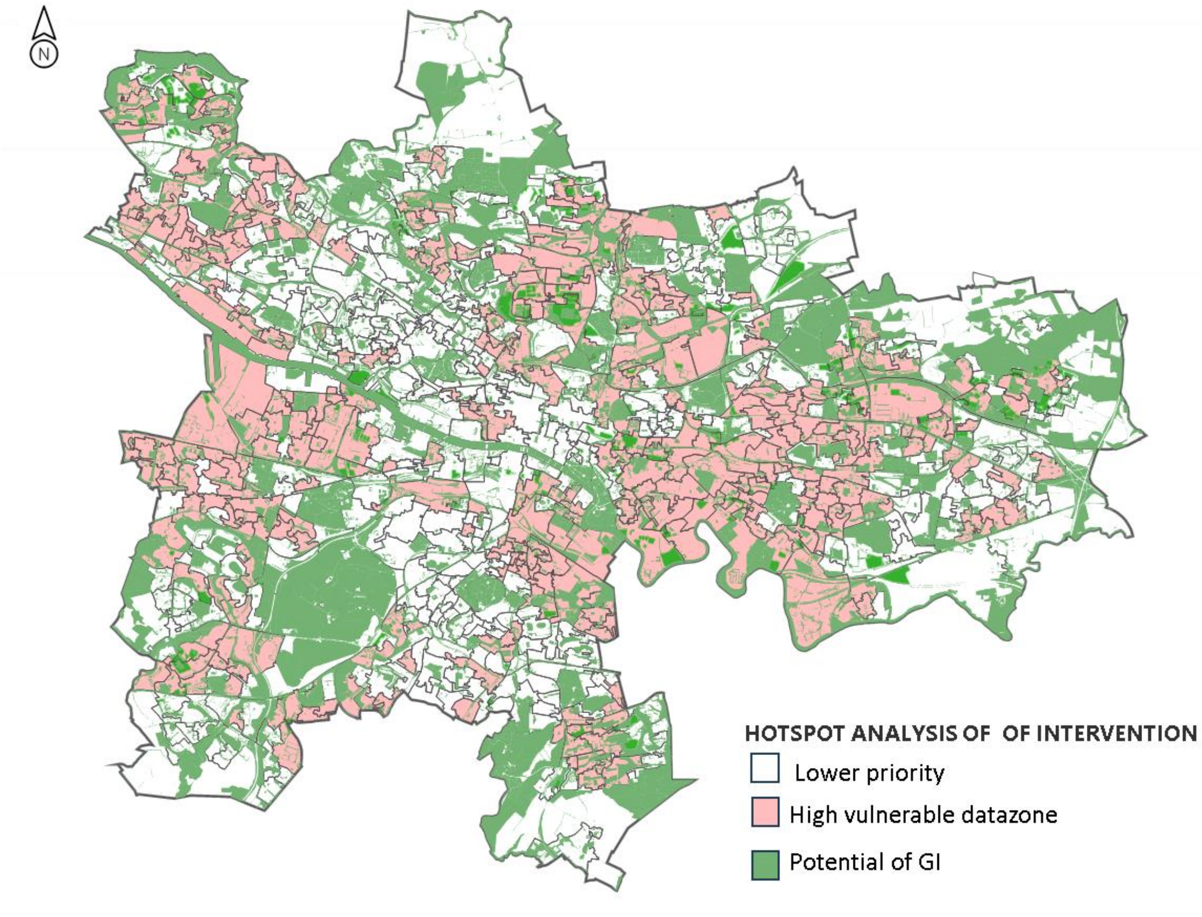


Figure 5.19. Hotspot analysis Map for prior interventions

5.4 Section 3

5.4.1 *Site selection and analysis*

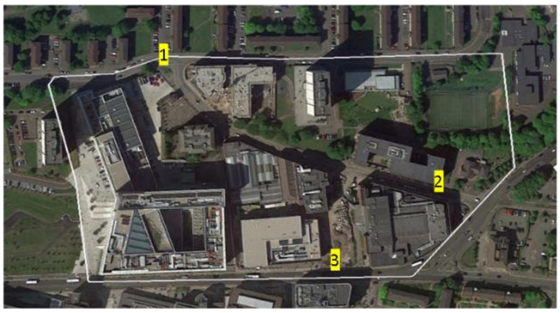
The two sites selected fulfil two main criteria: they fall under high-medium vulnerability and at the same time have a high-medium mitigation potential. They were chosen to demonstrate and analyse the influence of GI for two different urban structures.

The first site selected under the subzone "City centre East 04" presents a high Socio-Environmental vulnerability with low mitigation potential, a compact mid-rise urban structure referring to the LCZ classification conducted for the study.

The Second site selected is under the subzone "Milton East 03-04" and presents a high Socio-Environmental vulnerability, with high availability of vacant land under the administration of GCC, high mitigation potential, and an open-low rise urban structure (LC Z classification).

Table 5.5 presents the specifications and parameters used for developing the simulation models in ENVI-Met. Further specification of the simulation settings are presented in Appendix 1.

Table 5.5 Specifications of the site selected and details of the simulation model in ENVI-met.

SITE 1	SITE 2
    **"City centre East 04"** Urban structure (LCZ): Compact mid-rise High socio-environmental vulnerability Low potential	   **Milton East 03-04** • Urban structure (LCZ): Open low-rise • High socio-environmental vulnerability • Medium potential • High availability of vacant land
Envi-met model parameters : Site size: 410x250x150m Model gemotery: 82x50x30 grids Grid size: 5x5x5m Simulation date: 22.07.2019 (18:00) Simulation time: 30 hours Simple forcing: A simulation process only for temperature and humidity. Meteriological data: are used hipotetically to create the scenario.	**Envi-met model parameters:** *Site size:* 260x252x200m *Model gemotery:* 115x63x50 grids *Grid size:* 4x4x4m *Simulation date*: 22.07.2019 (18:00) *Simulation time:* 30 hours *Simple forcing:* A simulation process only for temperature and humidity. *Meteriological data:* are used hipotetically to create the scenario.

5.4.2 *Results from ENVI-met simulations*

The simulation scenarios were evaluated only for summer in order to estimate the model performance at its day-time peak, and it is considered the most widely evaluated model on ENVI-MET for microclimate with the accuracy in the results *(Stoka et. al, 2018).*

The two parameters MRT and PAT were calculated in ENVI-met at a pedestrian level to investigate the outdoor thermal comfort. Since the two sites present different model geometries and grid size, the temperature was analysed at the level of 1.5m for Site 1 and 1.2m for Site 2. *Figure 5.20* and *Figure 5.22*demonstrate the spatial distribution of MRT (a,b), and PAT (c,d) for the two sites in both current and proposed scenario. Results show that for both MRT and PAT the spatial average values are reduced.

Site 1 *(Figure 5.20)* presents a complex geometry with a low- intervention potential of integrating new GI elements due to a dense urban form.

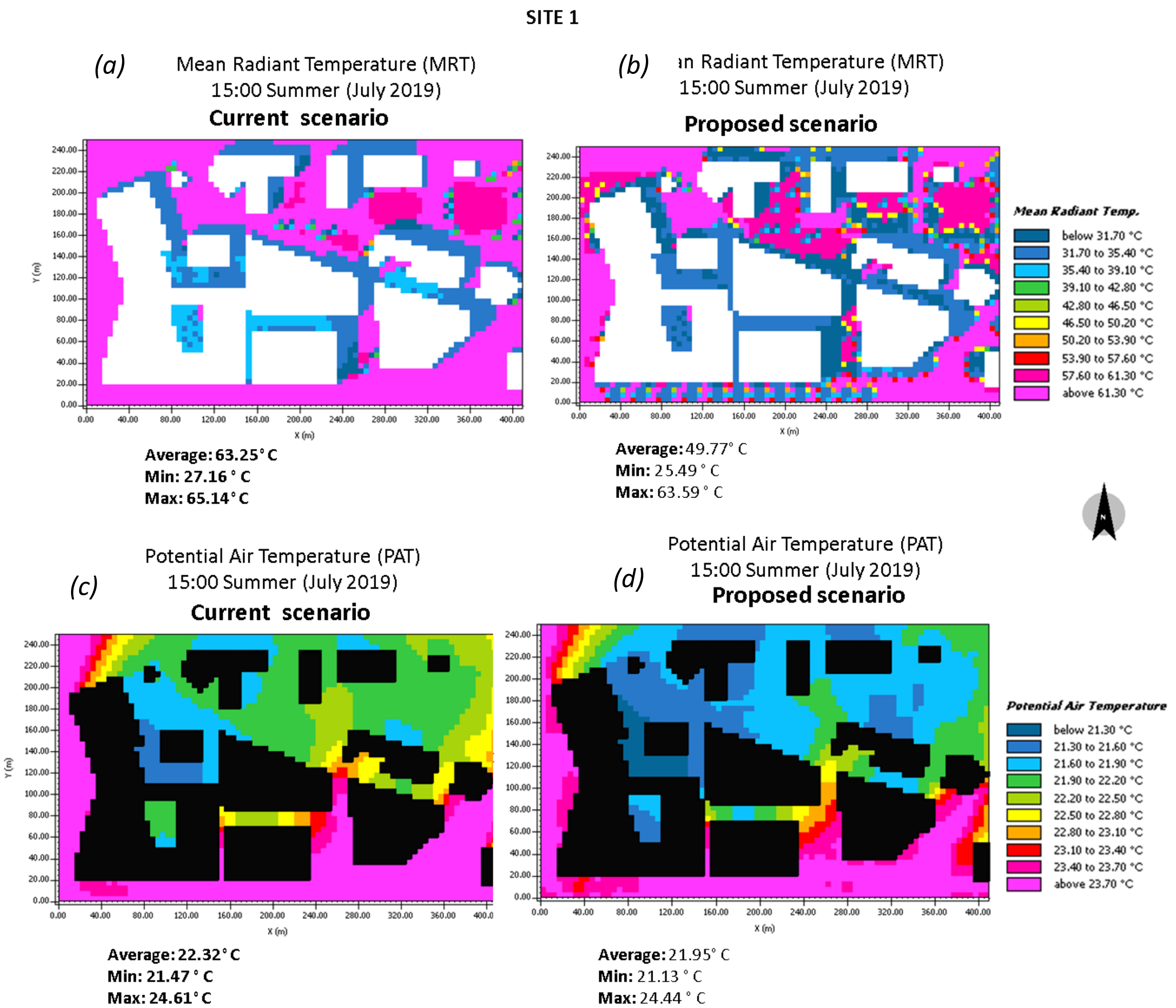


Figure 5.20.Spatial distribution of MRT (a,b),and PAT (c,d)at 15:00 for SITE 1 (a,b)

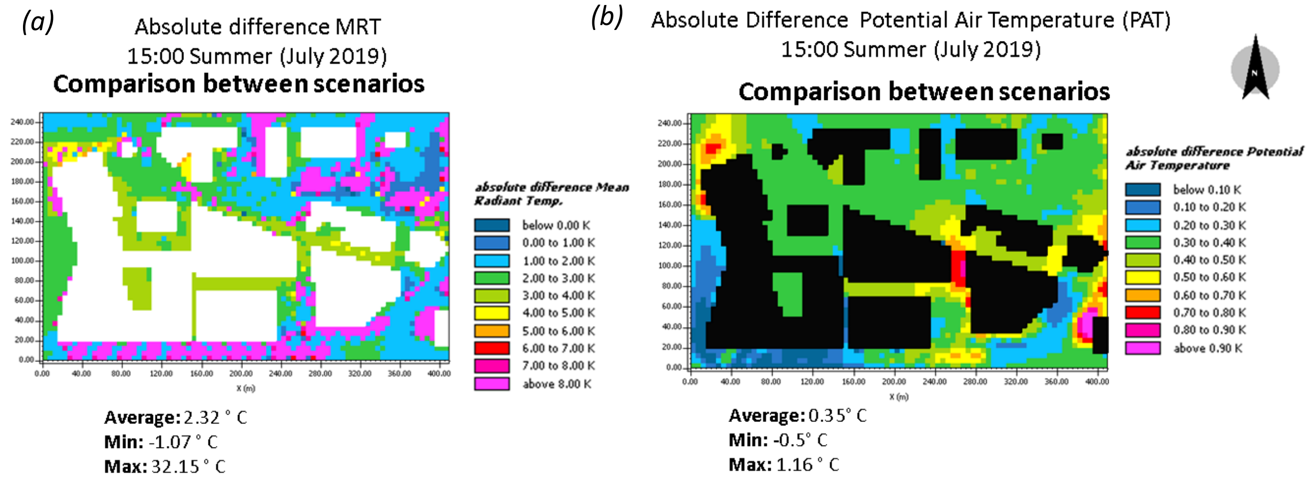


Figure 5.21.Spatial distribution of the difference of MRT (a) , and PAT (b) at 15:00 between the two scenarios.

Figure 5.21 illustrates the absolute MRT and PAT for Site 1 and compares the current and proposed scenarios.

The results offer an average reduction of MRT of 2.32°C and an average for PAT of 0.35°C. The highest temperature reduction is present where the highest volume of GI is proposed.

The dense urban structure demonstrates that in combination with addition GI can reduce the PAT mostly in street canyons. In the case of MRT, the decrease in temperature does not present a significant relation to the urban structure. We can conclude that it is present in street canyons and open spaces but not in all the cases.

Site 2 *(Figure 5.22)* presents a simple geometry compared to the first site, and it shows a better distribution of the temperature difference throughout the site. Given the opportunity to have within the site an existing vacant land under the administration of GCC, it gives the potential for creating a new park in the site with dense trees.

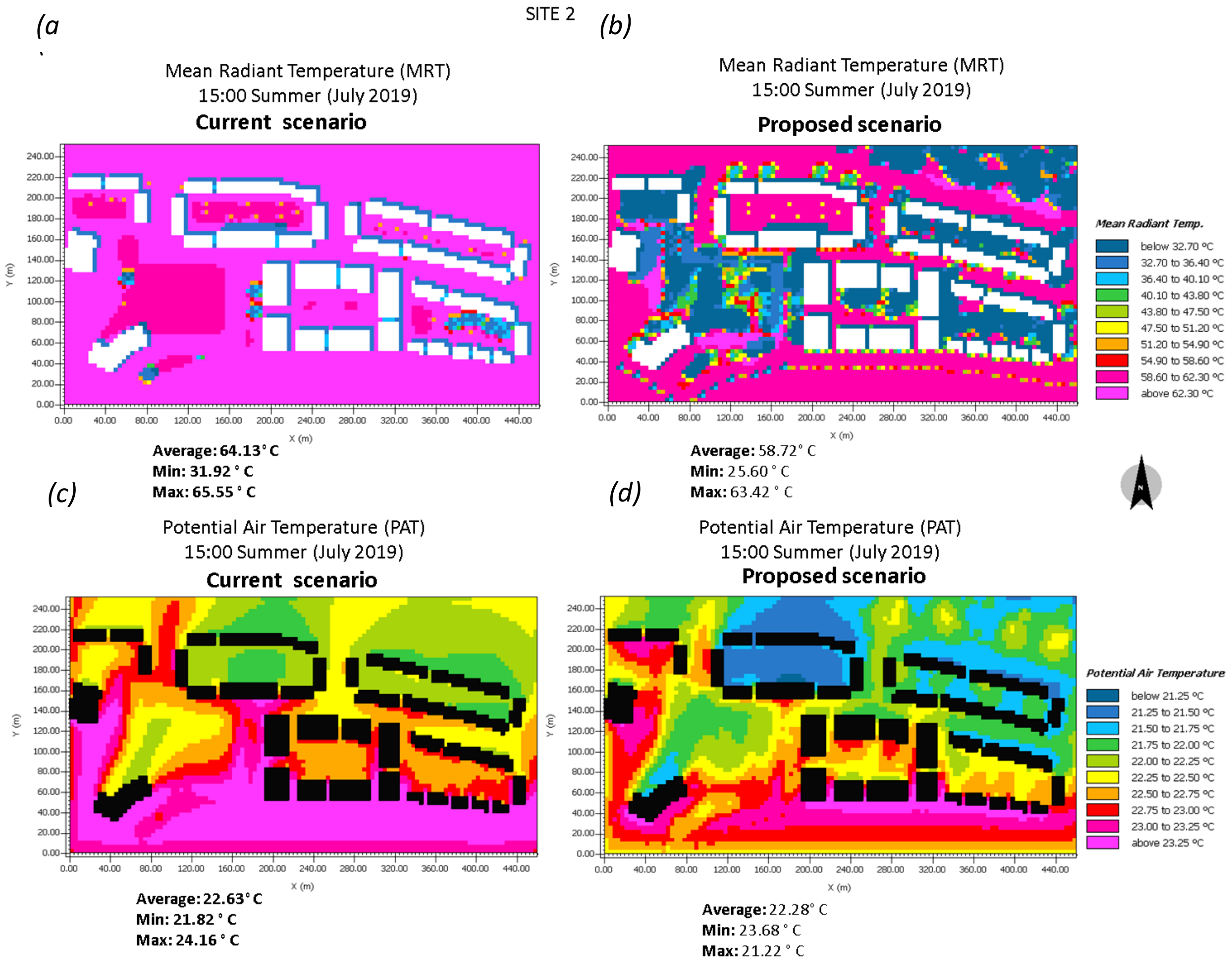


Figure 5.22. Spatial distribution of MRT (a,b),and PAT (c,d)at 15:00 for SITE 2 (a,b).

Figure 5.22 ilustrates the absolute MRT and PAT for Site 2 as a comparison of the current and proposed scenarios.

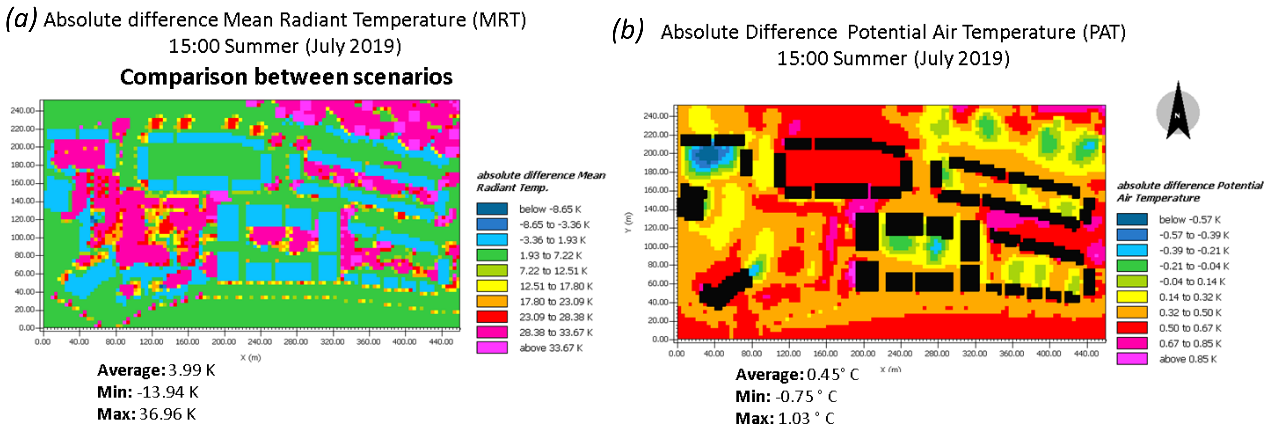


Figure 5.23. Spatial distribution of the difference of MRT (left) , and PAT (right)at 15:00 between the two scenarios (Site2)

It presents an average reduction of MRT of 3.99°C and an average for PAT of 0.45°C. This urban structure demonstrates that in combination with addition GI can reduce the PAT in both open spaces and street canyons. Nevertheless, MRT offers a more significant decrease in temperature for the open spaces.

In the following charts *(Figure 5.24 and Figure 5.25*) are presented a comparison between the current and proposed scenario for NST (h=0.5m for Site 1 and h=0.4m for Site 2), MRT and PAT for each site. Each profile presents the relation of temperature overtime during the simulation time of 30 hours. It is observed that for the three variables, the difference in temperature is more noticeable during the second part of the day (11am- 7pm), when the temperature is higher. Overall, site 2 presents a higher reduction in both MRT and PAT and therefore a better outdoor thermal comfort and a higher reduction of the UHI effect.

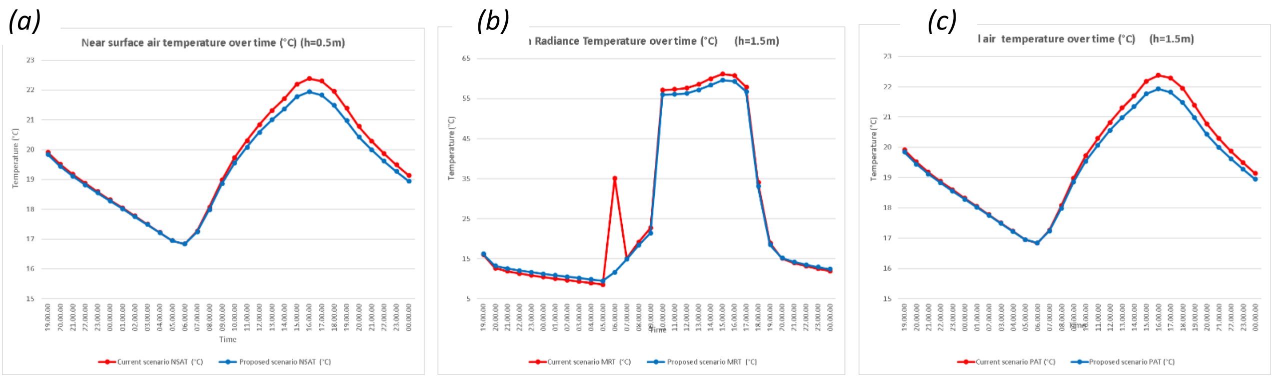


Figure 5.24. Profile of air temperature over time. Site 1: NST over time (a) / MRT over time (b) / PAT over time (c).

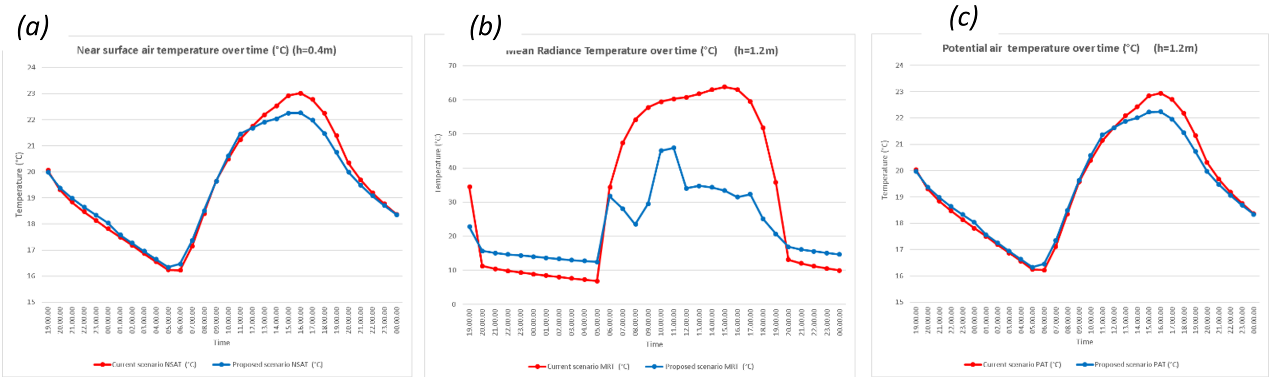


Figure 5.25.Profile of air temperature over time. Site 2: NST over time (a) / MRT over time (b) / PAT over time (c).

Further, to investigate the influence of green roofs, the profile of air temperature was analysed at the height of the green roofs with the help on ENVI-met (Leonardo). For the first site the receptor was set on the green roof of Townhead Village Hall Community Centre, while for the second site the receptor was set on the roof of a private residence.

The following charts (*Figure 5.26* and *Figure 5.27)* present a comparison between the current and proposed scenario for MRT and PAT (h=7.5m for Site 1 and h=10m for Site 2). Each profile illustrates the relation of temperature overtime during the simulation time of 30 hours. For both sites, the reduction of MRT is almost insignificant compared to the PAT that gives a higher impact on the difference in temperature after 13:00.

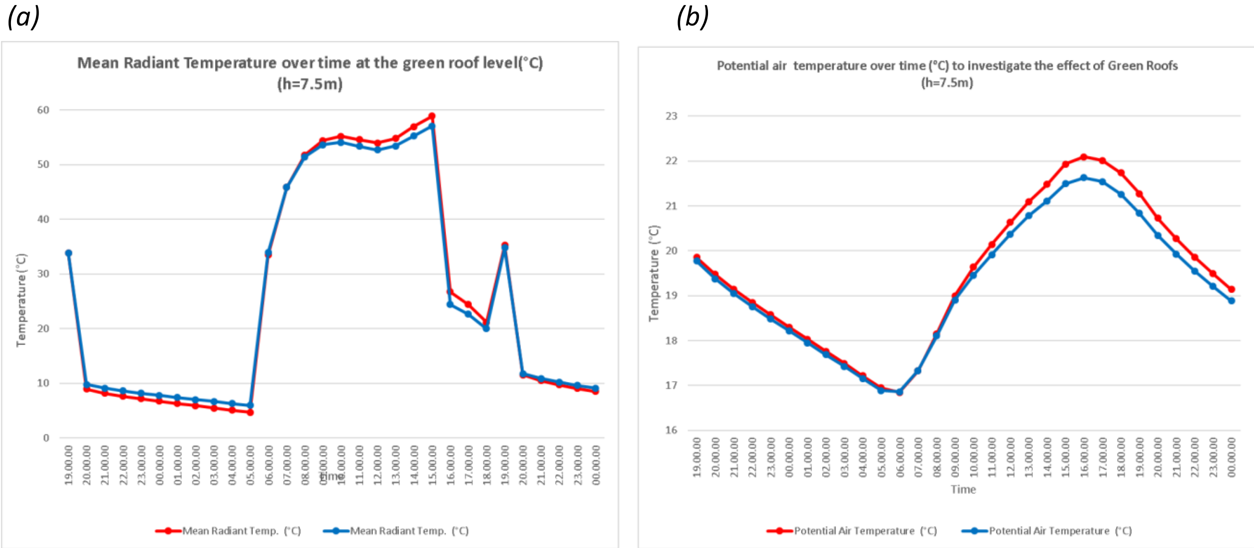


Figure 5.26 Profile of air temperature over time for green roofs. Site 1: / MRT over time (a) / PAT over time (b).

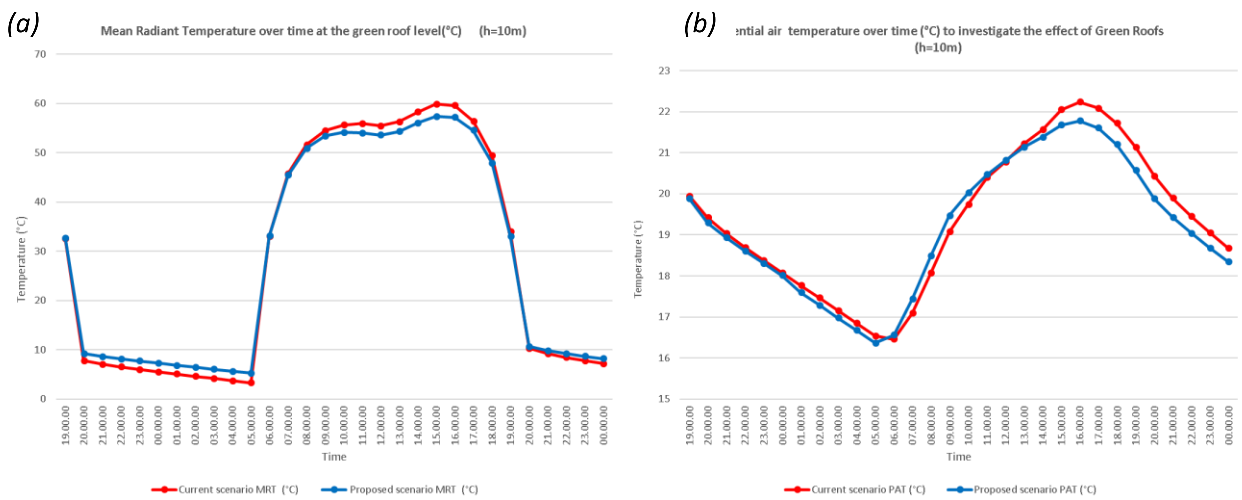


Figure 5.27. Profile of air temperature over time for green roofs. Site 2: / MRT over time (a) / PAT over time (b).

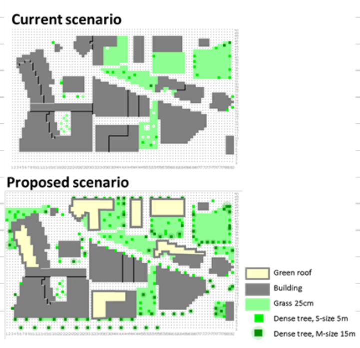
5.4.3 *Preliminary analysis of the Greendex*

Site 1 *(Table 5.6)* under the subzone "City centre East 04" presents a complex geometry ,a compact mid-rise urban structure as per LCZ classification and a low- intervention potential for GI. The site includes several new developments characterised by flat roofs such as City of Glasgow College, Strathclyde University, Student Roost St.Mungo's accommodation and Townhead Village Hall Community Centre that give the potential of integrating new extensive green roofs. The calculation of the Greendex for the current scenario results in a low Greendex score of 0.09.

Although the site does not offer a high possibility to integrate GI, the proposal scenario has tried to improve the existing GI whenever possible by adding more trees, new rain gardens, green roofs and therefore reaching a score of 0.25. The scoring analysis is presented in *Table 5.6* for the existing and new scenario.

It can be clearly observed that this site presents limitations on the implementation and choices of different type of GI. This example presents an urban structure commonly found close to the city Centre, where interventions are very limited.

Table 5.6. The Greendex Scoring analysis for Site 1



Site ilustration	No.	Surface cover type	Factor	Existing (m²)	New (m²)
	1	Semi natural vegetation / wetland / water surface	1		
	2	Large trees in natural soil (per m2 of canopy cover)	1	75	850
	3	Medium-small trees in natural soil (per m2 of canopy cover)	0.8	85	450
	5	Vegetation on deep soil	0.6	1500	2700
	6	Vegetation on shallow soil	0.4	6700	9700
	7	Rain Garden / vegetation	0.7		1000
	8	Intensive green roof (vegetation over structure) min depth 150mm	0.6		
	9	Extensive green roof (vegetation over structure) 60-150mm	0.3		8800
	10	Green walls / vertical vegetation	0.3		
	11	Green pavers	0.4		
	12	Permeable paving	0.2		
	13	Concreate/ asphalt / impermeable materials	0		
		TOTAL AREA = 95000 m²		**0.09**	**0.25**

Site 2 *(Table 5.7)* under the subzone "Milton East 03-04" presents a simple urban form of 1-4 stories buildings classified as open low-rise. Most of the buildings were built with the scheme in the early 1950' excluding a new development block of 2-3 stories located at the centre of the site. The buildings are characterised by a shared backyard. The site includes an existing vacant land under the administration of GCC that has a high potential to be converted into a dense park. The calculation of the Greendex for the current scenario results in a score of 0.22.

The new proposal offers the application of extensive green roofs for all the buildings, referring to similar successful regeneration projects in Buccleuch Street, funded by GCC and Scottish Government.

Further, an improvement of existing GI is proposed by adding supplementary trees and raingardens with an improvement score of 0.53. *Table 5.7* illustrates in detail the scoring analysis conducted.

Hence, site 2 presents an urban structure commonly found outside inner Glasgow and in the outskirts of the city.

Table 5.7. The Greendex Scoring analysis for Site 2

Site ilustration	No.	Surface cover type	Factor	Existing (m²)	Proposed (m²)
	1	Semi natural vegetation / wetland / water surface	1		
	2	Large trees in natural soil (per m2 of canopy cover)	1	175	12000
	3	Medium-small trees in natural soil (per m2 of canopy cover)	0.8	64	152
	5	Vegetation on deep soil	0.6	21000	25000
	6	Vegetation on shallow soil	0.4	1000	2000
	7	Rain Garden / vegetation	0.7		250
	8	Intensive green roof (vegetation over structure) min depth 150mm	0.6		
	9	Extensive green roof (vegetation over structure) 60-150mm	0.3		14737
	10	Green walls / vertical vegetation	0.3		
	11	Green pavers	0.4		
	12	Permeable paving	0.2		
	13	Concreate/ asphalt / impermeable materials	0		
		TOTAL AREA = 102000 m²		**0.22**	**0.53**

To summarise, the preliminary analysis presents a better understanding of the capacity of each site to integrate GI by quantifying and comparing the scenarios. Limitations can be observed in both sites, taking in consideration that the sites present an existing urban structure. For both the sites, the analysis was conducted to evaluate an approximate maximum potential of GI. However, site one clearly demonstrates a lower capacity compared to site two.

6 Discussion

This chapter summarises and discusses the research findings in relation to the six objectives of this dissertation. Firstly, Section 6.1 evaluates the research method presented in Chapter 4 and Chapter 5 and the suitability of this application. It also gives a comparison of this study approach with previous case studies *(Chapter 1).*

Secondly, Section 6.2 provides a summary of research findings and analyse the factor influencing these results.

The chapter concludes by presenting the limitations of the study in section 6.

6.1 Evaluation of the research method

As found in the literature, GI index is a tool that does not come as a result of specific research and framework. The practice has shown that despite the tool being in function for two decades, there are still uncertainties and gaps present. This dissertation provides a research method that helps in creating the bridge between vulnerability frameworks and this tool by including different characteristics that are important in the Glasgow context. This methodology finds similarities with the Green Infrastructure Focus Map created for London, that comes as a combination of several indicators to help for prioritizing GI and specific ecosystem services to the specific context.

Despite that some GI Index has given importance to the social aspects when developing the tool, such as the case of Stockholm, this indicator has been considered separately for particularly new developments and not in city-scale connected with the existing urban areas. In the other hand, in a case like London, social indicators as a combination of context-specific analysis have been integrated.

Therefore, this study demonstrates to have successfully archive objective 1, and presents the theory and assessment in which the analysis can be based on the combination of different indicators. In addition, this approach gives power to city planners and also gives focus to existing developments to help in improving the current environment, rather than just focus in new developments as seen in some of the case studies.

The vulnerability framework gives the possibility to provide a particular focus to the potential of GI, in which the derelict/ vacant land plays a vital role for a post-industrial city like Glasgow, similar to the case of Malmo. This approach comes in align with Climate Emergency working group suggestions to GCC.

Further, the Index proposed is developed in a simplified way and demonstrates similarities with Berlin, Southampton and London index.

6.2 Research findings

The framework vulnerability analysis and evaluation of the Greendex require the formulation of a methodological framework based on literature. Based on these analyses, the following findings are presented:

- Data zones with high income/employment rate have overall demonstrated to have a good indicator of health.
- City centre presents to have the lowest distribution rate of the sensitive population (0-5, +75).
- The maps generated identify clusters that present a relation between the sensitive population and availability of Green spaces. This can bring to the assumption that there is a lack of GI present for one of the most vulnerable groups and might require more attention to further analysis.
- The distribution and accessibility of green spaces do not follow the same pattern, clearly demonstrating the lack of public green spaces and the high proportion of private green spaces.
- Overall, Glasgow demonstrates to have an equal statistic distribution of socio-environmental vulnerability, in which 63% of the study area is classified as high-medium vulnerable for social conditions and, 64.21% for the environmental conditions. However, the environmental vulnerability demonstrates to have a significant impact for 60% of the city under medium vulnerability, compared to 47% for social vulnerability.
- The comparison of LST map with the NDVI demonstrates clearly the relation between the two indicators and confirms the presence of UHI effect in the study area. Thus, in align with the results of LCZ that reflects the highest urban sensitivity in the dense urban area where there is a lack of green spaces.
- Relatively High potential of improving and implemented GI is observed for the most vulnerable areas, giving the potential for intervention in future.
- By increasing the vegetation cover in urban areas can lead to a significant reduction of MRT but less significant reduction of PAT. However, these demonstrate to successfully improve the human thermal comfort in both the scenarios.
- The analysis of site number two presents a great example of how the GI Index can be implemented in producing good results. Further, it reflects how vacant/derelict land can be converted in a dense urban park, that has a significant impact for the urban microclimate and in the accessibility of GI.

6.3 Limitations

- The full study is based on secondary data which might lead to some limitations. For instance, Census 2011 and SIMD 2020 data delivered the vulnerability analysis in a small geographical scale, bringing more accuracy, but on the other hand, Census data are updated every ten years, and some of the SIMD 2020 data are estimations. In a nine years span, it can be considered outdated, and changes in composition might be present. Anyway, Census and SIMD data can still be considered of good use, presenting the official statistic data from National Records of Scotland and are used from central and local government, other authorities, organisations and researchers.
- Unavailability of building data limited the study by excluding the potential analysis of green roofs for Glasgow that could have been an excellent indicator to include in the adaptive capacity analysis.
- Experimental Limitations have been present. Meteorological measurements were unable to be conducted for the sites selected due to extreme circumstances caused by the pandemic. Therefore, to create the hypothetical scenario and validate the ENVI-met, the meteorological data were estimated referring to the GCU weather station data of 2018.
- The weightage criteria used for developing the vulnerability analysis is based on literature. This might be considered as a limitation of the study, but in the other hand, it can be considered as a not biased method.
- In the linkage between social and environmental vulnerability, the study measures the provision and accessibility of green spaces but does not take into consideration the use of green spaces. A complex pattern can occur, showing the use of green spaces from communities with a lack of accessibility which can lead to new studies.
- The study recognised and produced the Greendex classification into classes. Classes could have been broken down in further details by classifying and giving specific scores to different types of GI but giving the timeframe given, it was impossible to be included in this study.

7 Conclusions and recommendations for future studies

7.1 Conclusions

Green Infrastructure Index is a concept that still reflects uncertainties in implementation and due to missing knowledge or lack of scientific findings *(Wilkinson et al., 2013).* The literature review highlighted some of these limitations illustrated with case studies.

In the case of Berlin, regardless of being one of the greenest cities in Europe and having a good implementation of the GI Index, Berlin reflects an inequality distribution of GI where the most vulnerable communities were exposed to less GI.

Learning from previous case studies and to fill this knowledge gap, this research brings a holistic and comprehensive approach for Glasgow by considering the combination of Socio-Environmental indicators that can help in the implementation of the Index by emphasising where inequalities and potentials are present and prioritise decisions.

This study has demonstrated through a case study approach an example of how two different aspects such as social and environmental aspects that often are treated separately in relation to green infrastructure can be combined and integrated into the city planning strategies towards a common goal of sustainability and resilience. For instance, this study showed that many datazones could have a good indicator of GI per capita, but service areas can be limited due to accessibility or ownership.

As a support of the new Urban Agenda and SDGs, this approach incentives to be an addition to the climate change measures and strategies of Glasgow City Council and moreover counteract social inequities in support of sustainable cities and communities with inclusive and accessible green spaces for the most vulnerable. To follow up with evidence-based approach, better measurements are vital for the planning process, and this tool demonstrates it.

We have to acknowledge the limitations of implementing GI in dense urban areas that are mostly characterised by low availability of GI such as presented in the case of the selected site in *"City centre East 04"*. Nevertheless, GI reflects to has the potential to provide Glasgow with the various socio-environmental benefits and ecosystem services essential in combatting climate change and archive climate justice while preserving biodiversity.

The vulnerability framework analysis conducted for Greater Glasgow blended with the potential of GI implementation can archive a better comprehensive approach for the planning sector by helping in prioritise decision making where vulnerability and potential are high. The study has effectively communicated the potential and objectives where further research can be conducted.

7.2 Recommendations

Following the conclusions and considering the limitations of this dissertation, the recommendations suggested are presented in two sections: for the local authority and for further studies.

7.2.1 *Recommendation for Glasgow City Council*

- This approach can be beneficial for Planning decision making by giving power to decisions based on evidence and can serve as an addition to the climate change measures and strategies of Glasgow City Council.
- The adapted vulnerability framework can be developed further from GCC by adding other indicators that due to data limitation were not considered for this study. For instance, this research used NDVI as a proxy indicator of biodiversity due to limited data available. Hence, this indicator can be added to the framework by analysing to what degree biodiversity is exposed to climate change.
- LCZ map can be used on other studies as a proxy indicator to determine the ecosystem services available in local areas (e.g. some of the more open LCZ classes could be said to have higher cooling/flood mitigation potential). Following this, City Planners can carry out LCZ mapping as a shortcut to determining local environmental attributes.
- It can be beneficial to extend this study further and determine the minimum Greendex score per datazone to contribute in fulfilling the Quantity, Quality and Accessibility Standards established under Guidance SG6 (2017), in support of the City Development Plan and Open Space Strategy (OSS,2020).
- Supplementary guidance for the Greendex score should be considered further, giving a specific score to different series of trees according to their ecosystem services provisions and prioritising native species.
- Increasing awareness on the multi-dimension benefits of GI is essential for encouraging citizen to get involved in the process, especially on existing developments and in context of Glasgow where 30% of green spaces is classified as Private Garden.

7.2.2 *Recommendation for further studies*

- Additional research is needed to identify the capacity and potential of green roofs for Greater Glasgow, taking in consideration the age of the building, material and the structural capacity needed for extensive and intensive roofs.

- The NDVI analysis, LST and ENVI-met simulations were conducted only for the month of July. The analysis can be extended further by considering the winter season and quantify the annual benefits of GI.
- This dissertation looks at the linkage between socio-environmental vulnerability and potential of GI and does not incorporate the economic benefits of GI. This can be a new potential study to quantify the economic benefits of GI for Glasgow with the help of software such as I-Tree.
- Addition analysis can be performed for the selected sites or any pilot project to recalculate the environmental vulnerability of the new proposal and creating new indicators such as the Vulnerability Reduction Potential (VRP).
- The versatile nature of this methodology can be replicated and adapted for other case studies given the proper datasets.

To conclude, by determining the socio-environmental vulnerability and potential of GI, new standards can be archived and leveraged by planners, developers and other stakeholders.
Nevertheless, we need to acknowledge that we cannot solve every socio-environmental problem for the city by including the Greendex concept at the policy level. But giving its multi-dimension benefits and the metric ability can serve as an addition to the climate change measures and strategies, giving more power to decisions based on evidence.

8 Bibliography

1. Adaptation Scotland, (2017). Scottish climate change adaptation programme: progress report 2017. Scottish Government publication. Available from: https://www.gov.scot/publications/climate-ready-scotland-scottish-climate-change-adaptation-programme-third-annual/ [[Accessed 7 Jan 2020].

2. ADGER, W.N. AND KELLY, P.M. (1999) Social Vulnerability to Climate Change and the Architecture of Entitlements. Mitigation and Adaptation Strategies for Global Change, 4, 253-266.
http://dx.doi.org/10.1023/A:1009601904210

3. BAWA, K., J. ROSE, K. N. GANESHAIAH, N. BARVE, M. C. KIRAN, AND R. UMASHAANKER. (2002). Assessing biodiversity from space: an example from the Western Ghats, India. Conservation Ecology 6(2): 7. [online] URL: http://www.consecol.org/vol6/iss2/art7/

4. BECKER, C.& MOHREN R., (1990). The Biotope Area Factor as an Ecological Parameter Principles for Its Determination and Identification of the Target, Berlin: Landschaft Planen & Bauen. Retrieved from: https://www.berlin.de/senuvk/umwelt/landschaftsplanung/bff/en/grundlagen.shtml [Accessed 15 Jan 2020].

5. BECKETT, K.P., FREER-SMITH, P.H. & TAYLOR, G., (1998). Urban woodlands: their role in reducing the effects of particulate pollution. Environmental Pollution. 99(3), pp.347-360. Available from: 10.1016/S0269-7491(98)00016-5. [Accessed 3 March 2020].

6. BENEDICT, M. A., & MCMAHON.E.T., (2002). Green Infrastructure: Smart Conservation for the 21st Century. *Renewable Resources Journal*. 20(3), pp.12-17. Available from: https://www.merseyforest.org.uk/files/documents/1365/2002+Green+Infrastructure+Smart+Conservation+for+the+21st+Century.pdf [Accessed 9 Jan 2020].

7. BENEDICT, M. A., & MCMAHON, E. T., (2006). Green infrastructure: Linking landscapes and communities. Urban Land Washington, DC: Island Press.

8. BOLUND, P., & HUNHAMMAR, S. (1999). Ecosystem services in urban areas. Ecological Economics. 29(2), pp.293-301. [viewed Jan 10, 2020]. Available from: 10.1016/S0921-8009(99)00013-0 [Accessed 20 Feb 2020].

9. BONAN.G (2016). Ecological Climatology: Concepts and Applications. Cambridge, UK: Cambridge Univ. Press. 3rd ed..Available from: https://doi.org/10.1017/CBO9781107339200 [Accessed 25 Jan 2020].

10. BSDUDE - Berlin’s Senate Department for Urban Development and Environment. (2013).

11. Versorgung mit öffentlichen, wohnungsnahen Grünanlagen. Available from: www.astadtentwicklung.berlin.de/umwelt/umweltatlas/e_text/ka605.doc. [Accessed 29 Jan 2020].

12. BYRNE, J. & WOLCH, J., (2009). Nature, race, and parks: past research and future directions for geographic research:. Progress in Human GeographyAvailable from: 10.1177/0309132509103156. [Accessed 15 May 2020].

13. ClimateXChange., (2016). Indicators and trends: monitoring climate change adaptation. Available at: http://www.climatexchange.org.uk/files/8614/7558/3595/BB13_Impermeable_surfaces.pdf. [Accessed 13 Jan 2020].

14. COPPEL, G. & WÜSTEMANN, H., (2017). The impact of urban green space on health in Berlin, Germany: Empirical findings and implications for urban planning. *Landscape and Urban Planning.* 167, pp.410-418. Available from: 10.1016/j.landurbplan.2017.06.015. [Accessed 23 Feb 2020].

15. CRACKNELL, A.P., (1997). The Advanced Very High Resolution Radiometer. Taylor & Francis, London.

16. CULBERT, PD, RADELOFF, VC, ST-LOUIS, V., FLATHER, CH, RITTENHOUSE, CD, ALBRIGHT, TP & PIDGEON, A.M., (2012). Remote sensing of environment 118, pp.140-150. Available from: http://www.sciencedirect.com/science/article/pii/S0034425711003993.

17. DAILY, G. (ED.), (1997). Nature's Services: Societal Dependence of Natural Ecosystems.Island Press, Washington, DC, p. 392.

18. DERKZEN, M.L., TEEFFELEN, A.J., VERBURG, P.H., (2015). Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands. J. Appl. Ecol. 52, 1020–1032.

19. DEVANATHAN, P., DEVANATHAN, K., (2011). Heat island effects. In: Sabnis, Gajanan M. (Ed.), Green Building with Concrete:Sustainable Design and Construction. CRC Press, Boca Raton, FL, pp. 175–226.

20. DOHERTY, KAJ, ADAMS, RG & DAVEY, N., (2007). Unsupervised learning with normalised data and non-Euclidean norms. Applied Soft Computing. 7(1), pp.203-210. Available from: 10.1016/j.asoc.2005.05.005.

21. D. R. Streutker (2002) A remote sensing study of the urban heat island of Houston, Texas, International Journal of Remote Sensing, 23:13, 2595-2608, DOI: 10.1080/01431160110115023ç.

22. ELY, M & PITMAN, S., (2014). Green infrastructure: life support for human habitats. The compelling evidence for incorporating nature in urban environments, Botanic Gardens of

Adelaide. Available from: http://www.botanicgardens.sa.gov.au/greeninfrastructure [Accessed 13 March 2020].

23. EMMANUEL, R. & LOCONSOLE, A., (2015). ‘Green infrastructure as an adaptation approach to tackling urban overheating in the Glasgow Clyde Valley Region, UK’, *Landscape and Urban Planning*. Elsevier B.V., 138, pp. 71–86. Available from: 10.1016/j.landurbplan.2015.02.012 [Accessed 23 Feb 2020].

24. EMMANUEL, R., CLARIDGE, H. AND MAJEKODUNMI, M.,(2014). Climate Proof Glasgow: Nature-based solutions as indicators towards a climate-just transition | Oppla. [online] Oppla.eu. Available at: https://oppla.eu/casestudy/19235 [Accessed 14 May. 2019].

25. ELMQVIST, T. et al., (2013). Urbanisation, Biodiversity and Ecosystem Services: Challenges and Opportunities A Global Assessment . 1st ed. 2013. [Online]. Dordrecht: Springer Netherlands. [Accessed 2 Jan 2020].
26. European Commission (2013). Building a green infrastructure for Europe, Publications Office of the European Union, Luxembourg.

27. European Commission (2015). Towards an EU research and innovation policy agenda for nature-based solutions and re-naturing cities, Final Report of the Horizon 2020 Expert Group on Nature-Based Solutions and Re-Naturing Cities, Directorate-General for Research and Innovation, Publications Office of the European Union, Luxembourg. [Accessed 29 March 2020].

28. DE OLIVEIRA.L, F & MELL, I., (2019), *Planning Cities with Nature: Theories, Strategies and Methods*. Cities and Nature, Springer. Available from: https://doi.org/10.1007/978-3-030-01866-5 [Accessed 17 March 2020].

29. *FELLMANN T.(2012). The assessment of climate change related vulnerability inthe agricultural sector: Reviewing conceptual frameworks.In:Meybeck A,Lankoski J, Redfern S, Azzu N, Gitz V, editors.Building Resilience for Adaptationto Climate Change in the Agriculture Sector, FAO-OECD Workshop 23–24 April2012. Rome, Italy: Food and Agriculture Organization (FAO), pp 37–61*.

30. FORESTRY COMMISSION (2013). Air Temperature Regulation by Urban Trees and Green Infrastructure. Forestry Commission Research. Available from: http://www.forestresearch.gov.uk/research/air-temperature-regulation-by-urban-trees-and-green-infrastructure-2/. [Accessed 5 Feb 2020].

31. HANSEN, RIEKE, ANTON STAHL OLAFSSON, ALEXANDER P.N. VAN DER JAGT, EMILY RALL, AND STEPHAN PAULEIT., (2019). “Planning Multifunctional Green Infrastructure for Compact Cities: What Is the State of Practice?” Ecological Indicators 96 (January): 99–110. https://doi.org/10.1016/j. ecolind.2017.09.042. [Accessed 27 Jan 2020].

32. HANSEN, R., PAULEIT, S., (2014). From multifunctionality to multiple ecosystem services? A conceptual framework for multifunctionality in green infrastructure planning for urban areas, 43(4). pp 516-529.

33. HEIDT, V. & NEIF, M., (2008). Benefits of urban greenspace for improving urban climate. In: M.E. Carreiro, Y.C. Song and J. Wu (eds) Economy, planning and management of urban forests: international perspectives. New York: Springer. pp 336-345.

34. HISLOP,M.,SCOTT,A.J., & CORBETT,A., (2019). What Does Good Green Infrastructure Planning Policy Look Like? Developing and Testing a Policy Assessment Tool Within Central Scotland UK, Planning Theory & Practice, 20:5, 633-655, Available from: 10.1080/14649357.2019.1678667 [Accessed 25 Feb 2020].

35. GATTO , E, BUCCOLIERI, R, AARREVAARA , E, IPPOLITO , F, EMMANUEL, R, PERRONACE , L & SANTIAGO , JL (2020), 'Impact of urban vegetation on outdoor thermal comfort: comparison between a Mediterranean city (Lecce, Italy) and a Northern European city (Lahti, Finland)', Forests, vol. 11, no. 2, 228. https://doi.org/10.3390/f11020228.

36. Gensler and the Urban Land Institute (2011). Open Space: An asset without a champion? Report for the Urban Investment Network. Available from: https://www.gensler.com/uploads/document/220/file/Open_Space_03_08_2011.pdf . [Accessed 8 April 2020].

37. GILL, J., & P. JOHNSON., (2012). Research Methods for Managers, SAGE Publications Ltd.ProQuest Ebook Central, 32-45 http://ebookcentral.proquest.com/lib/gcal/detail.action?docID=254569. Created from gcal on 2019-06-25 14:19:49.

38. GILL, SE, HANDLEY, JF, ENNOS, AR & PAULEIT, S (2007), 'Adapting cities for climate change: The role of the green infrastructure', *Built Environment*, vol. 33, no. 1, pp. 115-133. https://doi.org/10.2148/benv.33.1.115 [Accessed 8 March 2020].

39. GILLHAM, B. (2000) Case Study Research Methods. Continuum, London.

40. GIZ (2014). Vulnerability assessments, Climate Change Adaptation in Rural Areas of India (CCA-RAI), Ministry of Environment, Forests and Climate Change, New Delhi.

41. Glasgow and Clyde Valley Strategic Development Planning Authority (2010). Vacant and Derelict Land Monitoring Report 2010. Glasgow: Glasgow and Clyde Valley Strategic Development Planning Authority.

42. Glasgow and Clyde Valley Strategic Development Planning Authority (2011). Green Network Spatial Priorities. Glasgow: Glasgow and Clyde Valley Strategic Development Planning Authority.

43. Glasgow and Clyde Valley Structure Plan Joint Committee (2006). Glasgow and Clyde Valley Joint Structure Plan 2006 Supplementary Written Statement Third Alteration to the 2000 Plan at

http://www.gcvcore.gov.uk/DOCS/structure_plan/2006_Plan_Supplementary _Written_Statement.pdf [Accessed 5 March 2020].

44. GOWARD, S.N., TUCKER, C.J., DYE, D.J., (1985). North American vegetation patterns observed with the NOAA-7 advanced very high resolution radiometer. Plant Ecology 64 (1), 3–14. http://dx.doi.org/10.1007/BF00033449

45. GOMEZ-BAGGETHUN E, DE GROOT R, LOMAS PL, MONTES C., (2010). The history of ecosystem services in economic theory and practice: from early notions to markets and payment schemes. Ecol Econ 69:1209–1218

46. GÓMEZ-BAGGETHUN.E., DE GROOT.R., LOMAS.L.P. & MONTES.C., (2009). The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. Ecological Economics. 69(6) pp 1209-1218. Available from: https://doi.org/10.1016/j.ecolecon.2009.11.007 [Accessed 3 April 2020].

47. GRAY M AND BARFORD A., (2018). The depths of the cuts: The uneven geography of local government austerity. Cambridge Journal of Regions, Economy, and Society 11(3). pp.541-563. Available from: 10.1093/cjres/rsy019. [Accessed 22 March 2020].

48. GREENSPACE SCOTLAND., (2018). The third State of Scotland's Greenspace Report. [online] greenspacescotland.org.uk. Available at: https://www.greenspacescotland.org.ukRi4QKBCuZJ92oT8eM2sxd3/view [Accessed 25 Jun. 2019].

49. GREEN SURGE. (2017). What benefits does green infrastructure in the cities offer? [online] Greensurge.eu. Available at: https://www.e-pages.dk/ku/1335/html5/ [Accessed 5 Jul. 2019].

50. HARRISON, HELENA; BIRKS, MELANIE; FRANKLIN, RICHARD & MILLS, JANE (2017). Case Study Research: Foundations and Methodological Orientations [34 paragraphs]. Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, 18(1), Art. 19, http://nbn-resolving.de/urn:nbn:de:0114-fqs1701195.

51. IPCC (2014), Climate change: impacts, adaptation and vulnerability, In Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R. and White L.L., eds., Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, New York, Cambridge University Press.

52. JANSSEN, M.A, OSTROM, E. (2006). Resilience, vulnerability, and adaptation: A cross- cutting theme of the International Human Dimensions Programme on Global Environmental Change. Global Environmental Change, vol. 16, no. 3, p. 237-239.

53. JIM, C.Y. & CHEN, W.Y., (2008). Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). Journal of Environmental Management. 88(4), pp.665-676. Available from: 10.1016/j.jenvman.2007.03.035. [Accessed 19 April 2020].

54. JOHANSSON, ROLF (2003). Key note speech at the international conference "Methodologies in Housing Research," Royal Institute of Technology in cooperation with the International Association of People–Environment Studies, Stockholm, September 22-24, 2003, http://www.psyking.net/htmlobj-3839/case_study_methodology-_rolf_johansson_ver_2.pdf [Accessed: May, 03, 2020].

55. KABISCH, N., (2015). Ecosystem service implementation and governance challenges in urban green space planning—The case of Berlin, Germany. *Land use Policy.* **42**, pp.557-567. Available from: 10.1016/j.landusepol.2014.09.005 [Accessed 20 March 2020].

56. KACZOROWSKA, A., KAIN, J., KRONENBERG, J. & HAASE, D., (2016). Ecosystem services in urban land use planning: Integration challenges in complex urban settings—Case of Stockholm. Ecosystem Services. 22, pp.204-212. Available from: 10.1016/j.ecoser.2015.04.006 [Accessed 18 March 2020].

57. KAMBITES, C & OWEN, S., (2006). 'Renewed prospects for green infrastructure planning in the UK', Planning, Practice & Research, vol.21, no.4, pp.483-496 .

58. KEELEY, M., (2011). The Green Area Ratio: an urban site sustainability metric. Journal of Environmental Planning and Management. 54(7), pp.937-958. Available from: 10.1080/09640568.2010.547681. [Accessed Jan 2020].

59. KENDON, M., MCCARTHY, M., JEVREJEVA, S. AND LEGG, T. (2017): State of the UK Climate 2016, Met Office, Exeter, UK. Available at: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/state-of-uk-climate/mo-state-of-uk-climate-2016-v4.pdf [Accessed 27 Feb. 2020]

60. KRÜGER, E., DRACH, P. & EMMANUEL, R., (2018). Atmospheric Impacts on Daytime Urban Heat Island. Air, Soil and Water Research. 11, pp.1178622118810201. Available from: 10.1177/1178622118810201 [Accessed 6 Feb 2020].

61. KRUUSE A., (2011). GRaBS Expert Paper 6: The Green Space Factor and the Green Points System,TCPA, London.

62. LITTLE, C. E. , (1990). Greenways for America (Baltimore, MD, The Johns Hopkins University Press).

63. Ljungby stad (2000) Gro¨nstrukturplan fo¨r Ljungby stad (Green Structure Plan for Ljungby City) (Ljungby,Ljungby stad).

64. LU, CY, GU, W., DAI, A.H., WEI, H.Y., (2012). Assessing habitat suitability based on geographic information system (GIS) and fuzzy: a case study of Schisandra sphenanthera Rehd. et Wils. in Qinling Mountains, China. Ecol. Modell. 242, 105–115. https://doi.org/10.1016/j.ecolmodel.2012.06.002.

65. MAANTAY.J.A., (2013). Collapse of Place: Derelict Land, Deprivation, and Health Inequality in Glasgow, Scotland. *Urban Land Use*. pp.23-70. Available from: 10.1201/9781315365794-9.

66. MAJEKODUNMI, M, EMMANUEL, R & JAFRY, T 2020, 'A spatial exploration of deprivation and green infrastructure ecosystem services within Glasgow city', *Urban Forestry and Urban Greening*, vol. 52, 126698. https://doi.org/10.1016/j.ufug.2020.12669

67. MALCZEWSKI, J., & RINNER, C., (2015). Multicriteria Decision Analysis in Geographic Information Science. Berlin, Heidelberg: Springer Berlin Heidelberg. Available from: https://doi.org/10.1007/978-3-540-74757-4

68. MAZZA, L., G. BENNETT, L. DE NOCKER, S. GANTIOLER, L. LOSARCOS, C. MARGERISON, (2011). Green infrastructure implementation and efficiency. Final report for the European Commission, DG Environment on Contract ENV.B.2/SER/2010/0059. Brussels and London: Institute for European Environmental Policy.

69. MCCARTHY J.J. , CANZIANI O.F, LEARY N.A. , DOKKEN D.J. , WHITE K.S. (2001). Climate Change 2001: Impacts, Adaptation, and Vulnerability. Published for the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge 1032pp.

70. MELL, I.C., (2017). Green infrastructure: reflections on past, present and future praxis. Landscape Research. 42(2), pp.135-145. Available from: 10.1080/01426397.2016.1250875. [Accessed 6 March 2020].

71. MELL, I.C., HENNEBERRY, J., HEHL-LANGE, S. & KESKIN, B. (2013). Promoting urban greening: Valuing the development of green infrastructure investments in the urban core of Manchester, UK. Urban Forestry & Urban Greening. 12(3), pp.296-306. Available from: 10.1016/j.ufug.2013.04.006. [Accessed 14 Feb 2020].

72. MELNIK9OVAS, A. (2018) Towards an Explicit Research Methodology: Adapting Research Onion Model for Futures Studies. Journal of Futures Studies. 23 (2), 29-44. DOI:10.6531/JFS.201812_23(2).0003

73. MEMON, R.A., LEUNG, D.Y.C. & LIU, C., (1986). Atmospheric research. *Atmospheric Research*. 94(3), pp.491-500. Available from: http://www.sciencedirect.com/science/article/pii/S0169809509002166. [Accessed 27 March 2020].

74. Millennium Ecosystem Assessment, (2005). Ecosystems and Human Well-being: Synthesis. Washington, DC.Island Press. Available

from:https://www.millenniumassessment.org/documents/document.356.aspx.pdfv [Accessed 10 Feb 2020].

75. NAUMANN, S., DICK, M., KERN, E. & JOHANN, T., (2011) The GREENSOFT Model: A reference model for green and sustainable software and its engineering. *Sustainable Computing: Informatics and Systems*. 1(4), pp.294-304. Available from: 10.1016/j.suscom.2011.06.004. [Accessed 16 Feb 2020].

76. Nature Scotland (2014). Scotland's People and Nature Survey 2013/14 [online],Available :https://www.nature.scot/naturescot-commissioned-report-679-scotlands-people-and-nature-survey-201314 [Accessed 20 Jan 2020].

77. OKE, T.R., MILLS, G., CHRISTEN, A. & VOOGT, J.A., (2017). Urban climates. Cambridge: Cambridge University Press. Available from: doi: 10.1017/9781139016476 [Accessed 20 May 2020].

78. O'NEIL-DUNNE, J.P.M., S.W. MACFADEN, H.M. OKE, T.R., MILLS, G., CHRISTEN, A. & VOOGT, J.A., (2017). Urban climates. Cambridge: Cambridge University Press.

79. FORGIONE, AND J.W.T. LU. 2014. Urban ecological land-cover mapping for New York City. Final report to the Natural Areas Conservancy. Spatial Informatics Group, University of Vermont, Natural Areas Conservancy, and New York City Department of Parks & Recreation. 22 pp. Available from: https://naturalareasnyc.org/media/pages/in-print/research/b2d9fc964f-1492159094/urbanecologicalmap_newyorkcity_report_2014.pdf . [Accessed 23 March 2020].

80. RAMYAR, R., (2019). Social–ecological mapping of urban landscapes: Challenges and perspectives on ecosystem services in Mashhad, Iran. Habitat International. 92, pp.102043. Available from: 10.1016/j.habitatint.2019.102043. [viewed Feb 5, 2020].

81. RAMYAR, R., SAEEDI, S., BRYANT, M., DAVATGAR, A. & MORTAZ HEDJRI, G., (2020) Ecosystem services mapping for green infrastructure planning–The case of Tehran. Science of the Total Environment. 703, pp.135466. Available from: 10.1016/j.scitotenv.2019.135466. [Accessed 15 March 2020].

82. RILEY, B., 2017. The state of the art of living walls: Lessons learned. Building and Environment. 114, pp.219-232. Available from: 10.1016/j.buildenv.2016.12.016. [viewed Jun 2, 2020].

83. RIZWAN, A.M., L.Y. DENNIS, AND L.I.U. CHUNHO. (2008). A review on the generation, determination, and mitigation of urban heat island. J. Environ. Sci. 20(1):120–8. doi:10.1016/S1001-0742(08)60019-4.

84. ROE, M. & MELL, I., (2013). Negotiating value and priorities: evaluating the demands of green infrastructure development. Journal of Environmental Planning and Management. 56(5), pp.650-673. Available from: 10.1080/09640568.2012.693454. [Accessed 6 March 2020].

85. ROUSE. D.C. & BUNSTER-OSSA. I., (2013). Green Infrastructure: A Landscape Approach. American Planning Association, Chicago.

86. RPA & Cambridge Econometrics. (2008). The Economic Impact of Scotland's Natural Environment. Scottish Natural Heritage Commissioned Report No.304 (ROAME No. R07AA106). Available from: https://www.nature.scot/sites/default/files/2017-07/Publication%202008%20-%20SNH%20Commissioned%20Report%20304%20-%20The%20Economic%20Impact%20of%20Scotland%27s%20Natural%20Environment.pdf.

87. PAPATHOMA-KÖHLE, M., CRISTOFARI, G., WENK, M. & FUCHS, S., (2019). International journal of disaster risk reduction 36, pp.101103. Available from: http://www.sciencedirect.com/science/article/pii/S2212420918308665.

88. PATAKI, D.E., CARREIRO, M.M., CHERRIER, J., GRULKE, N.E., JENNINGS, V., PINCETL, S., POUYAT, R.V., WHITLOW, T.H., ZIPPERER, W.C., (2011). Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions. Front. Ecol. Environ. 9, 27–36.

89. PATEL, S., (2015). [Online] Available at: http://salmapatel.co.uk/academia/the-research-paradigm-methodology-epistemology-and-ontology-explained-in-simple-language [Accessed 13 08 2018].

90. PATEL, S. (2015) The research paradigm – methodology, epistemology and ontology – explained in simple language. (online) Available at: http://salmapatel.co.uk/academia/the-research-paradigmmethodology-epistemology-and-ontology-explained-in-simple-language [Accessed: April, 15, 2020].

91. PICKETT, S.T.A., M.L. CADENASSO, J.M. GROVE, C.G. BOONE, P.M. GROFFMAN, E. IRWIN, S.S. KAUSHAL, V. MARSHALL, (2011). Urban ecological systems: Scientific foundations and a decade of progress. Journal of Environmental Management 92: 331–362.

92. POLSKY, C., NEFF, R. & YARNAL, B., (2007). Building comparable global change vulnerability assessments: The vulnerability scoping diagram. Global Environmental Change. 17(3-4), pp.472-485. Available from: 10.1016/j.gloenvcha.2007.01.005

93. PUGH, T.A.M., MACKENZIE, A.R., WHYATT, J.D. & HEWITT, C.N., (2012). Effectiveness of Green Infrastructure for Improvement of Air Quality in Urban Street Canyons. Environmental Science & Technology. 46(14), pp.7692-7699. Available from: 10.1021/es300826w. [viewed May 6, 2020].

94. SAUNDERS, M., LEWIS, P., & THORNHILL, A. (2007). Research Methods for Business Students, (6th ed.) London: Pearson.

95. SAUNDERS, M. & TOSEY, P., 2012. The Layers of Research Design. s.l.:Academia.

96. SAUNDERS, M., LEWIS, P & THORNHILL, A, (2016). Research Methods for Business Students. 5th ed. Essex: Pearson Education Ltd.

97. SCHRAMM, W. (1971). Notes on case studies for instructional media projects. Working paper for Academy of Educational Development, Washington DC.

98. SCOTTISH NATURAL HERITAGE AGENCY., (2014). Greenspace Team People & Places Unit.Urban Green Infrastructure Benefits Factsheets. [viewed Jan 2, 2020]. Available from: https://www.nature.scot/sites/default/files/2019-10/Urban%20Green%20Infrastructure%20Benefits%20Factsheet.pdf [viewed March 6, 2020]

99. SENATSVERWALTUNG FÜR STADTENTWICKLUNG UND UMWELT., (2013). Der Park amGleisdreieck Idee, Geschichte, Entwicklung und Umsetzung, Berlin., pp. 53,Retrieved from: http://www.stadtentwicklung.berlin.de/umwelt/stadtgruen/gruenanlagen/downloads/gleisdreieck der-park-am-gleisdreieck broschuere.pdf ,[Accessed 18 Feb 2020].

100. SENATSVERWALTUNG FÜR STADTENTWICKLUNG UND UMWELT., (2013). Urban Green,Retrieved from: http://www.stadtentwicklung.berlin.de/umwelt/stadtgruen/gruenanlagen/index.shtml [Accessed 27 Feb 2020].

101. SEPA.,(2015) Flood Risk Management Strategy Clyde and Loch Lomond. Available at: http://apps.sepa.org.uk/FRMStrategies/pdf/lpd/LPD_11_Full.pdf. [viewed Jan 6, 2020].

102. SIMPSON, J.R., 2002. Improved estimates of tree-shade effects on residential energy use. Energy and Buildings. 34(10), pp.1067-1076. Available from: 10.1016/S0378-7788(02)00028-2. [Accessed 22 Feb 2020].

103. SNEATH, PHA & SOKAL, RR, (1973). Numerical taxonomy. The principles and practice of numerical classification. Numerical Taxonomy. the Principles and Practice of Numerical Classification. Available from: https://www.cabdirect.org/cabdirect/abstract/19730310919. [viewed May 29, 2020].

104. SNIFFER., (2017). Climate Ready Clyde Risk and Opportunity Assessment Workshop. Available at: http://climatereadyclyde.org.uk/wp-content/uploads/2018/06/CRC-Risk-and-Opportunity-Workshop_8-November-2017_FINAL_For-circulation.pdf. [viewed Feb 3, 2020].

105. STREUTKER, D.R., (2002). A remote sensing study of the urban heat island of Houston, Texas. International Journal of Remote Sening. 23(13), pp.2595-2608. Available from: 10.1080/01431160110115023.

106. STEWART, I.D., OKE, T.R., AND E.S. KRAYENHOFF (2014). Evaluation of the 'local climate zone' scheme using temperature observations and model simulations. International Journal of Climatology, 34: 1062-80.

107. STOK,S, TSIKALOUDAKI, A. & THEODOROS,T., (2018). Analysing the ENVI-met microclimate model's performance and assessing cool materials and urban vegetation applications–A review. Sustainable Cities and Society 43, pp.55-76. [viewed June 13, 2020]. Available from: 10.1016/j.scs.2018.08.009.

108. STROHBACH, M.W. & HAASE, D., (2012). Above-ground carbon storage by urban trees in Leipzig, Germany: Analysis of patterns in a European city. Landscape and Urban Planning. 104(1), pp.95-104. Available from: 10.1016/j.landurbplan.2011.10.001 [viewed Feb 3, 2020].

109. TEEB., (2011) The Economics of Ecosystems and Biodiversity. TEEB Manual for Cities: Ecosystem Services in Urban Management. Available from: www.teebweb.org

110. TURNER,B.L. , R.E. KASPERSON, P. MATSON, J.J. MCCARTHY, R.W. CORELL, L. CHRISTENS EN, N. ECKLEY, J.X. KASPERSON, A. LUERS, M.L. MARTELLO, C. POLSKY, A. PULSIPHER, A. SCHILLE R (2003). A framework for vulnerability analysis in sustainability science Proceedings, National Academy of Sciences, 100 (14) , pp. 8074-8079

111. TZOULAS, K, KORPELA, K, VENN, S, YLI-PELKONEN, V, KAŹMIERCZAK, A, NIEMELA, J & JAMES, P., (2007). 'Promoting ecosystem and human health in urban areas using green infrastructure: a literature review', Landscape and Urban Planning, no. 81, pp.167–178.

112. UNDP (2017). Social Vulnerability Assessment tools for climate change and DRR programming. A guide to practitioners. [viewed May 2, 2020]. Available from:
    a. https://www.adaptation-undp.org/sites/default/files/resources/social_vulnerability05102017_0.pdf.

113. VARTHOLOMAIOS.A ., PAPADOPOULOU.M & ATHANASSIOU.E., (2013) .The green space factor as a tool for regulating the ur ban microclimate in vegetation-deprived Greek cities.," . Available at: doi: 10.13140/2.1.1598.8484. [Accessed 26 Dec 2019].

114. WILKINSON, A., TOWNSEND, K. & BURGESS, J., (2013). Reassessing employee involvement and participation: Atrophy, reinvigoration and patchwork in Australian workplaces. Journal of Industrial Relations. 55(4), pp.583-600. Available from: 10.1177/0022185613489419. [viewed May 6, 2020]

115. WHITING, D., R. TOLAN, B. MECHAM, AND M. BAUER. (2005). Water-wise gardening: creating practical turf areas. Colorado State University Cooperative Extension. Available from: (http://www.ext.colostate.edu/pubs/garden/07761.html). [Accessed 1 March 2020].

116. XIE, M.,WANG, Y., CHANG, Q., FU,M., YE, M., (2013). Assessment of landscape patterns affecting land surface temperature in different biophysical gradients in Shenzhen, China. Urban Ecosyst. 16, 871–886.

117. YIN, R. K. (2009). Case study research: Design and methods. Thousand Oaks, Calif: Sage Publications.

118. YIN, ROBERT K. (2014). Case study research: Design and methods. Los Angeles, CA: Sage.

119. Wood, E.M., Pidgeon, A.M., Radeloff, V.C. & Keuler, N.S., 2013. Image Texture Predicts Avian Density and Species Richness. PloS One. 8(5), pp.e63211. Available from: 10.1371/journal.pone.0063211.

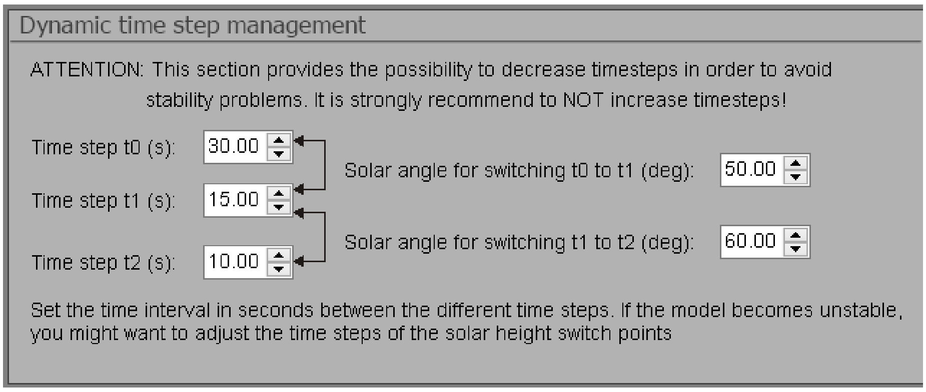
120. ZAIDAH, Z. (2007) Case Study as a Research Method. Jurnal Kemanusiaan, 9, 1-6.

9. Appendix 1

9.1 Specification on the simulation settings in ENVI- Met used for both the scenarios.

Forcing: Simple
Wind Speed @10m above ground: 1.8 m/s
Wind Direction: 203^{o}
Roughness Length: 0.01
Temperature for Forcing:
min @ 06:00 hrs = 14^{o}C; max @ 18:00 hrs = 22^{o}C
Relative Humidity for forcing:
min @ 17:00 hrs = 66%; max @ 04:00 hrs = 94%
Main Analysis: Thermal Comfort
CPU: single Core

Simulation time steps:



Soil conditions data: