MUrCS
Master in Urban Climate & Sustainability

Co-funded by the
Erasmus+ Programme
of the European Union

A DECISION-MAKING FRAMEWORK FOR SUITABILITY ANALYSIS OF URBAN AGRICULTURE AS A FLOOD RISK REDUCTION STRATEGY IN VULNERABLE COMMUNITIES

(A CASE STUDY OF GLASGOW)

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A thesis submitted for the Joint programme of
Master in Urban Climate & Sustainability

September 2022

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	Number of pages: 117	
Supervisor I Prof./Dr. Slobodan Mickovsi	**Supervisor II** Prof./Dr. Francisco Perez	

Title

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Degree: Master in Urban Climate & Sustainability

Abstract

Academic study emphasises Urban Agriculture's multifunctionality in its ability to address numerous benefits. However, at a time when natural/green infrastructures are becoming a preferred method of intervention in flood management worldwide, UA's multifunctionality has been limited to its provisional (food, fibre, etc.) or cultural (social participation, community development, etc.) benefits, with little to no research addressing its regulatory services. Many studies discuss the potential of its water management capacities, but little research exists in systematically exploring this, especially when viewed as a flood strategy. The research on the food system, flood risk, and urban agriculture is largely neglected, leaving numerous gaps that impede its applicability to flood management measures in urban areas. Given how flood hazards affect the entire food supply chain, particularly in already vulnerable communities, this relationship is crucial for addressing and evaluating the interconnectivity of rising flood risks and food systems. In the face of a hazard, both vulnerabilities and exposure dictate the extent of impact and therefore this study explores UA's potential in reducing vulnerabilities at the very heart of the flood-food nexus. To that purpose, this study defines common relationships between the two challenges, investigates their interdependencies in terms of both vulnerabilities and hazards, and proposes a framework for decision-making processes to identify prime intervention areas. Because the importance of urban agriculture and research in the global north is relatively limited, the assessment is carried out in Glasgow, Scotland, a city with high levels of land degradation, flood concerns, and food poverty.

The simulation exercises - conducted using InVEST and geospatial analysis - for the city of Glasgow exhibited substantial enhancements in flood retention and nutrition in the case study area. Thus, highlighting the potential of UA in addressing flood risk and food poverty. These findings, alongside the outcomes of a comprehensive literature review and expert consultation exercises (AHP), paved way for a decision-making framework. The framework is intended for use as a preliminary decision-making tool at the normal level for local governments and flood risk management practitioners while serving as a starting point for further research into UA as a flood risk reduction technique.

Keywords

urban food production; agriculture; flood risk reduction; social vulnerability; resilience

Originality statement. I hereby declare that this Master's dissertation is my own original work, does not contain other people's work without this being stated, cited and referenced, has not been submitted elsewhere in fulfilment of the requirements of this or any other award.	**Signature**

ACKNOWLEDGEMENTS

I would like to thank MUrCS for the opportunity for a great learning experience and the guidance of my supervisors, Professors Slobodan Mickovsi and Francisco Perez.

A special note of gratitude to Professor Emmanuel Rohinton for his support and direction throughout the course of the programme.

I'd like to thank Kiran Apsunde for his endless patience and guidance, as well as my dear friends and colleagues Mushfik Jalal, Fernanda Berlitz, Arooj Humayun and Samson Ogunfuyi for their compassion.

Thank you

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 01

1 INTRODUCTION

1.1 THE NEXUS OF FLOOD, FOOD, AND SOCIAL VULNERABILITY

Flood-related disasters are becoming more common as precipitation intensity and climate variability increase globally (FAO, 2015), affecting the entire food supply chain from agricultural production to food consumption (Dubbeling and Halliday, 2019; Atanga and Tankpa, 2021). Weakened food systems further, has social and economic consequences (FAO, 2015) from reduced capacities of a household to afford food (Atanga and Tankpa, 2021), deteriorating chances for access and utilisation of essential nutritional value (Atanga and Tankpa, 2021) affecting overall food security. Furthermore, a growing population and changing consumption habits are expected to result in a 60% increase in overall global food consumption by 2050, necessitating the need for a strong food system at home (FAO, 2015). Food insecurity as described by (FAO, 2015) exists,

> “when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life”

In the global north, food insecurity is generally linked to nutrient deficiencies (Opitz *et al.*, 2016), 2016), cost (Sniffer, 2021b), food waste (wrap, 2021), and quality (Artmann and Sartison, 2018), with the more commonly used interchangeable term ‘Food Poverty, which results from issues of ‘too much poverty and not too little food’ (NHS Health Scotland, 2018; Weakley, 2021). While food production is not a primary concern of the global north's food security stance, some debates and research on the concepts of self-sufficiency and food resilience are underway (Mok *et al.*, 2014), highlighting the issue of food dependency from rural or trans-boundary supply networks vulnerable to periods of low food supply caused by natural disasters (Dubbeling and Halliday, 2019). In the event of a disaster, resilient food systems that can survive and recover in the face of acute shocks, chronic stressors, and unforeseen conditions are required, as is restoring food availability as quickly and equitably as possible, ensuring that all residents in affected areas have adequate access to food (Dubbeling and Halliday, 2019).

‘Disasters’ according to (Wisner *et al.*, 2014; Ulibarri, 2017), are not caused by natural hazards but is usually a product of interlinked social, political, and economic demographics of a community (Berndtsson *et al.*, 2019). Naturally, vulnerable households (urban poor or marginalised groups) in urban systems, have limited capacity to respond to a disaster and are affected disproportionately (Dubbeling and Halliday, 2019). While investments in Disaster Risk Reduction (DRR) methods have shown a considerable reduction in disaster-related vulnerabilities (UNISDR and UNESCAPE, 2012), the contrary has also been true. Investments made to minimise a disadvantaged group's vulnerabilities have been found to reduce its potential to recover from and adapt to a disaster, thereby reducing risks (Huq and Hossain, 2015; SEPA, 2015; UNDRR, 2017; Dubbeling and Halliday, 2019) and therefore, a significant aspect in Flood Disaster Management techniques.

1.2 THE NEXUS OF FLOOD, FOOD, AND NATURAL INFRASTRUCTURE

(IUCN, 2020) defines Nature-based Solutions (NbS) as,

> “actions to protect, sustainably manage and restore natural or modified ecosystems, which address **societal challenges** (e.g., climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing **human well-being and biodiversity benefits.**”

The capacity of NbS to reduce vulnerabilities and flood risks of social-ecological systems (Shah et al., 2020) make them suitable contenders for the provision of natural flood insurance in vulnerable communities (Ebissa and Desta, 2022).

Urban agriculture (UA) is one such infrastructure that has gained a lot of attention in recent years due to its 'multifunctionality' from its proven ability to address multiple urban issues (See Appendix C) besides food production (De Zeeuw *et al.*, 2011; Artmann and Sartison, 2018; Lucertini and Di Giustino, 2021; Wadumestrige Dona *et al.*, 2021); and yet, research around either its ability to approach comprehensively multiple issues (Artmann and Sartison, 2018) remains or a critical evaluation of its ecosystem service delivery, remains largely unexplored.

Urban Agriculture is simply the practice of agriculture in urban areas for either consumption or sale (EPA, 2011). With between 15% and 20% of the world's food currently being produced in cities worldwide, benefits of UA in terms of its contribution to food production in cities has long been well-researched and has been a conventional solution to food insecurity and income generation in many developing countries (Artmann and Sartison, 2018) unlike in the global north where it has mostly been used as a tool for social and political change (Aerts, Dewaelheyns and Achten, 2016; Artmann and Sartison, 2018).

Maintaining natural ecosystems for the continued delivery of essential services supporting life via various direct and indirect contributions to human health and well-being is key to resilient cities and their coping mechanisms. However, when it comes to UA, the interest in its multifunctionality, is confined to its cultural (recreation, mental and physical health) or provisional (food supply) services, with very few studies on its delivery of regulating services (regulation of floods, drought, land degradation and disease, etc.) (Shah et al., 2020), and fewer still, on the ecological benefits it can offer, especially in the global north (Aerts, Dewaelheyns and Achten, 2016; Artmann and Sartison, 2018; Wadumestrige Dona *et al.*, 2021). A scoping review of literature made it clear that UA can support regulation of hydrological services (Setälä *et al.*, 2014; Ebissa and Desta, 2022), but there is a lack of a comprehensive assessment making its integration into flood management strategies and urban policies an untapped opportunity (Doherty, 2015; Artmann and Sartison, 2018; Dubbeling and Halliday, 2019).

UA like any green infrastructural intervention works with natural processes to manage the sources and pathways of flood waters (Artmann and Sartison, 2018; Dubbeling and Halliday, 2019) . Due to the effects of plant morphology and composition at a species level on regulation of eco-hydrological processes (Wang and Duan, 2010), exploring this aspect of UA can provide a greater insight into its viability as a flood risk management method (Zandersen *et al.*, 2021).

Framework: A conceptual framework, as described by (Bazeley and Jackson, 2015), "explains either graphically or in narrative form, the main things to be studied – the key factors, variables or constructs – and the presumed interrelationships among them". In order to promote UA as a tool capable of delivering essential regulatory ES, there is a need for a system to evaluate key variables informing the flood-food-social vulnerability nexus. While various frameworks exploring the links between social factors and flood disadvantage exist (SEPA, 2015; Sayers and Partners, 2017), and similarly, those exploring links between food insecurity and social vulnerabilities exist as well, there is a need for a decision-making tool to understand confluence of the flood-food potential in terms of UA as discussed above. Climate appropriateness is enabling newer crops and a proportional increase in overall agricultural productivity in the future, giving many nations, like the UK, the chance to achieve food self-sufficiency. Furthermore, in the face of changing climatic conditions, cities with sustainable local food systems and decreased vulnerabilities can adapt to, withstand, and recover from disasters (ACCCRN), (Dubbeling and Halliday, 2019).

This study builds on this intention and conducts an overall assessment of the potential of Urban Agriculture and its flood and food services.

1.3 RESEARCH QUESTIONS

The discussion above provides an overview of the essential elements that regulate urban agriculture and the research gaps that impede its use to flood management strategies. In order to develop a narrative toward the goals and objectives of the study, the next section examines these findings through the following questions.

1. **Social Vulnerabilities:** Which social vulnerability indicators are shared by flood risk and food insecurity?
   a. How do they influence each other?
   b. Is there any evidence of UA's role in it?
2. **Components of Urban Agriculture:** How can UA be developed as an effective and efficient flood management practise in floodplain conditions?
   a. **Selection of Crops:** Which are the critical parameters for selection of food crops optimum for flood risk reduction in urban areas? What characteristics of plants are recognised to contribute most to flood regulation?
   b. **Selection of Agricultural Practices:** In the context of anthropogenic conditions within urban areas, which are the practices most suited for preparing land for flood mitigation? Which of these topographical aspects in cities impede agricultural suitability?
3. **UA suitability and implementation:** Which are the key parameters that inform the selection of interventions in reducing flood risks and enhancing food production?
   a. To what extent can UA be integrated (contribute to) into urban policies for flood risk reduction?
   b. Can UA substitute or enhance the current flood risk mitigation strategies in Scotland? How reliable is the Urban Agricultural approach?

1.4 AIMS AND OBJECTIVES

Postulated Hypothesis: Based on a preliminary examination of the literature, evidence of contribution to flood regulation and food provisional aspects of agriculture in general is suggestive of the potential of Urban Agriculture in tackling these societal concerns in disadvantaged populations.

Aim: The goal of this research is to investigate the multifunctionality of UA as a pre-disaster risk reduction strategy in communities with food and flood vulnerabilities, and to establish a process for identifying this convergence through a decision-making framework for UA

The objectives and sub-objectives are divided into three phases, with each phase's results contributing to the next. These are, i)a conceptual understanding, ii) a case study based on the understanding and finally, iii) development of a framework from the results.

1.4.1 For Conceptual Understanding

Objective_01: To develop a comprehensive understanding of aspects of agriculture that contribute to flood regulation.

- To review the Soil – Plant – Atmosphere Continuum (SPAC) to identify key elements of hydrological process of urban areas.
- Review of Natural Flood Management/Land Management practices in agriculture.
- To develop from this a procedure for selection of relevant indicators.

1.4.2 Case Study

Objective_02: To find suitable areas of intervention

- To conduct a land suitability analysis for areas having high flood disadvantage and agricultural suitability
- To identify indicators common between worst case scenario of floods and best--case scenarios for agricultural suitability.

1.4.3 Development of a Framework

Objective_03: To develop a framework that can be used to find communities suitable for UA for addressing the two challenges

- Volumetric assessment of flood retention before and after UA interventions.

- Assessment of common anthropogenic land characteristics favourable to flood prevention and crop output.
- Examination of intervention's contribution to food insecurity.

1.5 STRUCTURE OF THE DOCUMENT

Chapter One provided a rationale for the study by scoping literature available on Urban Agriculture, principal research gaps in the existing information and the paper's overall strategy.

This is followed by **Chapter Two** with a 'Critical Literature Review' of the findings. There are **three sections** to this chapter: **Part One** highlights flood hazards and associated vulnerabilities in Scotland along with key management strategies in action; **Part Two** characterises food security in the case study area, current practices, and its potential as an urban area for implementation of UA; and **Part Three** continues the discussion around UA in further detail. **Chapter Three** provides an outline of the Methodological Framework, for the three phases of objectives, including data collection and preparation, literature review informing the process of indicator selection for the framework. The chapter is constructed in a way that findings and results of each phase informs the assessment in the next. These are:

Phase I: Opportunity Mapping

For this phase, a literature review of policies and implementation limitations are evaluated to identify developable spaces within vulnerable communities.

Phase II: Characterisation of Urban Soils, Vegetation

Characteristics common to anthropogenic soils and vegetation are evaluated in this phase to evaluate the relevance and suitability of i) Land management practices ii) agricultural suitability and iii) urban hydrological processes

This is followed by the process for selection of indicators, their relative importance towards the intent of the paper.

Phase III: Development of a Framework

Hydrological Modelling of the selected study area to test the flood retention and food production potential

Chapter Three is a brief overview of the case study area of Glasgow highlighting aspects relevant to the study.

Chapter Four is the Methodological Approach and the backbone of the report contributing to the development of the framework. This chapter aims at Data Collection, Analysis and preparation towards compilation of indicators for:

- Suitability analysis for available land in Glasgow – Opportunity Mapping
- Review of Hydrological functions in urban areas to select
    - Soil Indicators
    - Plant Morphological Traits
- Agricultural Suitability of available land in Glasgow
- Narrowing down of relevant criteria
- Hydrological Modelling for Flood retention potential
- Food production calculations

Results and analysis from this chapter is shown in **Chapter Five** followed by discussion of the findings in **Chapter Six** along with Limitations, Conclusions and Scope for further Research

Chapter 02

2 LITERATURE REVIEW

2.1 PART I: CHARACTERISING FLOOD DISASTERS IN SCOTLAND

Scotland faces risks of flooding from its coasts, rivers (Fluvial Flooding) and from enhanced surface runoff (Pluvial Flooding). Fluvial floods have impacted a substantial proportion of agricultural lands in Scotland in recent years, particularly in the floodplains of major rivers such as the Tay and Tweed (Sniffer, 2021b)**.** Flooding from surface water flooding or Pluvial Floods, results from intense rainfall and lack of a well-defined floodplain, that are made worse due to a variety of factors (city drainage capacity, construction, etc.) (Houston *et al.*, 2011). As they can occur without warning in areas that are not prone to floods, they are often considered an "unseen threat." (Houston *et al.*, 2011). Pluvial Flooding being the hardest to manage due to their inherent unpredictable in nature, these floods alone cost the UK government £270 million a year on average, despite government investments in flood defences such as the £320 million invested in 2003-04. (Flood and Coastal Defence project, 2022). In terms of potential damage, it is one of the biggest concerns in Scotland today, responsible for 23% of annual damage, as reported by SEPA, 2015 (The Scottish Government, 2018). Given that 3.2 million people are estimated to be at danger by 2050 (Houston *et al.*, 2011), several research are being conducted to better understand pluvial flood threats (Sörensen and Mobini, 2017), with Scotland integrating it in its Flood Risk Management since the 2009 Climate Act.

Climate Change in Scotland (Trends): Weather extremes are becoming more common in Scotland as a result of warming trends, changed rainfall patterns, and rising sea levels (Sniffer, 2021b), as seen by the series of flash floods and severe storm events in the summers of 2019, 2020, and 2021. The rainfall trends, which are already above average in comparison to the rest of the UK, are anticipated to increase in winters by 7% by the 2050s and by 7% to 13% by the 2080s, and to drop in summers by 12% to 16% by the 2080s, depending on worldwide efforts to reduce greenhouse gas emissions (Sniffer, 2021b).

Besides an overall shift in climate patterns, what makes Scotland susceptible to floods, is its generally low evapotranspiration levels, soils with poor infiltration rates and a moist temperate climate allowing the runoff rates to be at an average high, with flash floods in steeper areas, further exacerbating flood conditions in Scotland (Forbes, Ball and McLay, 2015).

The Third UK Climate Change Risk Assessment (CCRA3) Report lists 61 climate change-related risks and opportunities in the UK of which 32 have been categorised as needing "more action" based on their level of urgency (Sniffer, 2021a). The risks under examination for the review were chosen based on their relevance to present societal concerns in Scotland, including i) food security, ii) social deprivation, and iii) flood vulnerabilities.

Health, Communities, and the Built Environment - An area identified as "more action needed' is the 'Health, Communities, and the Built Environment' category divided into 13 risks and opportunities, with a particular focus on its sub-category H3 - Risks to people, communities, and buildings from flooding and H9 - Risks to food safety and food security (Scottish Government, 2020).

H3: Risks to people, communities, and buildings - This risk has been categorised as needing more action and is considered one of the most severe risks in Scotland (Sniffer, 2021b). In terms of potential damage to properties, pluvial flooding accounts for more damage than rivers/fluvial flooding in the UK (Sniffer, 2021b). This category's associated dangers include death or injury, as well as long-term and severe mental health consequences. Development in floodplains, management of SWF (Surface Water Flooding) via Suds, and a lack of UK-wide norms are all difficulties for Scotland to address in order to mitigate this risk.

H9: Risks to food safety and food security - Further investigation [medium confidence]

While weather-related pollutants threaten Food Safety in Scotland, Food Security sees access to healthy and cheap food as a problem due to stock shortages and higher pricing. Risks associated with food security will be partially managed in the future for Scotland (Kovats and Brisley, 2021) but floods impeding rural production and food imports, can negatively impact health, as extreme weather patterns raise the likelihood of crop yield reductions.

The greater the vulnerability, the more severe the impact of flooding (SEPA, 2015). The ability of individuals to work together as a community is critical to adapting to and recovering from natural disasters (Bixler *et al.*, 2021). While community vulnerability is impacted by changing local conditions, it is also important to recognise the simultaneous national and global socio-economic developments that contribute to local development opportunities.

Vulnerability to Floods can be defined as communities experiencing a loss of wellbeing during a flood event due to a limitation of societal resistance or resilience to hazards (Cutter, Boruff and Shirley, 2003)**.** Since 'socially disadvantaged' groups recover more slowly (Houston *et al.*, 2021), assessing social vulnerability at the grassroot level can lead to more socially equitable risk reduction initiatives.

Lower-income families are less resilient to flooding's long-term effects (Houston *et al.*, 2021), as they are less likely to be insured (Sayers *et al.*, 2020; Werritty and Chatterton, 2022).

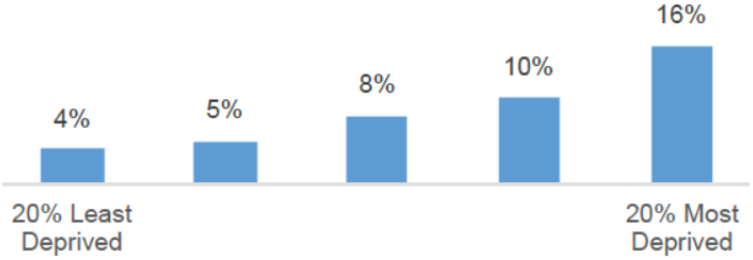
Social Vulnerability from Climate Change is defined by

> “the inability of a community to predict danger, react with an emergency, modify its behaviour during a crisis, and rebuild itself” (Da *et al.*, 2022). When faced with floods, the degree to which an individual's health and well-being are jeopardised is determined by a combination of I sensitivity, ii) adaptive capacity, and iii) enhanced exposure (SEPA, 2015).

2.2 PART II: WHICH SOCIETAL VULNERABILITIES ARE INCREASING THE RISK OF FLOODING?

Vulnerabilities in Glasgow/Scotland: Glasgow and the greater City Region are densely populated areas, making it one of the ten UK local authorities that account for half of the socially vulnerable people living in flood-prone areas (Sniffer, 2021b). The Scottish Environment Protection Agency (SEPA, 2015) through a National Flood Risk Assessment, identifies areas of flood disadvantage based on The Scottish Index of Multiple Deprivation (SIMD) that takes into account a relative measure of deprivation in Scotland to identify Potentially Vulnerable Areas (PVAs)

Figure 1: Proportion of adults with food insecurity based on the SIMD quintile

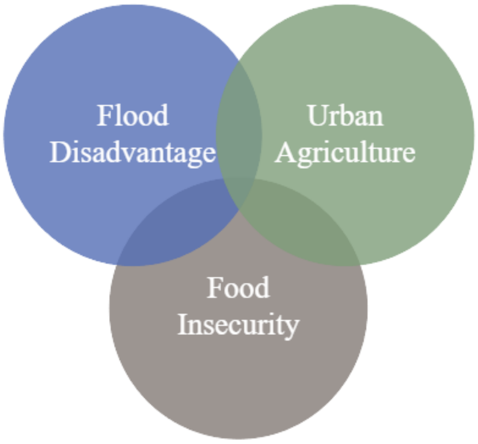


Source 1: Scottish Health Survey

2.3 PART III: URBAN AGRICULTURE

Effects of Climate change on food security and health and well-being Food security is dependent on four dimensions – i) availability, ii) accessibility, iii) utilisation and the iv) stability of these components (FAO, 2015) (See) which are dependent on the sustainability of the different levels of the food system – i) production, ii) processing iii) distribution and iv) preparation and consumption. The research around UA and its contribution to a resilient food system is at its infancy with most studies focusing on the 'availability' aspect (Capone *et al.*, 2014). The transparency of UA regarding the origin of food and production procedures makes its contribution to food production valuable. UA has also shown benefits in the processing and distribution aspects of a food system, with reduced food loss and waste as produce from UA is directly consumed or marketed (Capone *et al.*, 2014; Opitz *et al.*, 2016). While food availability is important, nutritional security, being one of the major concerns in the global north, also happens to be an integral part of food sustainability process (Capone *et al.*, 2014).

Social Factors: Low-income households are not only more vulnerable to the consequences of flooding (SEPA, 2015), but their food consumption and dietary patterns are also influenced by food availability, accessibility and choice, indirectly influenced by the absence of a disposable income (Capone *et al.*, 2014). This directly affects overall 'health and well-being' making the reduction of this health inequality, a priority. Although, the motivation behind UA in the global north is seen as a source of supplemental income or community development (Opitz *et al.*, 2016), it is the primary motivation regardless and offers the opportunity to reduce the income divide in vulnerable communities. Furthermore, the ability to respond to a flood event, is also dependent on 'mobility'(SEPA, 2015), a factor applicable to low-income neighbourhoods, where number of grocery stores are far fewer than fast food restaurants, making the overall 'access' to food a limitation (Opitz *et al.*, 2016).



UA can reduce vulnerability by i) encouraging adaptive management within a community, ii) diversification of food sources, with reduced food dependency during a disaster and iii) income opportunities and skill development and providing, amongst other ways (De Zeeuw *et al.*, 2011)

While incorporating agricultural ecosystems into current and proposed urban areas has potential benefits it comes with its own set of constraints such as increased rates of soil erosion or chemical pollution (Mawoneke and King, 2000). Increased rainfall, floods, and temperature will have an impact on urban and peri urban agriculture (for example, disease outbreaks, yields, crop failures, and livestock mortality) (Dubbeling and Halliday, 2019). Furthermore, a study evaluating ES pointed out that vegetation necessary for climate regulation may not be favored for food production (Artmann and Sartison, 2018). The evaluation of these ecosystem services has not extensively been studied for urban farms but for community gardens or similar UAs. Areas and scales of interventions assessed further, showed a 'favouritism for communal gardens in developed nations' (Wadumestrige Dona, Mohan and Fukushi, 2021), while scales of agricultural intervention have been at the neighbourhood community level, with larger scales of intervention, such as Urban Farms (Artmann and Sartison, 2018), never researched. There is also a scarcity of research for the Global North.

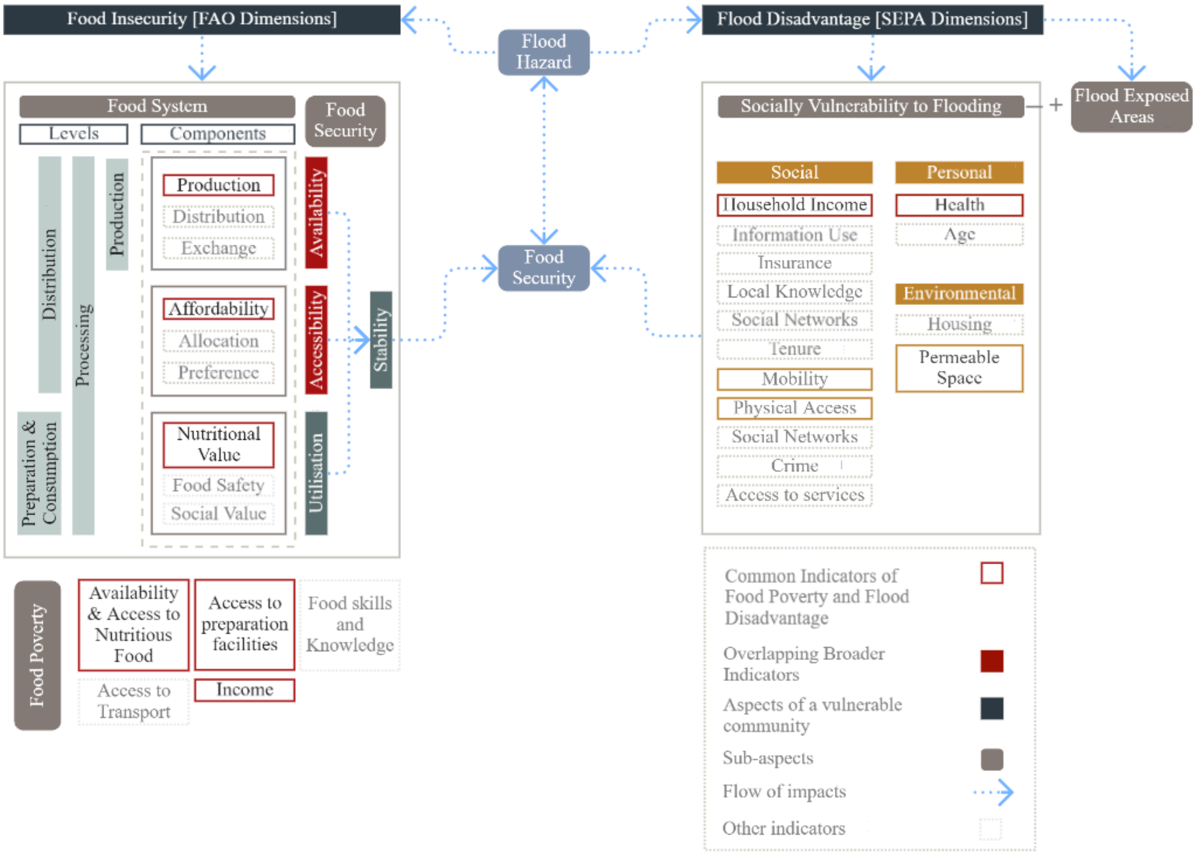
Its potential to retain surface water flow and increasing infiltration into the soil, makes it strong contender for mitigating and adapting (Aciksoz, Özbek and Dal, 2021) to combat climate change extremes while also bringing numerous benefits such as improved wellness, people-nature linkages, and food security (Artmann and Sartison, 2018). Urban agricultural areas aid in disaster risk reduction (Aciksoz, Özbek and Dal, 2021) and can be more cost effective as an

NbS when compared to conventional methods of flood risk management (Ebissa and Desta, 2022).

Regulatory ES of NbS or GI in flood mitigation services is plenty (Dubbeling and Halliday, 2019), but it is in the ability of UA to address food security (Opitz *et al.*, 2016) essential services tackling multiple urban challenges of social vulnerability originating

Within the limited amount of literature available on UA in the global north, a few attributes are discussed towards its success. These are i) the scale of intervention ii) Efficiency of production (Gulyas and Edmondson, 2021). The framework Figure 2 developed from food security frameworks of FAO and SEPA's Flood Disadvantage mapping, looks at vulnerability indicators common to food security and flood disadvantage which the report targets.

Figure 2: Framework of Food Security and Flood Disadvantage



Source 2: FAO, SEPA

Glasgow: Under the Healthier City Theme, the government seeks to assist the development of Glasgow as a Sustainable Food City, with a focus on child hunger, period poverty, and mental health. (Glasgow City Council, 2017). Existing Strategies and Plans and Actions for Local Food include 'The Climate Emergency Working Group' that recommends a **Sustainable Food**

Strategy for Glasgow where food is encouraged to grow locally in new housing developments (Glasgow city council, 2020). The Open Space Strategy (OSS) responsible for identifying existing and proposed areas suitable for growing food.

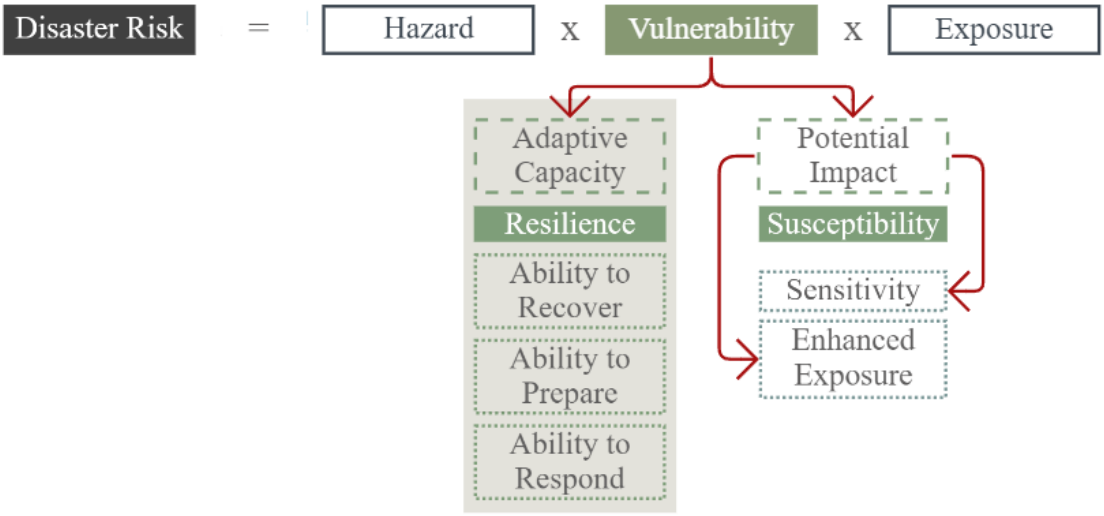
2.4 PART V: HOW CAN COMMUNITIES REDUCE VULNERABILITIES TO FLOOD DISASTERS?

Water is both a resource and a menace if mishandled (UNISDR, 2017). So, it all comes down to effective flood management and building resilience as is reflected in the Scottish government's action plans. Flood risks have reduced since the CCRA2 but the CCRA3 report expresses concerns over keeping the risks 'at a constant' given future climate change scenarios.

The strategies looked at consider the i) relevance to urban areas ii) offering interconnectedness of social vulnerabilities and flood risk reduction iii) the use of Nature-based solutions/ blue-green infrastructure.

SEPA defines Flood Disadvantage as "a situation when vulnerable neighbourhoods are exposed to flooding. In other words, disadvantage occurs where high social vulnerability to flooding spatially coincides with flood hazard-exposure represented by flood extents.". For the purpose of assessing the Social Vulnerability to Flooding, the framework based on the methodology created by (Lindley, Sarah Lawson, Nigel O'Neil, Martin Uddin, Md Kamal O'Neil, Jhon Kandeh, 2013) using the risk triangle (See Figure 3) was employed.

Figure 3:Disaster Risk Framework



Source 3: (SEPA, 2015; United Nations Environment Programme, 2015)

2.5 PART VI: INTEGRATION INTO CURRENT DECISION-MAKING PROCESSES

Green Space management (For NbS Implementation): The CCRA3 recognises the importance of 'conventional flood defences' in the face of the climate emergency but encourages investment in Natural Flood Management (NFM) infrastructural measures to address risks associated with 'Health, Communities, and the Built Environment' (Kovats and Brisley, 2021; Sniffer, 2021b). The Scottish Government's adaptation methods for mitigating surface water floods are in line with international blue-green city trends (Scottish Government, 2019) and can be identified in many of its strategies such as strategic tree planting, peatland restoration and green infrastructure under the Open Space Strategy and Local Action Biodiversity Plan (Glasgow city council, 2020).

For Pluvial Flooding: PFs were given more importance post the Flood Risk Management (Scotland) Act 2009 in local FRM plans. While grey infrastructure interventions continue to accommodate higher capacities of floods (Glasgow City Council, 2017), the presence of nature-based solutions offering multiple benefits is not enthusiastic. The overarching strategy for management of surface water flooding to drain Glasgow is i) slowing the run-off rates and ii) create capacities in existing sewer infrastructure (Glasgow city council, 2020) to support city resilience. Improvement of **drainage infrastructure** under the River Clyde Infrastructure Strategy under the priority theme of A Sustainable and Low Carbon City set by the Glasgow City Council's Strategic Plan for the period of 2017 – 2022 (Glasgow City Council, 2017).

CCRA3 recognises the implementation of SuDS for surface water flooding as a challenge (Sniffer, 2021b). Sustainable Urban Drainage Systems are utilised to improve water infiltration into the soil by retaining green spaces, increasing permeability, slowing overland flow, and improving water quality (Sniffer, 2021b).

In terms of dangers to health, communities, and the built environment, the government is considering limiting growth in flood-prone locations (Sniffer, 2021b) where Urban Agriculture might be utilised to manage urban floods through production and other uses. (Ebissa and Desta, 2022).

Interventions that are not incentive intensive: There is continued promotion for the use of Sustainable Urban Drainage Systems within Glasgow but often not the first choice as retrofitting into existing neighbourhoods is not cost effective (Sayers *et al.*, 2020) or the notion that lack of incentives by companies from investing in interventions offering multiple benefits (Sayers *et al.*, 2020). SWF risk will increase under all scenarios, convincing argument for greater enforcement (Sniffer, 2021b). Even though documented information on implementation monitoring is scarce, the use of SUDS (Sustainable Urban Drainage Systems) in new developments is high in Wales and Scotland (70 percent)(Sayers *et al.*, 2020; Sniffer, 2021b).

The strategies for newer development in at-risk areas are to be made safe and resilient (Sniffer, 2021b) but current properties/development, as well as their existing drainage systems (foul/stormwater), are likely to be a part of the urban fabric for many decades (Houston *et al.*, 2011). Where not feasible in older developments, (Scottish Government, 2021) proposes disconnect, diversion and retrofitting from sewer networks to blue-green infrastructure

Social Vulnerability: Overarching aim of reduction of inequalities and promotion of human rights (Glasgow City Council, 2017). While socially impoverished communities in Scotland are already selected for financial assistance, greater emphasis is being placed on decreasing overall socioeconomic vulnerabilities in these areas as a means of lowering the social costs of floods (Sniffer, 2021b).

Chapter 03

3 STUDY AREA: GLASGOW

3.1 THE CITY

Population: Glasgow City, with an area of 175 km2 and a population of 635,640 in 2020 (National Records of Scotland, 2021), is the most populous of Scotland's 32 council areas.

Demographics: Primarily a lowland area surrounded by hill ranges, it is located along the banks of the River Clyde in West Central Scotland (National Records of Scotland, 2021). Glasgow has an overall cool and wet climate with daily variations in the weather. Glasgow’s post-industrial landscape comprises lands not suitable for agriculture with soils having poor drainage or contamination from prior use. Atmospheric deposition, construction debris, industrial wastes from the industrial wake has left Glasgow with the largest percentage of derelict lands, in relation to the size of its administrative area in all of Scotland.

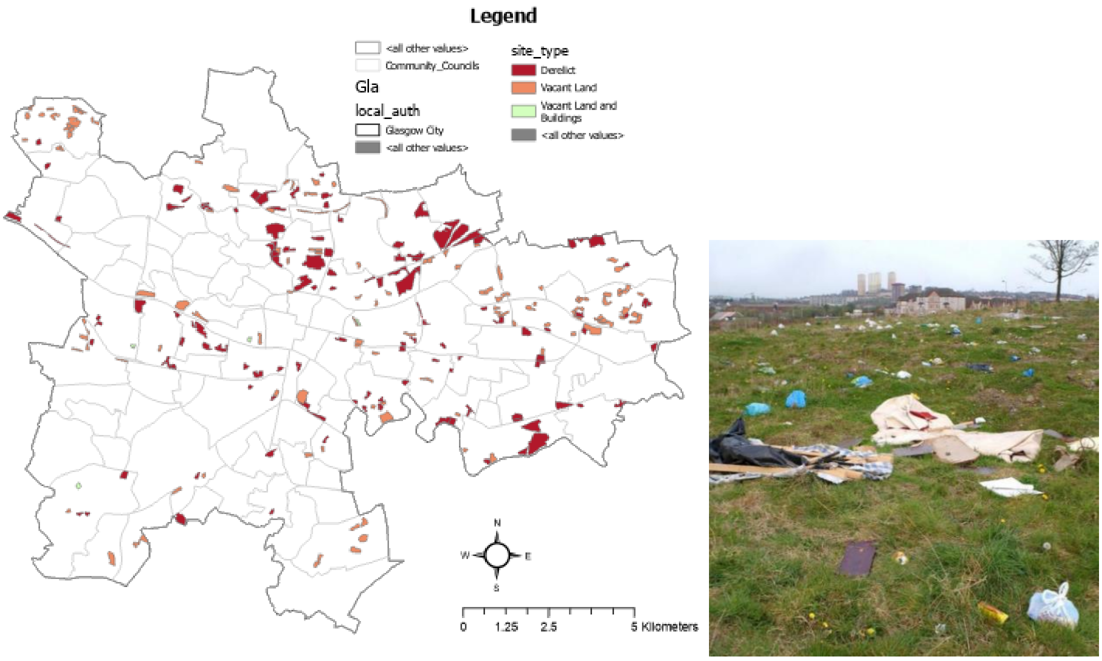
Figure 4: A satellite view of Glasgow, Scotland

Source 4: Google Earth

3.2 FLOOD DISADVANTAGE

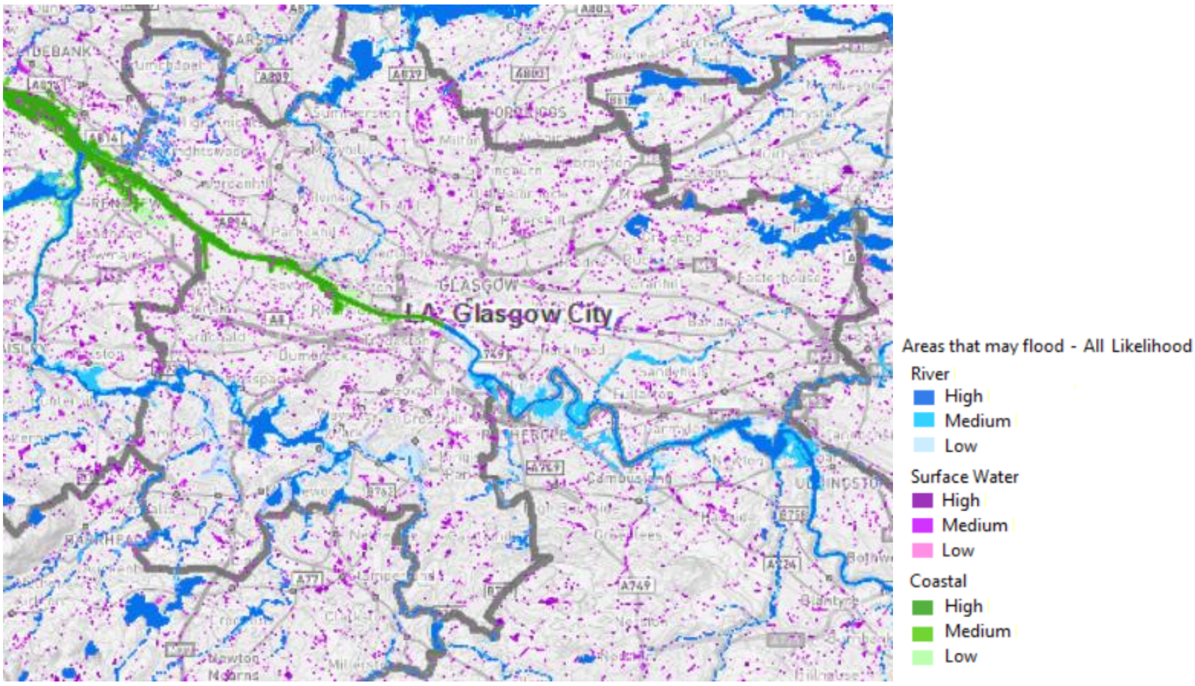
Dereliction and Deprivation: 92% of people living in Glasgow live within 1000 meters of a derelict site, commonly characteristic of poor drainage and surface water vulnerabilities. Most of these lands (66.4%) have been originally residential areas, with transport, recreation and leisure making up the remainder. According to the (Glasgow City Council, 2022), there are 954 hectares of Vacant and Derelict Lands as of 2019 and a percentage of which have been identified suitable for flood risk mitigation by the Open Space Strategy.

Figure 5: Vacant and Derelict Lands, Glasgow



Source 5: (Glasgow City Council, 2022)

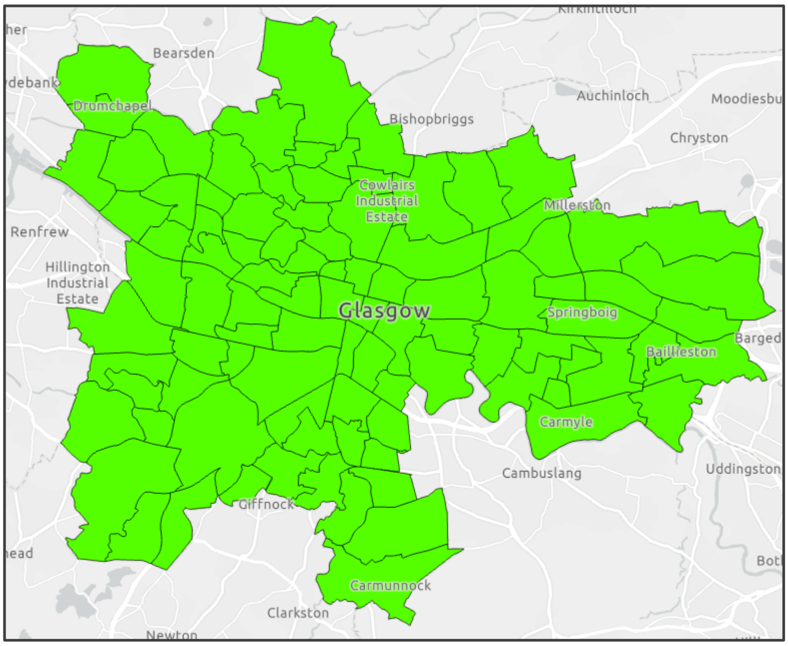
Figure 6: Flood Likelihood Map for Glasgow



Source 6: SEPA

The goal of Glasgow's present flood mitigation efforts is to drain the city sustainably by slowing down stormwater runoff before it enters the sewage system and expanding the drainage system's total capacity.

Figure 7: Glasgow City Area, council areas



Source 7: Digimap

Chapter 04

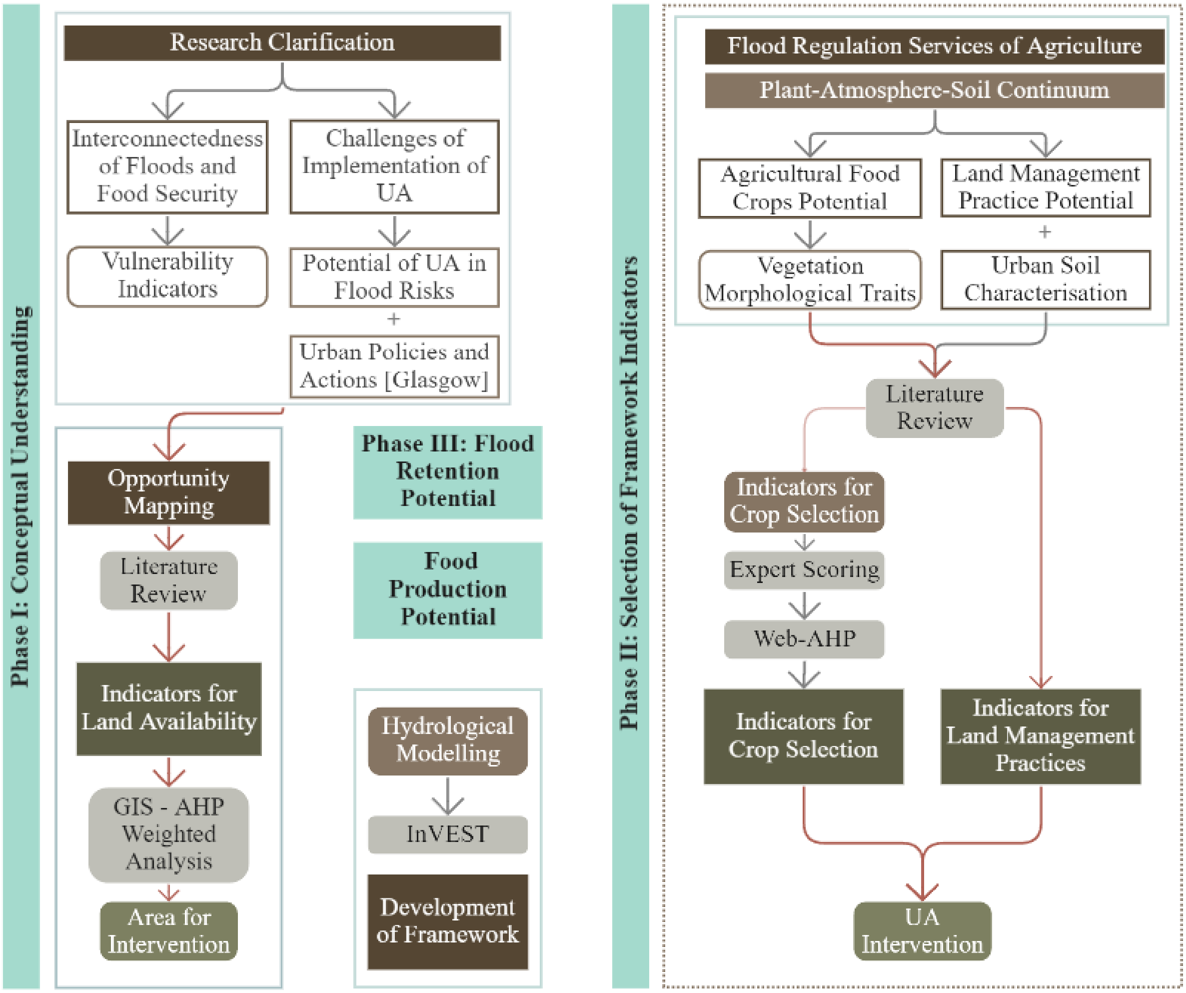
4 METHODOLOGICAL APPROACH

This chapter includes the basis for the development of the framework and the valuation method employed in the study through a series of research phases. Each phase is described briefly with details on the data used including its collection, preparation, and presentation. The intent of the grouping of methods, phase wise is to address the aforementioned research gaps, objectives and questions.

Overview: The general methodological approach used for the research includes a scoping examination of literature, largely from 2012 to 2022, expert engagement, and spatial analysis of open data from the Scottish Government. Two societal challenges from the (IUCN, 2020) framework were examined to assess the capability of urban agriculture. - i) Climate mitigation and ii) Food Resilience. This study primarily focuses on the micro (neighbourhood) level because many flood management initiatives already exist at the watershed level or the meso (national) level. Ward level intervention can further, support local action planning and enable a bottom-up community-based strategy that considers the "underlying development context" of flood vulnerabilities, making intervention more sustainable (Thapa, Borne and Murayama, 2011; DST and SDC, 2014) (Thapa, Borne, and Murayama, 2011).

4.1 OVERALL FRAMEWORK

Figure 8: Methodological Approach



4.2 DATA COLLECTION

The table below provides a summary of the data used in this research.

Table 1: Data and data sources

S.No.	**Information**	**Data**	**Source**	**Coverage**
1	Flood Disadvantage	Flood Disadvantage Index (FDI)	SEPA	2015
2	Space to Grow based on ownership of land (public and private)	Vacant and Derelict Lands (VDLs) Vector Data	EDINA Digimap Ordnance Survey Service [Improvement Service Scottish Local Government Data]	National (Scotland) 1:10000, 2021
3	Native Species List of suitable food crops.	Agricultural Census 2019	Digimap	City Level (Glasgow)
4	Water Sources		EDINA Digimap Ordnance Survey Service	City Level (Glasgow)
5	Permeability Indices	Qualitative Classification	British Geological Survey	City Level (Glasgow)
6	Green Spaces	High resolution maps from city data	Open Space Strategy	City Level (Glasgow)
7	Topographical Attributes	digital elevation model (DEM) dataset	Scottish Remote Sensing Portal	| a density of 4ppm (points per square metre) | LiDAR for Scotland Phase 5 - LAS
8	Land Use – Land Cover	Digimap | UKCEH Land Cover Maps	Digimap | UKCEH Land Cover Maps	National (UK) 2020 | 1:250000 (25m pixel dataset)
9	Local Topography			City Level (Glasgow)
10	Soil Properties	Texture	British Geological Survey	City Level (Glasgow)

Criteria	**Data**	**Data Source**	**Description/ Tools**	**Coverage**
Urban Flood Risk Mitigation model	Map of soil hydrologic groups.	part of the USDA curve number (CN) approach for calculating rainfall runoff	ORNL DAAC, NASA – EARTH DATA	250-m (GeoTIFF)
	Map of Land Use/Land Cover	UKCEH Land Cover Maps +		City Level
	Rainfall Depth (number, units: mm,)	Met Office (Station:	Depth of rainfall for the design storm of interest	Glasgow
	Biophysical Table	USDA Engineering Handbook	Table of curve number data for each LULC class.	Global

Chapter 05

5 FINDING A PLACE TO GROW - OPPORTUNITY MAPPING

Finding available space for UA is one of its major challenges (Cookson and Stirk, 2019) and therefore, the UA suitability assessment phase for Glasgow begins with this challenge (See Appendix). Literature findings suggests The indicators covered in this section were influenced by the limitations for UA found in the literature review (See Appendix).

UA's evidence of success has been on fertile soils (Opitz *et al.*, 2016), a limiting factor in the urban context, and therefore, the assessment begins with finding just available land regardless of its agricultural suitability. This also provides the opportunity to explore land management practices. Areas of interventions discovered from this chapter is further assessed for agricultural suitability in the next chapter.

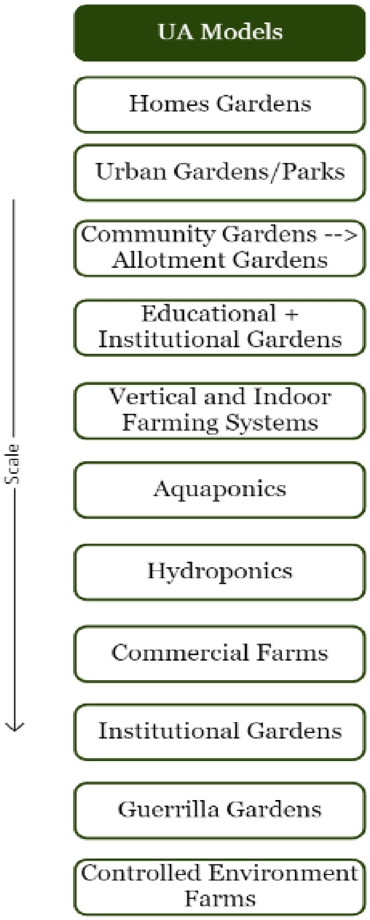
5.1 OVERVIEW OF SITE CONDITIONS

Vacant Lands are lands not in need for rehabilitation and are a much-preferred choice based on its previous use. "which is unused for the purposes for which it is held and is viewed as an appropriate site for development. The land must either have had prior development on it or had preparatory work taken place in anticipation of future development." (National Statistics for Scotland, 2019).

Available Vacant and Derelict Lands (VDLs) were narrowed down based on i) current land ownership, with preference given to public-owned sites since they may be easily exploited for city-level flood interventions , are more exposed to sunlight and have smoother slopes when compared to private owned sites (Feola and Sahakian, 2020) and ii) Areas.

5.2 SCALE OF INTERVENTION

Figure 9: Scale of various Urban Agriculture Models



This component of appropriateness considers the VDL's soil reconditioning and food production aspects, as no clear data on the relationship of UA sizes (See Figure 9)and impact was found. These are discussed below:

Soil Reconditioning: While inspection of small lot sizes are easier to undertake, larger open spaces (above 1 Ha) provide more undisturbed soils and in case of human-altered and human-transported (HAHT) material, the entire area would still have uniform soil distribution (Cookson and Stirk, 2019).

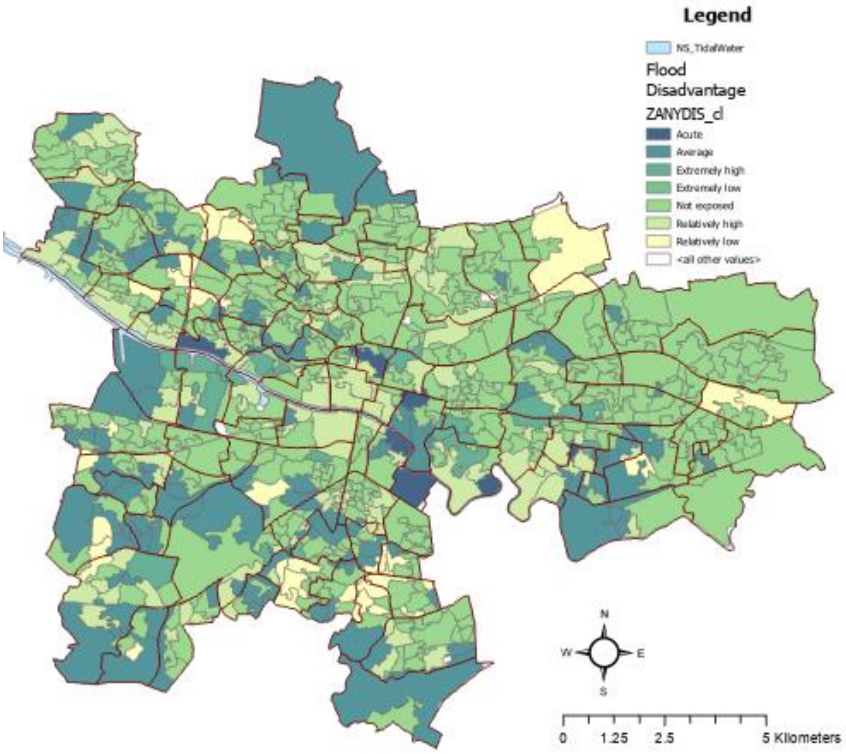
Food Production: Furthermore, in terms of meeting food requirements of a vulnerable community, a study conducted in the 1970s by Jhon Jeavons, suggests, that only 0.0743 Ha (including growing area and access) of land is required to maintain a person on a vegetarian diet for a year. While the ‘total yield per acre’ is dependent on various local meteorological and topographical considerations besides area available, an acre of land is considered for the assessment using the select by attribute from the site tool in GIS at this stage to remove any VDLs smaller than 1 Ha.

Using these criteria, a new VDL raster map is prepared with the conditions i) land not privately owned and ii) areas > 1Ha.

5.3 FLOOD DISADVANTAGED

For testing the multifunctionality of Urban Agriculture, zonal areas having high flood disadvantages towards any type of flooding (Fluvial, Pluvial and Coastal) for a 1 in 200 period year return period (low probability-high damage flood scenario have been considered (See Figure 10)

Figure 10: Map of Flood Disadvantage Index from all kinds of flooding



Source 8: (SEPA, 2015)

5.4 OPPORTUNITY MAPPING

The Flood Disadvantage map for vulnerabilities from all types of flooding, as well as the newly produced VDL raster maps, are appraised in GIS utilizing Weighted Overlay tools based on a suitability scale (See Table 2) to determine the most ideal site for suitable areas of intervention (See Figure 11). Both indicators have been ranked equally important as availability of land in a flood disadvantaged are the premise of the study. Councils or wards with a high appropriateness analysis of 4 or 5 were selected to finalise intervention zones.

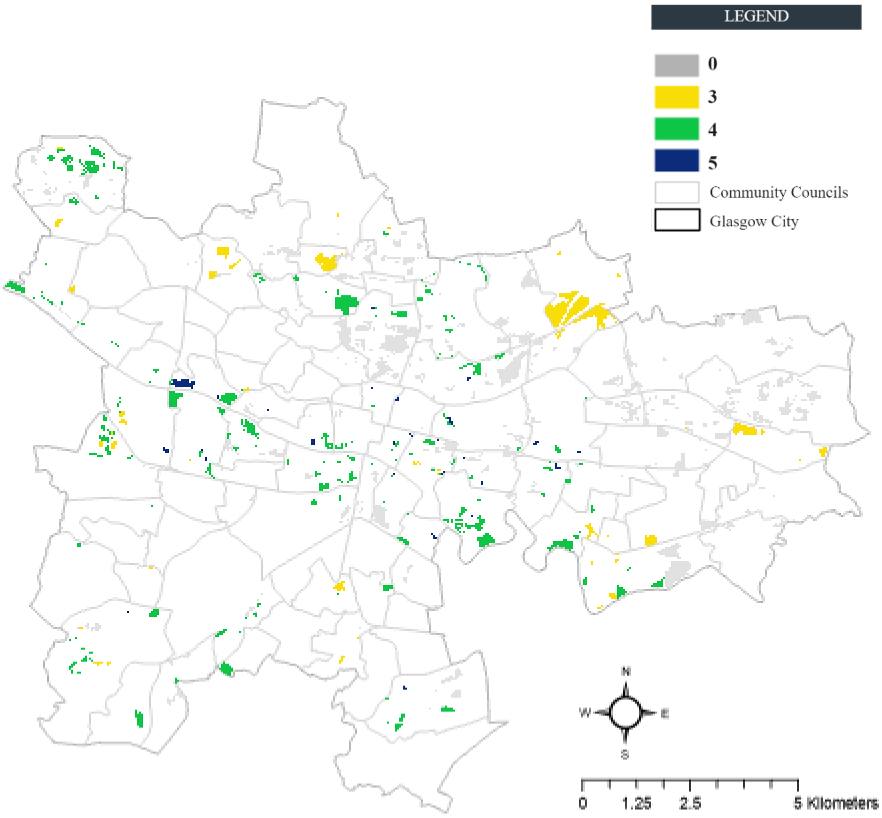
Table 2: Suitability Scale for Opportunity Mapping

Description	Suitability	
Extremely suitable	5	Areas of intervention meet both criteria, will most likely be a Vacant Land with High flood disadvantage
Highly Suitable	4	Areas maybe have above average flood disadvantage, may or may not have vacant land availability
Moderately suitable	3	Exposure to floods aren't acute and some lands are available, that may be derelict
Extremely unsuitable	2	Below average flood vulnerability with no available lands.
Unsuitable	1	No lands are available and no flood disadvantage

Table 3: Weighted Analysis for Opportunity Mapping

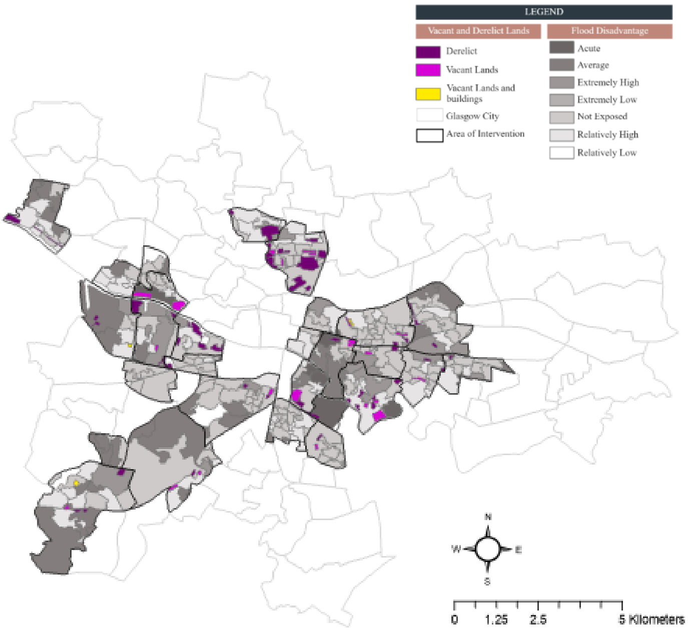
Indicator	Sub-indicator	Rank	Weight influence (%)
VDLs with areas > 1 Ha	Vacant Lands	5	50
	Derelict Lands	3	
	Vacant Lands and Buildings	4	
Flood Disadvantage	Acute	5	50
	Extremely High	5	
	Relatively High	4	
	Average	3	
	Relatively Low	2	
	Extremely Low	1	
	Not exposed	Restricted	

Figure 11: Opportunity map for Glasgow



The results show relatively higher flood disadvantages may exist in areas with suitability of score 4, clustered around the river in the middle, made clearer in Figure 12.

Figure 12: Areas of Flood Disadvantage and Location of Suitable VDLs



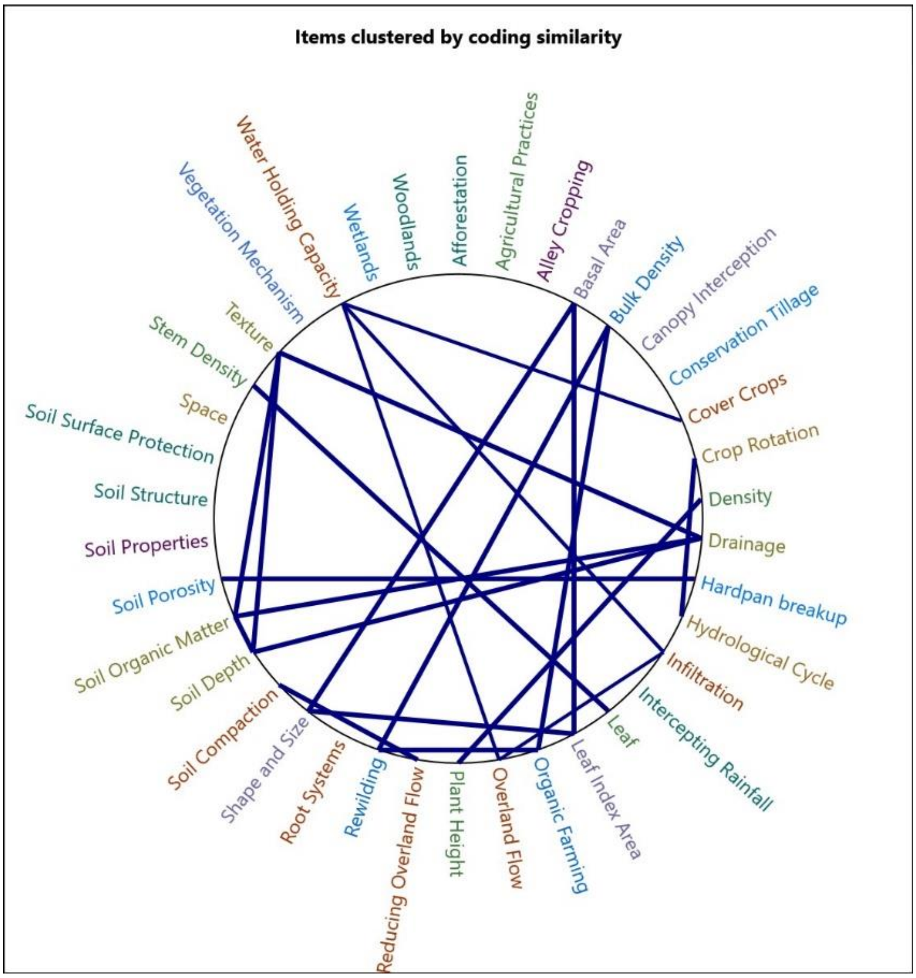
5.5 EXPLORING THEMES

Utilizing a "Word frequency query" feature of the qualitative data analysis program NVivo 12, literature acquired as part of a preliminary assessment was examined based on recurrent ideas, concepts and terminology in agriculture and flood control (Bazeley and Jackson, 2015).

Through the software's "coding" capability, the topics were then grouped/"coded" to larger themes of hydrological processes, agricultural techniques, and vegetation features enabling a depiction of patterns sharing similar terminology or attribute. In order to determine the most pertinent themes, a cluster analysis of the codes (See **Error! Reference source not found.**) w as developed using the Pearson's correlation coefficient technique.

An initial analytical framework was developed using this (See Figure 14).

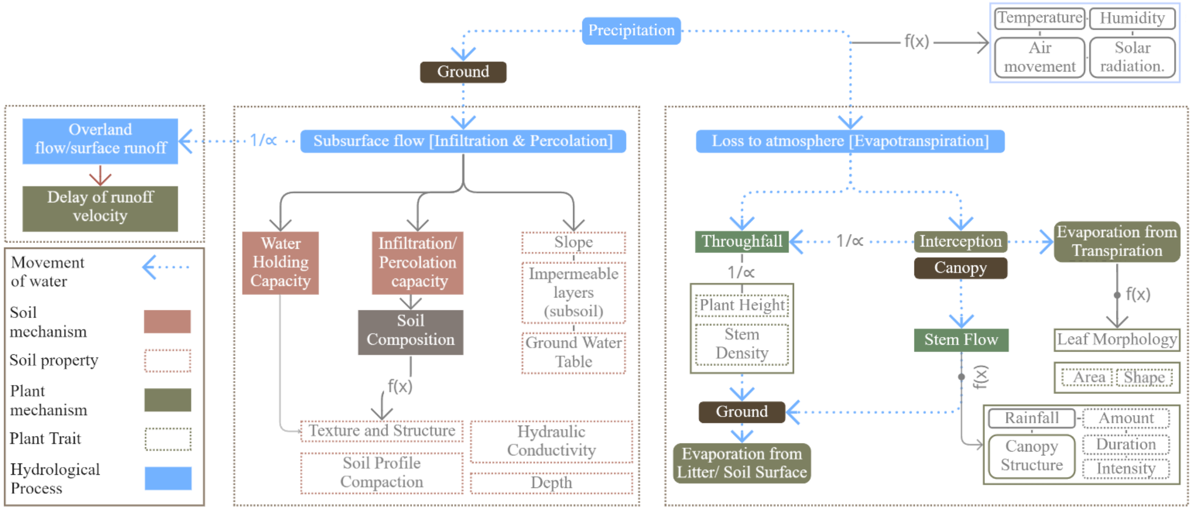
Figure 13: Term co-occurrence map



6 SPATIAL DISTRIBUTION AND STORM INTENSITY CONTROL

While hydrological functions within a system are strongly influenced by meteorological conditions (storm intensity, duration or total number of sun hours), vegetation and soil characteristics play a significant role in directing the path of rain impacting the water balance (Liu and Zhao, 2020). To understand the potential agriculture can have in flood regulation in cities, it is worth looking at the hydrological processes in an urban context. Precipitation has a general pathway where, water either i) runs over the surface to a water course as Overland Flow/Surface Runoff ii) infiltrates into the soil and move through it or iii)returns back to the atmosphere through Evapotranspiration (Weil and Brady, 2015) (See Figure 14)

Figure 14: Hydrological Processes in Urban Areas



6.1 CHARACTERISATION OF URBAN SOILS

Local climatic variables acting on soil parent material over time develop unique soil properties that are significantly altered in cities as a result of various construction and demolition processes, with local soils constantly moved and shifted, resulting in the introduction of non-native soils (EPA, 2011), compaction, low organic matter, and contamination, causing restricted water movement across land (Mouazen, no date; EPA, 2011; Weil and Brady, 2015)

6.2 THE INFILTRATION ROUTE AND OVERLAND FLOW

Both soil surface and profile, and vegetation traits influence how much water runs off versus how much is absorbed (Illgen, 2011; Weil and Brady, 2015). Specific vegetation morphological characteristics governs a plant canopies' ability to intercept rainfall, modify the spatial distribution of rain, promote penetration, and so on whereas hydraulic properties of soils dictate its hydraulic conductivity and water retention characteristics. Some soils do not infiltrate water fast enough or readily enough, so to buy it time, overland flow can be delayed by vegetation by providing surface roughness/hydraulic roughness

In the absence of vegetation, rain reaching the ground takes either the direct path of infiltration into the soil to become soil water or in cases where precipitation exceeds soil infiltration capacities, in the form of runoff where rain water tends to go towards depressions (Weil and Brady, 2015). Furthermore, compacted soils in cities, have degraded soil structure having higher bulk densities, surface crust formation and/or low porosity (Smith, 2017; Cookson and Stirk, 2019) which not only reduces soil infiltration but restrict root growth making it unsuitable for agriculture as well (Weil and Brady, 2015).

6.3 THE EVAPOTRANSPIRATION ROUTE

Precipitation that does fall on vegetation, may be returned to the atmosphere through two routes, either be intercepted by the canopy and evaporated back to the atmosphere or water that doesn’t touch the canopy, or exceeds the canopy storage may fall to the ground as throughfall or crown drip or by way of stem flow (Bruijnzeel, 2004; Illgen, 2011; Ufoegbune, Eruola and Awomeso, 2012).

Due to an unequal distribution of pervious and impervious surfaces, the evapotranspiration process, accounting for a sizeable portion of precipitation in a water cycle, is also the most vulnerable feature of cities (Illgen, 2011). The ‘Interception Capacity’ of a plant is the amount of water a plant can hold by way of surface tension before falling off as throughfall. This is an important indicator as it prevents a major percentage of precipitation in the hydrological cycle from reaching the soil (Weil and Brady, 2015).

7 AGRICULTURAL SUITABILITY ANALYSIS

In the section 5, suitable areas of intervention were identified, but not every available piece of land can be used for food production (Cookson and Stirk, 2019; Gulyas and Edmondson, 2021) and therefore, a land suitability analysis for UA in these land parcels is conducted in this phase using a suitability framework by (FAO, 1981). The study methodology includes a sequence of different steps and procedures of data collection and analysis (See Section 5.5) which are weighed on a suitability scale defined in Table 4

Table 4: Framework for suitability classification

Suitability Class	**Suitability Score**	**Code**	**Description**
Highly Suitable	5	S1	Land having no significant or only minor limitations.
Moderately Suitable	4	S2	the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to S1
Marginally Suitable	3	S3	Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.
Currently Not Suitable	2	S4	Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.
Permanently Not Suitable	1	S5	Land having limitations which appear so severe as to preclude any possibilities Of successful sustained use of the land in the given manner.

Source 9: (FAO, 1981)

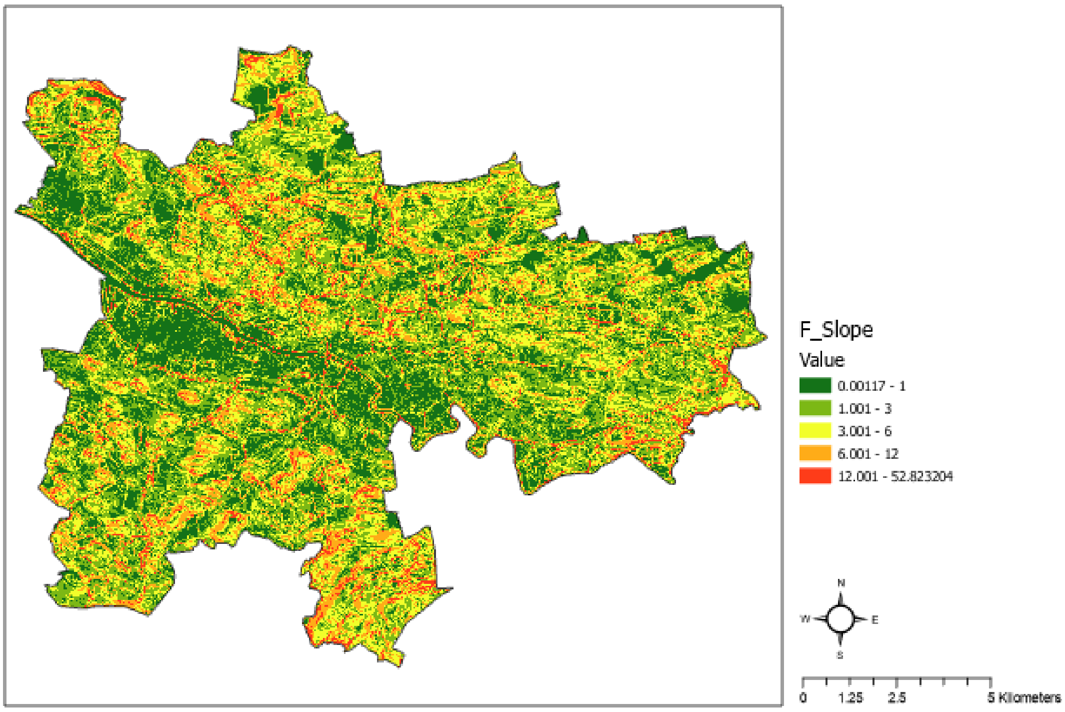
7.1 TOPOGRAPHIC INDICATORS - SLOPE GRADIENT

The slope of the land generates an imbalance between water infiltration and runoff where steeper the slope, more the probability of overland flow (Weil and Brady, 2015). Its impact over soil parameters such as depth, texture, and so on adds greatly to hydrological processes of an area.

Table 5: Classification of Slopes

Slope Gradient (% rise)	**Impacts on Flooding/Agriculture**	**Weighting**	**References**
Gentle (0 – 1)	Water tends to collect on surface causing more runoff, Deeper Soils but Poor Drainage. There is increased lag time as water is allowed to infiltrate into the [Suitable for Agriculture]	5	(Weil and Brady, 2015)
Moderate (1-3)	Effective rainfall received is greater, here the soils are deeper having better potential to infiltrate rainwater [Suitable for Agriculture]	4	
Stiff (3-6)	Soils on steeper slopes have shallow, poorly developed profiles, and thinner soils, making them vulnerable to rapid soil loss and erosion, as well as lower infiltration, as water rapidly flows downwards, causing an overall rise in sediments and rising river levels. [Not ideal for agriculture]	3	
Steep (6 – 12)		2	
More (> 12)		1	

Figure 15: Map of Slopes



Source 10: GIS, LIDAR

7.2 SOIL FACTORS

Permeability describes whether or not water can flow through a rock. To assess the drainage potential of urban soils for both Flood Risk Management and Agricultural Productivity, two kinds of geological layers have been considered – i) Artificial Permeability (See Figure 16) and ii) Superficial Permeability (See Figure 17)

Figure 16: Map of Artificial Permeability, Minimum

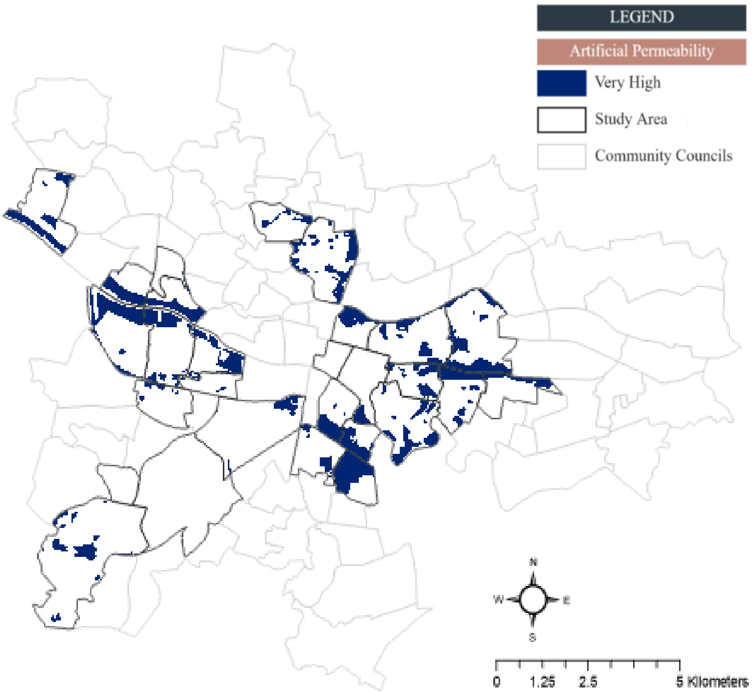


Figure 17: Map of Superficial Permeability - Minimum

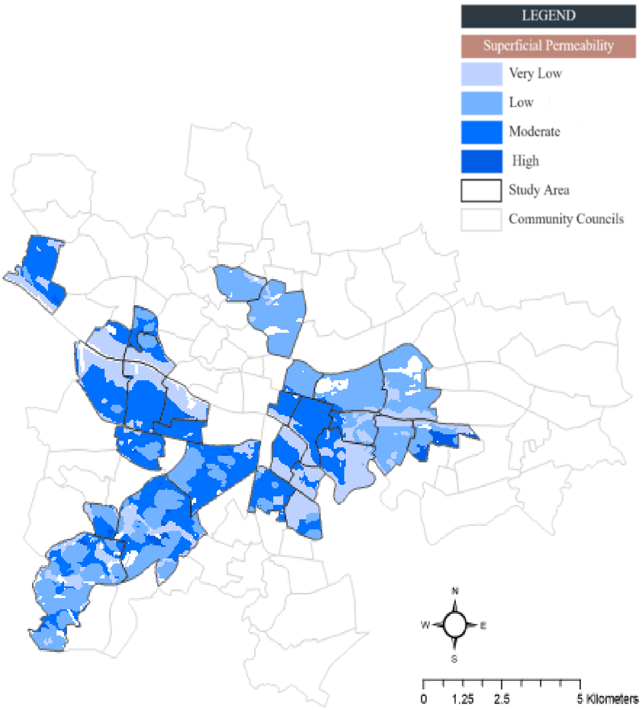


Table 6: Ranking Indicators - Permeability Indicators

Permeability	Impacts on Flooding/Agriculture	Rank
Artificial Permeability		
High	Only high permeability values for artificial ground were available for Glasgow and therefore, these are given the highest weightage	5
Superficial Permeability		
Very Low	Higher the permeability of a soil layer, the faster water can infiltrate through and avoid flooding (Weil and Brady, 2015)	2
Low		3
Moderate		4
High		5

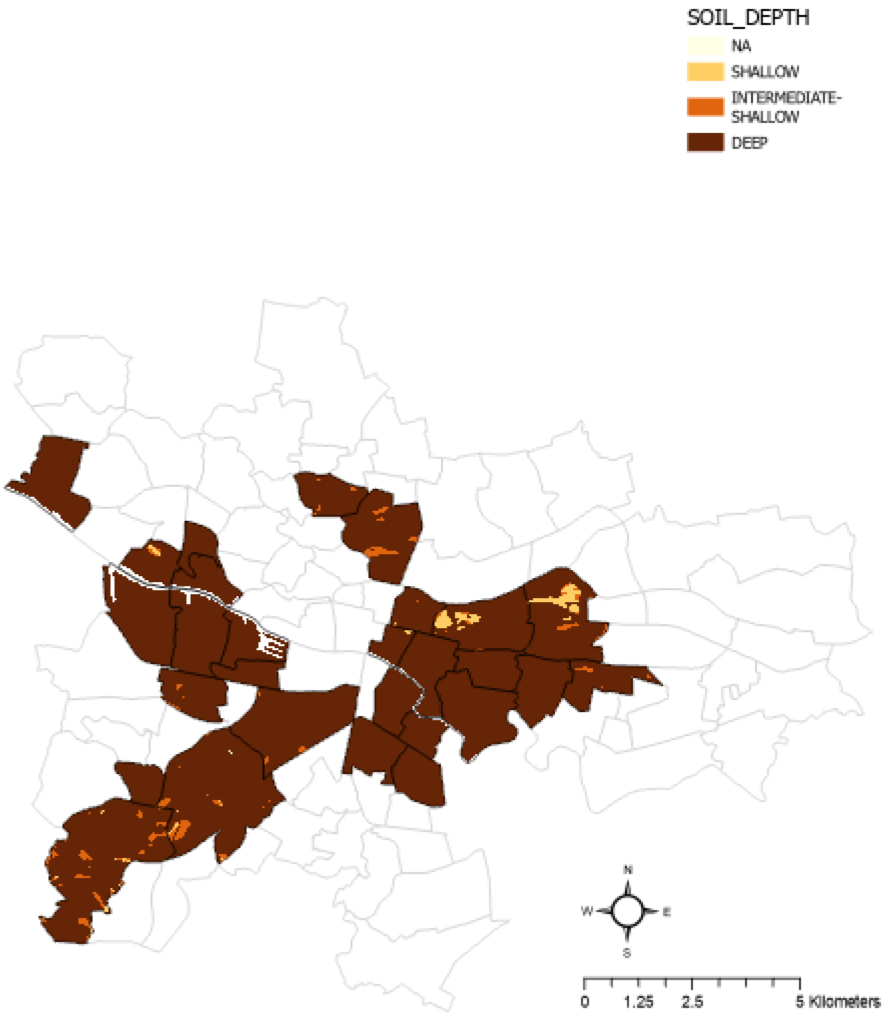
7.2.1 Soil Depth

Influences both infiltration and soil water retention capacity in a given region, qualitative data for soil depth have been reclassified based on Chapter 10 and represented in Figure 18

Table 7: Ranking Indicators - Soil Depth

Soil Depth (rise)	Impacts on Agricultural Productivity/Flooding	Rank
Deep	can provide more water and nutrients to plants than more shallow soils. --> >1 m | soil and subsoil can be easily dug to a depth of more than 1 m	5
Intermediate	Impacts the amount of soil water available to plants (Weil and Brady, 2015) | The soil and subsoil can be easily dug to a depth of 1 metre, sometimes more in places.	4
Intermediate - Shallow	The soil and subsoil can be easily dug to a depth of 1 metre, but not more.	3
Shallow	can be dug to depths of only half a metre, sometimes less.	2
Other	N/A	1

Figure 18: Soil Depths in Glasgow



7.2.2 Soil Texture

Influences pore size and porosity with looser and more open soils having majority of the incoming water is infiltrated compared to water that will runoff (See Figure 19)

Figure 19: Map of Soil Textures in Glasgow

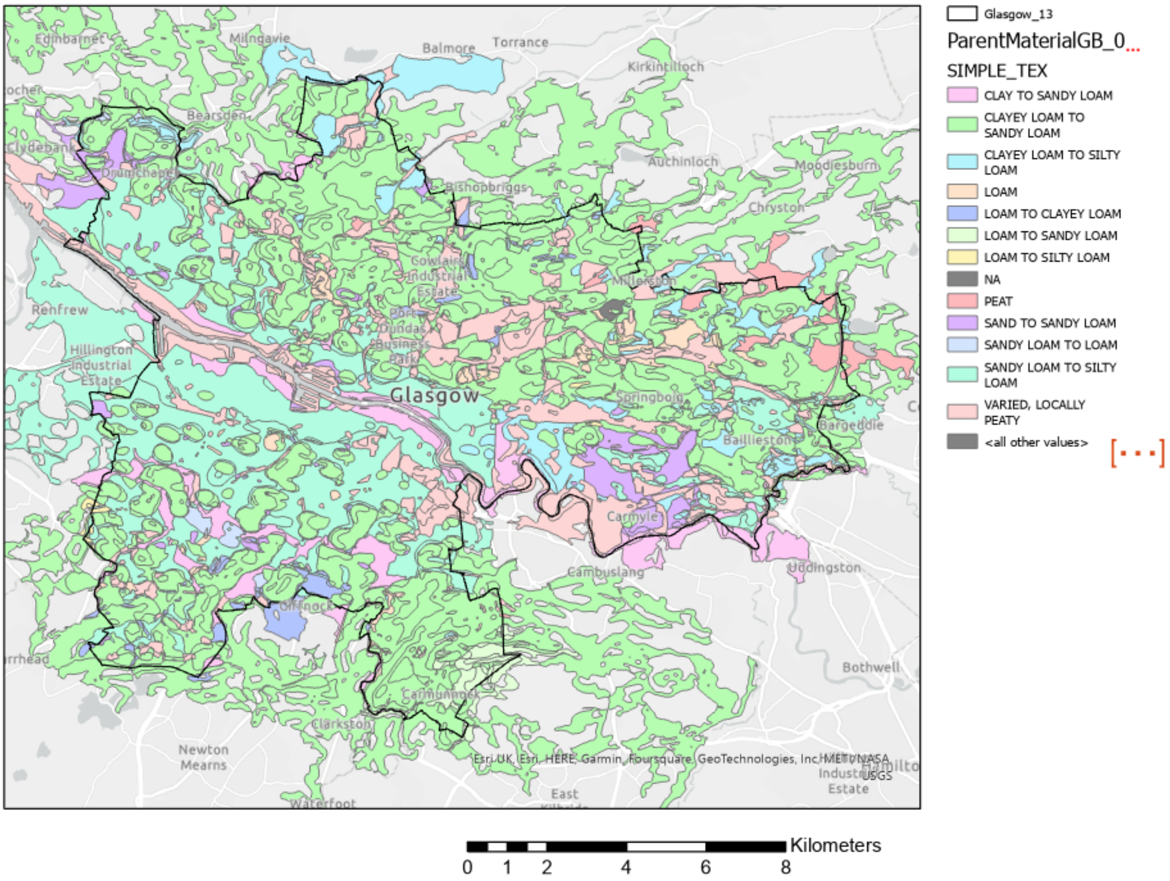


Table 8: Ranking Indicators – Soil Textures

Soil Texture	*Weighting*
Loam, Loam to Silty Loam,	5
Sandy Loam To Loam, Loam to Clayey Loam	4
Loam to Sandy Loam, Clay to Sandy Loam, Peat	3
Clayey Loam to Silty Loam, Sandy Loam to Silty Loam, Sand to Sandy Loam	2
Clayey Loam to Sandy Loam, Varied, Local Peaty	1

Table 9: Evaluation of Soil Texture s and their impact on flooding

S.No.	**Major Textural Class**	**Impacts on Flooding**	**General Textural Names**	**Basic Soil Textural Class Names**	**Availability of Nutrients**	**Tilling**	**Permeability/ Infiltration Rates**	**Source**
1	coarse-textured soils: Sand particles range from 0.05 to 2.00 millimetres (mm) in diameter	tendency to drain quickly after rainfall or irrigation | subject to nutrient loses | tend to have low pH | often acidic | less likely to have severe compaction |	Sandy Separates	Sands	(Poor)	(Easy)	Rapid	(Weil and Brady, 2015)
2				Loamy Sands			Rapid	(Soil types as a paramount aspect of agricultural productivity, 2019)
3	medium textured soils: silt particles range from 0.002 to 0.050 mm	tend to drain water slowly, can easily be compacted if trampled while wet, and harden when dry | prone to compaction, and wind and water erosion	Loams	Sandy Loam	High Nutrients	(Easy)	Moderately Rapid	(Weil and Brady, 2015)
4				Fine Sandy Loam				
5				Very fine sandy Loam			Moderate	
6				Loam				
7		tendency to compact easily when moist and form crusts when wet. | might be fairly well-drained, but they usually retain more water than sandy soils.	Silt Separates	Silty Loam	Sufficient Nutrients		Moderate	
8				Silt				

9				Sandy Clay Loam			Moderately Slow	
				Silty Clay Loam				
10				Clay Loam				
11	fine-textured soils: clay particles are smaller than 0.002 mm	to drain water slowly, Susceptible to compaction during wet conditions (Floods) -->restricted infiltration	Clay Separates	Sandy Clay	(Rich)	(Difficult)	Slow	
12				Silty Clay			Slow	
13				Clay			Very Slow	

Table 10: Summary of Indicators for agricultural suitability

Indicator	**Sub-indicator**	**Rank**	**Weight influence (%)**
Slope	Gentle (0 – 1)	5	40
	Moderate (1-3)	4	
	Stiff (3-6)	3	
	Steep (6 – 12)	2	
	More (> 12)	1	
Soil Texture	Loam, Loam to Silty Loam,	5	20
	Sandy Loam To Loam, Loam to Clayey Loam	5	
	Loam to Sandy Loam, Clay to Sandy Loam, Peat	4	
	Clayey Loam to Silty Loam, Sandy Loam to Silty Loam, Sand to Sandy Loam	3	
	Clayey Loam to Sandy Loam, Varied, Local Peaty	2	
Soil Depth	Deep	5	20
	Intermediate	4	
	Intermediate - Shallow	3	
	Shallow	2	
	Other	1	
Soil Permeability (Artificial)	High	5	5
Superficial Permeability	Very Low	2	15
	Low	3	
	Moderate	4	
	High	5	

Using the weighted analysis classification in Table 10, agricultural suitability of the area of intervention is conducted. The suitability analysis based on Table 4, shows high suitability areas for almost half of the vacant and derelict lands in the region.

Figure 20:Agricultural Suitability of Area of Intervention

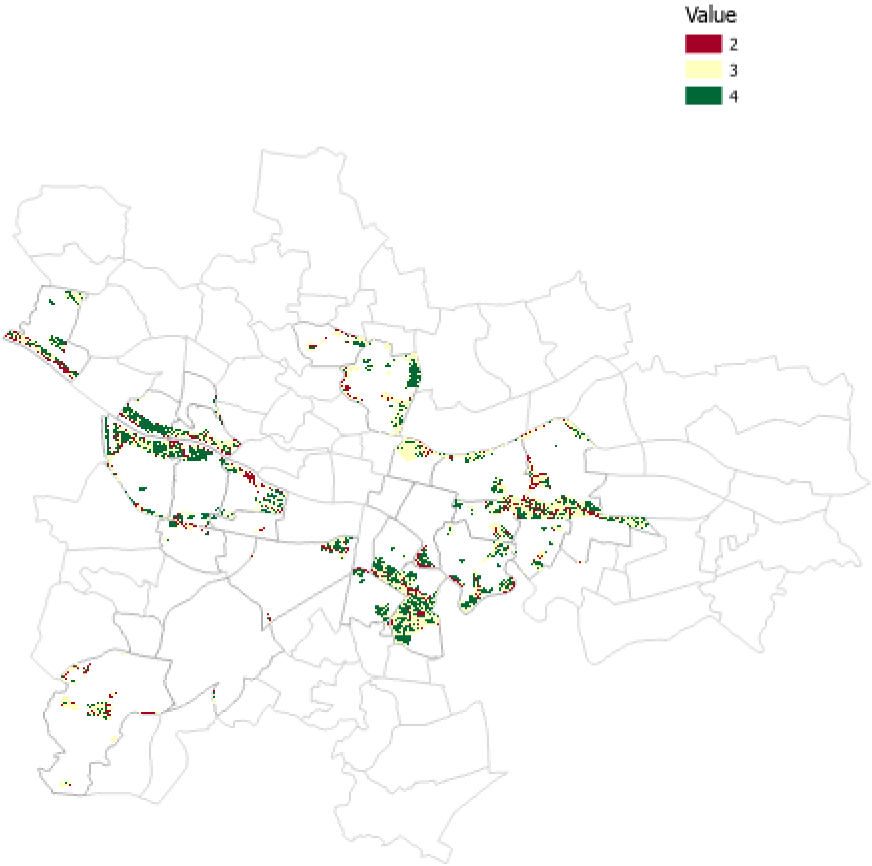
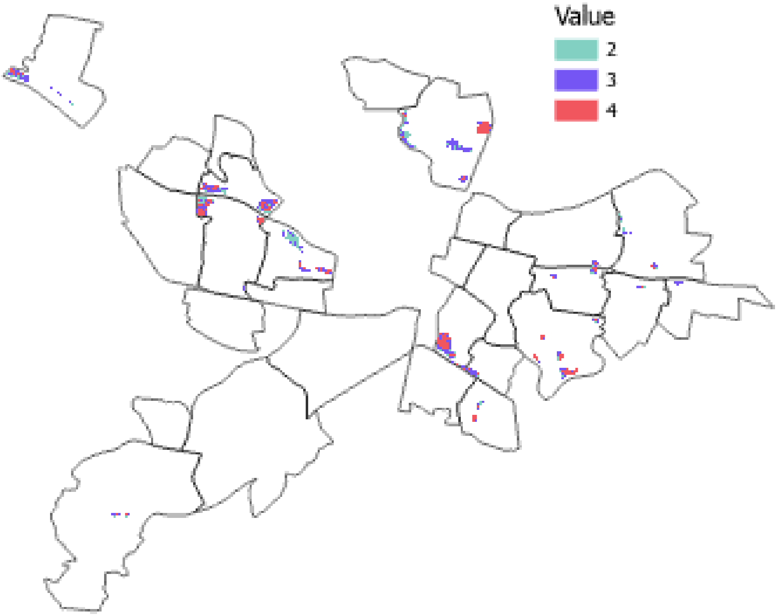


Figure 21: Agricultural Suitability Analysis of individual VDLs



8 CROP SUITABILITY - ECOHYDROLOGICAL TRAITS OF PLANTS

This section summarises ecohydrological traits Table 11 based on their contribution to hydrological processes as discussed in (Chapter 5.5) and attempts to find key morphological characteristics for selection of appropriate crops. The literature review of the traits is followed with an expert score review, before being finalised through a pair-wise comparison, to detect relevant traits.

Table 11: Summary of Morphological Traits for suitable crops

Hydrological Process	***Plant Traits that influence this process***	***Sub traits***	***Mechanism of trait***	***Best Case Scenario***	***References***
Transpiration	Leaf Morphology	Thickness, pubescence, colour	∝ **Water Adhesion Capacities** of leaves regulate the size of water droplet creation; smaller droplets evaporate more quickly, lowering throughfall.	small and fragmented leaves may crack the raindrops into smaller droplets | small, light, soft, and noncircular	(Monteiro, Blanuša and Verhoef, Anne Hadley, Paul W.F., 2016; Liu and Zhao, 2020; Yan *et al.*, 2021)
		Leaf Area Index and Leaf Shape Factor	Greater **radiation absorption** and as a result, higher transpiration rates result from increased leaf area per unit land area.		
Interception Capacity	Stem Morphology	Stem density (Stem/m^2)	Surface Area and Evaporation - higher stem densities, have consequently a higher plant surface area allowing more evaporation		(Wang and Duan, 2010; Liu and Zhao, 2020)

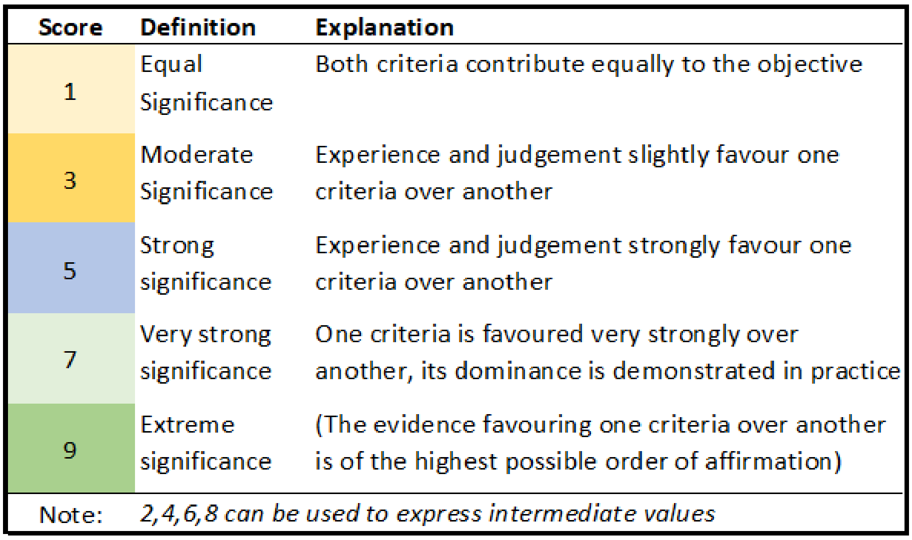
Infiltration from enhanced soil structure	Root Morphology	**Extensive Root Systems (**Root Depth and Structure)	Ability to connect deep soil/groundwater to the atmosphere (reduced compaction, etc.)	deep rooting plant species | long tap root, example - fast growing crops - fodder radish (Lane, 2021)	(Schenk and Jackson, 2002; Lane, 2021)
Delaying Overland Flow	Leaf and Stem Morphology	density, area and height of leaves and stems	Hydraulic Roughness – provides frictional resistance due to the contact of runoff with the vegetation and Sediment Retention	Herbaceous Vegetation	(Faucon, 2021)
Spatial Distribution and Saturate Flow	Canopy Cover	Plant Height	Canopies of the vegetation allow for the spatial distribution of rain as intercepted rain is directed towards plant stem, affecting the saturated flow and spatial distribution		(Weil and Brady, 2015)
	Stem Flow				

Few comparisons found in literature demonstrate the importance of **Plant Density compared to** Leaf Sizes of vegetation (Ufoegbune, Eruola and Awomeso, 2012) whereas **Vegetation ground cover** compared to stem density and basal area for having adhering water volume (Wang and Duan, 2010). The information collated from literature allowed for a generic compilation of traits and plant traits. However, no integrated assessment is found.

8.1 EXPERT SCORING AND PAIRWISE COMPARISON

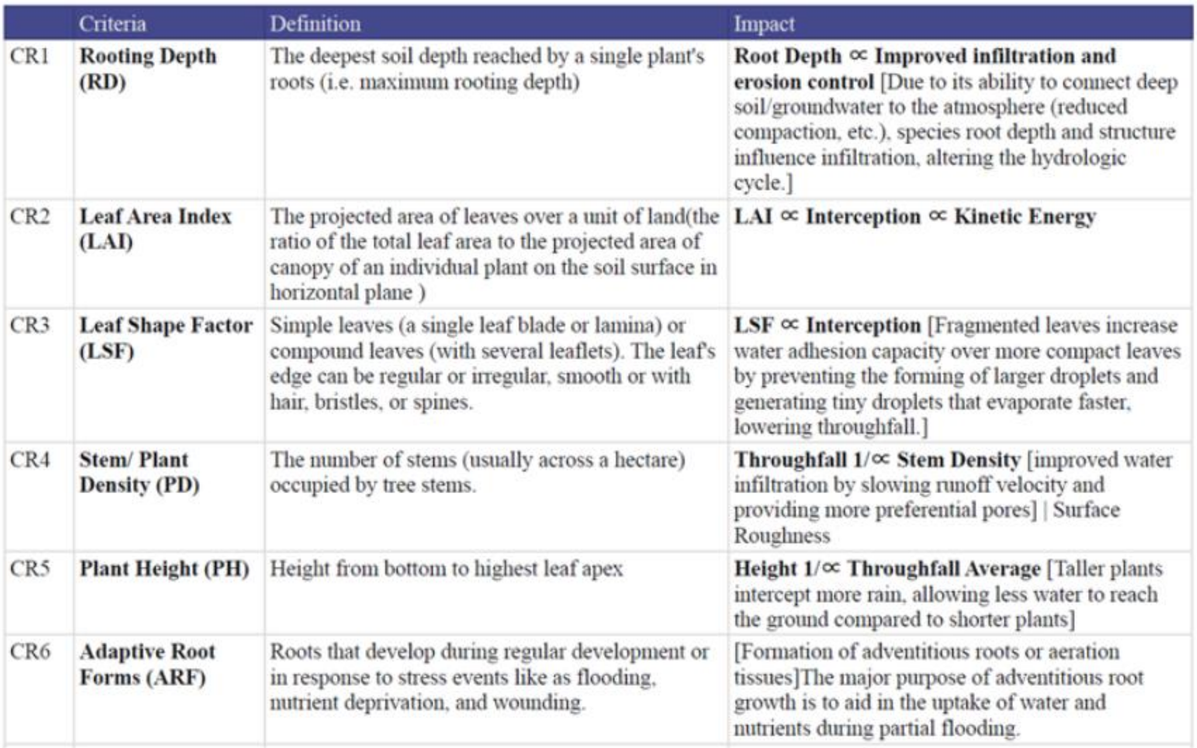
Experts from the background of soil sciences were sent these traits identified from literature to score using Saaty's Analytic Hierarchy Process developed by Thomas Saaty, responses from the 2 experts were measured for a pairwise comparison of criteria (See Table 13) based on Saaty's priority scale (Table 12)

Table 12 : Priority Scale - Saaty



Score	Definition	Explanation
1	Equal Significance	Both criteria contribute equally to the objective
3	Moderate Significance	Experience and judgement slightly favour one criteria over another
5	Strong significance	Experience and judgement strongly favour one criteria over another
7	Very strong significance	One criteria is favoured very strongly over another, its dominance is demonstrated in practice
9	Extreme significance	(The evidence favouring one criteria over another is of the highest possible order of affirmation)
Note:	*2,4,6,8 can be used to express intermediate values*	

Table 13: Morphological Traits for Expert Evaluation



	Criteria	Definition	Impact
CR1	**Rooting Depth (RD)**	The deepest soil depth reached by a single plant's roots (i.e. maximum rooting depth)	**Root Depth ∝ Improved infiltration and erosion control** [Due to its ability to connect deep soil/groundwater to the atmosphere (reduced compaction, etc.), species root depth and structure influence infiltration, altering the hydrologic cycle.]
CR2	**Leaf Area Index (LAI)**	The projected area of leaves over a unit of land(the ratio of the total leaf area to the projected area of canopy of an individual plant on the soil surface in horizontal plane)	**LAI ∝ Interception ∝ Kinetic Energy**
CR3	**Leaf Shape Factor (LSF)**	Simple leaves (a single leaf blade or lamina) or compound leaves (with several leaflets). The leaf's edge can be regular or irregular, smooth or with hair, bristles, or spines.	**LSF ∝ Interception** [Fragmented leaves increase water adhesion capacity over more compact leaves by preventing the forming of larger droplets and generating tiny droplets that evaporate faster, lowering throughfall.]
CR4	**Stem/ Plant Density (PD)**	The number of stems (usually across a hectare) occupied by tree stems.	**Throughfall 1/∝ Stem Density** [improved water infiltration by slowing runoff velocity and providing more preferential pores] | Surface Roughness
CR5	**Plant Height (PH)**	Height from bottom to highest leaf apex	**Height 1/∝ Throughfall Average** [Taller plants intercept more rain, allowing less water to reach the ground compared to shorter plants]
CR6	**Adaptive Root Forms (ARF)**	Roots that develop during regular development or in response to stress events like as flooding, nutrient deprivation, and wounding.	[Formation of adventitious roots or aeration tissues]The major purpose of adventitious root growth is to aid in the uptake of water and nutrients during partial flooding.

Selection of Indicators (Table 13) based on their contribution to flood mitigation processes Section 5.5, were evaluated using Web – AHP. Using a geometric mean of 2 responses, a matrix was developed (See Table 14), using 15 comparisons of the 6 traits. The results included a consistency ratio of 28%

Table 14: Matrix of response from experts for ecohydrological traits of plants

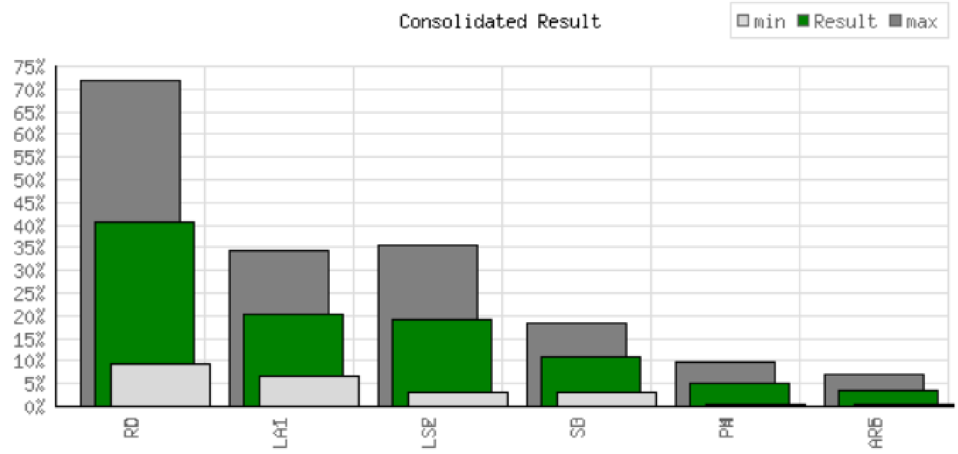
Cat		Priority	Rank	(+)	(-)
1	RD	40.6%	1	31.3%	31.3%
2	LAI	20.4%	2	13.7%	13.7%
3	LSF	19.3%	3	16.2%	16.2%
4	SD	10.8%	4	7.7%	7.7%
5	PH	5.2%	5	4.7%	4.7%
6	ARF	3.7%	6	3.5%	3.5%

A Decision Matrix with Principal eigen value = 7.756 and Eigenvector solution of 10 iterations and delta value of 2.2E-8 can be seen in Table 15 with the final consolidated results depicted in a graph (See Figure 22**)**

Table 15: Decision matrix

	1	2	3	4	5	6
1	1	6.00	4.00	3.00	6.00	3.00
2	0.17	1	3.00	3.00	5.00	4.00
3	0.25	0.33	1	6.00	5.00	6.00
4	0.33	0.33	0.17	1	6.00	5.00
5	0.17	0.20	0.20	0.17	1	5.00
6	0.33	0.25	0.17	0.20	0.20	1

Figure 22: Graphical representation of AHP analysis of Plants Traits



9 LAND MANAGEMENT PRACTICES

The objectives of this chapter include compilation of natural soil management practices suitable for urban soil conditions to enhance their hydrological properties and consequent crop productivity. In Natural Flood Management (NFM) associated with land management practices contribute to both increased runoff retention and increased agricultural productivity (Forbes, Ball and Mclay, 2015). NFM, according to (Lane, 2021), involves:

> "implementing measures to restore or mimic '**natural hydrological and morphological processes**, features, and characteristics **to manage the sources and pathways of flood waters"**

NFM measures reduce runoff by i) slowing water, ii) storing water, iii) increasing soil infiltration and iv) intercepting rainfall (Lane, 2021). The study looks at this aspect of agriculture since agricultural lands have very high permeability both from the usage of crops and from land management employed for enhanced crop productivity. Various practices similar to NFM exists with the same overall intent, such as Best Management Practices (BMP), aimed at improving water quality or Natural Water Retention Measures (NWRM) aimed at safeguarding and enhancing the water storage potential of ecosystems.

The practices that fall in these practices have been summarised in (See Table 16) based on their goal of management of soil. Since the hydrological benefits of vegetation have already been described in (See section 8), this component of management methods that utilise plant functions are not discussed here. A review of the literature found that an assessment of deterioration, growing circumstances, and a cost-benefit analysis are required prior to selecting repair and restoration procedures.

9.1 SHORT TERM GOALS - TO IMPROVE AGRICULTURAL SUITABILITY

For immediate preparation of land to make it suitable for food production. These may include improving the hydrological soil conditions, hardpan breakup, aggregating soils, etc.

9.2 LONG TERM GOALS - PREVENTION OF DEGRADATION

Once the site has been prepped and the plants have been established, it is vital to maintain the current degree of remediation to achieve continuous improvements in the future.

9.3 SUPPLEMENTARY

Practices that play a vital role but were not found in the literature to be major management options in flood risk practices have been grouped together. They augment bigger management approaches and make them more successful, earning them a place in the discussion.

Table 16: Summary of Land Management Practices

	Aim	Practice	Description	Management Goal	Supporting Benefits	Ideal Location	Selection of Food Crops	Food Crops
Spatial Patterns	Long Term | Improvement	Trees in Croplands: Alley/Intercropping/Crop Diversification	Growing food crops in between rows of trees/ shrubs (hedgerows) (Weil and Brady, 2015)	Natural Buffer: wind and soil erosion Hydrological: retention, Reduced runoff (Anderson and Gough, 2021) Soil Properties: SOM, stabilizing soil aggregates, reducing soil compaction, etc.	Improved i) crop production diversity ii) resource efficiency iii) Soil fertility and nutrient cycling iv) biodiversity (Anderson and Gough, 2021)	Moderately fertile soil and sufficient rainfall to reduce competition for resources between hedgerow and food crops (Weil and Brady, 2015)	Annual Crops (usually legumes and Woody Perennials (Cary and Frey, 2020). The source of mulching comes from trimming the hedgerows regularly.	Legumes
		Buffer Strips and Riparian Tree Planting		Hydrological: Roughness for Flood Attenuation	Buffer zone to safeguard environmentally vulnerable communities?	-	-	-
Mechanical	Short Term | Soil Reconditioning	Hardpan Breakup – Tillage	Hardpan Layers are dense (high bulk densities) and compacted soils, found anywhere between 0.1 to 1.0m under the soil surface (Hovis et al., 2021)	Reduced Soil Compaction: Increased soil water infiltration and consequent reduced runoff (Hovis et al., 2021). Infiltration iii) Water Holding Capacity (Ebissa and Desta, 2022).	Improved water quality	Effective where soils are permeable and hardpan layer is extensive vs less permeable soils (Hovis et al., 2021)	N/A	N/A
		Hardpan Breakup - *Crop rotation | re-seeding or overseeding using deep rooting plant species*		Promotes strong root growth | Reduced soil loss | Enhanced heat and drought stress tolerance | Improved Water Quality	-	-	-	festulolium and clovers for grassland.
		Artificial Drainage	Surface Drainage [Shallow low ditches + Swales] or Subsurface Drainage	Agricultural Productivity: Enhanced rooting depth, growth and productivity Hydrological: For Fine Textured Soils with low drainage capacities (Weil and Brady, 2015).	-	Levelled landscape + Fine Textured Soils (having low percolation rates) (Weil and Brady, 2015)	-	-

Soil Protection	Long term | Improvement	No till farming/ Subsoiling | aerating, or sward lifting		Prevention of Soil Compaction (hardpan layers) and erosion (Hovis et al., 2021), improved infiltration/ drainage by increasing soil pore space by adding carbon to the soil [Infiltration]	-	-	Extensive root structures	-
		Cover Cropping in between Crop Rotation	Any non- cash crop grown on land in between regular crop production periods to protect the land by i) reducing primarily for the purpose of protecting the land between periods of crop production (Weil and Brady, 2015; Lane, 2021).	i) Reduces overland flow before saturation of soil - during the first part of an extreme precipitation event ii) Increased [Infiltration] (by formation of open root channels) iii) and protecting soil surface structure/compaction iv) Soil surface protection -prevents soil loss (Weil and Brady, 2015; Lane, 2021).	By increased SOM	arable or temporary grassland adjacent to watercourses, particularly on sloping fields (Lane, 2021). Land vulnerable to nitrate leaching (Lane, 2021).	Crops complementing row crop production that i) have a low seed rate, ii) are inexpensive, and iii) will pull up nutrients and store them in their green, leafy canopy; iv) are easy to establish (Crop management for Flood Defence, 2020).	cucurbits (courgettes, pumpkins, squashes, marrows, and cucumbers), salads (endive, lettuce, and chicory) and sweetcorn | fodder radish and Phacelia
		Organic Farming: Mulching/ Weeds/Chipped Branches/Catch Crops		Prevent runoff and Erosion from Soil and Water -Reduced evaporation from soil (Weil and Brady, 2015) – Soil Conditions – WHC and Infiltration Capacity (Keesstra et al., 2018)	Agro-tourism	Control Weeds	-	Lettuce, salad leaves, coriander, rocket, and radish
		Cover Cropping and No-till farming	Cover crops that limit the need for tilling as soil structure is improved over time.	Cons: Could cause hardpan	-	Highly erodible land or high clay soils (Hovis et al., 2021)	UK: phacelia, vetch, ryegrass, grazing rye, barley and mustard, or a mix of these depending on local conditions and needs (Lane, 2021).	Mulching (EPA, 2011)
		Trees in Croplands: Agroforestry/Silvoarable	Integration of trees in farming	Sponge Effect: Infiltration Capacity + permanent Soil surface protection + Water Retention + Interception + Soil Quality	Supply and cycling of plant nutrients + Increased productivity	Small-scale farming systems	Nitrogen-fixing woody species	(Weil and Brady, 2015)

Supplementary Practices	🟩	Compost /Peat amendment/Aged Manure	-	SOM + Bulk Density + Infiltration + Porosity + Aggregation + Acidic Soils, Lacking Macronutrients	-	-	-		(Cookson and Stirk, 2019)
	Short Term | Improvement	Managed Rewilding (no-till, wetland and peatland restoration)	‘Restoration of habitats and natural processes’ (Berry and Brown, 2021)	Soil Functions: SOM, Nitrogen Content, bulk density and aggregate stability (Keesstra et al., 2018)	Ecosystem Resilience: Soil biodiversity, carbon sequestration | Water Quality regulation (Keesstra et al., 2018)		Boreal and Mediterranean climates	Peat moss, nectar rich plants	
				Hydrological Functions: Water Holding Capacity, Erosion, runoff discharge, Infiltration, Interception, Soil surface protection					

10 SELECTION OF CRITERIA

10.1 WEIGHTING METHOD SELECTION OF INDICATORS

The indicator selection technique has focused on components that can both withstand and ameliorate floods by moderating hydrological processes that would otherwise be lost to urban areas and have agricultural productivity. All criterion maps have been converted to 10 x 10 raster maps for a weighted analysis.

10.1.1 Sensitivity to Management

If appropriately assessed, managed, and used in accordance with best management practises (BMPs) or alternative agricultural methodologies, certain anthropogenic soil conditions have the potential to be altered and consequently utilised in urban agriculture (Weil and Brady, 2015). The indicators for agricultural suitability discussed in Chapter 5.5, have been classified in this section (See based on their permanence and sensitivity to management according to the classification presented by (Weil and Brady, 2015) shown in (Table 17).

Table 17: Selection Criteria: Sensitivity to Land Management

Classification of Permanence and Sensitivity to Management	*Description*	*Suitability to the study*
Ephemeral	Changes in routine management practises or weather can cause rapid changes from day to day.	2
Intermediate	Subject to management over several years	3
Permanent	Management has negligible effect on this because it is inherent in the soil profile or site.	5

Source 11: (Weil and Brady, 2015)

The classification allows in deciding which indicators are non-negotiable in the land suitability assessment. Indicators that are permanent in nature are selected for the final suitability assessment as other indicators can be modified to some extents.

Table 18: Summary of Indicators and their Sensitivity to Management and Change

Soil Condition	**Reason**	**Sensitivity to Management/ Anthropogenic scope for modification**	**Description**	**References**
Infiltration Capacity	High Water Table (perched water table)	Ephemeral - Intermediate	Can be artificially drained	(Weil and Brady, 2015)
	Slope	Permanent	High costs of excavation if altered	
	Soil Depth	Permanent		(Weil and Brady, 2015)
	Soil Texture	Permanent		
	Macro Nutrients	Ephemeral		
	Soil Organic Matter	Intermediate		
	Soil pH	Ephemeral		
	Soil Porosity			
	Soil Permeability/Aggregation/ Bulk Density [BD]	Intermediate		

10.1.2 Sphere of Influence: Soil Traits

To understand and document the influence each of the indicators have on the hydrological processes, their sphere of influence was evaluated through a flow chart and summarised in Table 19

Table 19: Summary of Indicators and their sphere of influence

Weighted Influence	***Suitability Indicator***	***Direct Influence on Soil Properties***	***Influence [Agricultural Suitability]***	***Influence on [Hydrological Regulation]***	***Sensitivity to Management***	***Reference***
40	Topographic Slope	∝ Soil Depth	Lessening of Root Depth ∝ Plant Nutrient Availability	∝ Infiltration Rates ∝ Overland flow ∝ Soil Moisture	Permanent	(Aytenew, 2015)
		∝ Degraded Soil Structure		∝ Risk of Erosion with loss of topsoil		
		Soil Texture				
		Soil Organic Matter				
20	Soil Depth	1/ α SOM	α Plant Nutrient Availability	Rate of Infiltration	Permanent	

		α Bulk Density	structural support			
		Soil Texture		α WHC		
20	Soil Texture	Soil Porosity (pore size)	α Nutrient Retention	Drainage / Percolation of water	Permanent	
		Bulk Density	α Soil Fertility	Infiltration Capacity + Rate of Permeability		
		Soil Depth		Erosion Potential		
		Soil Moisture		WHC/Retention		
	Macro Nutrients		α Agricultural Productivity		Ephemeral	
	Soil Organic Matter (SOM)	α Soil Structure (soil aggregates & macropore formation)	α Plant available water (PAW)	α Infiltration rates α Water Holding Capacity	Intermediate	(Weil and Brady, 2015)
	Soil pH	Nutrient Availability	availability of plant nutrients + plant growth + production		Ephemeral	(Weil and Brady, 2015)
	Soil Porosity	1/ α Bulk Density		1/ α Drainage and Infiltration, Storage Capacity		
		Permeability		α Infiltration rates		
15	Soil Permeability/ Stoniness	α Soil Texture and Structure			Permanent	
10	Artificial Permeability/Soil Sealing/Compaction	Bulk Density			Ephemeral	
	Bulk Density [BD]	Soil Textures – Finer soils, lower BD	α Stunted root growth	1/ α Infiltration		
		1/ α Soil Porosity		1/ α Drainage		
		α Soil Depth				

11 FLOOD RETENTION POTENTIAL OF VDLS

The major purpose of this section is to try to quantify the capacity of VDLs to retain and reduce runoff under four different crop and land management scenarios of UA. The Urban Flood Mitigation Model of the InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) programme used for the hydrological modelling process, takes into account local precipitation data of the area of interest and the potential of permeability of natural infrastructures to calculate runoff potential of the areas.

11.1 THE MODEL

Runoff production and runoff attenuation index: The model uses ‘Curve Numbers’(CN) that are simple empirical calculations specific to land use and soil conditions, developed based on estimations used to forecast direct runoff or infiltration potentials (USDA, 2007). The software makes use of the Curve Number Method (CNM) (See Equation 1) to evaluate runoff generated per pixel compared to the storm volume, based on the unique CNs.

11.2 PRELIMINARY DATA INPUT

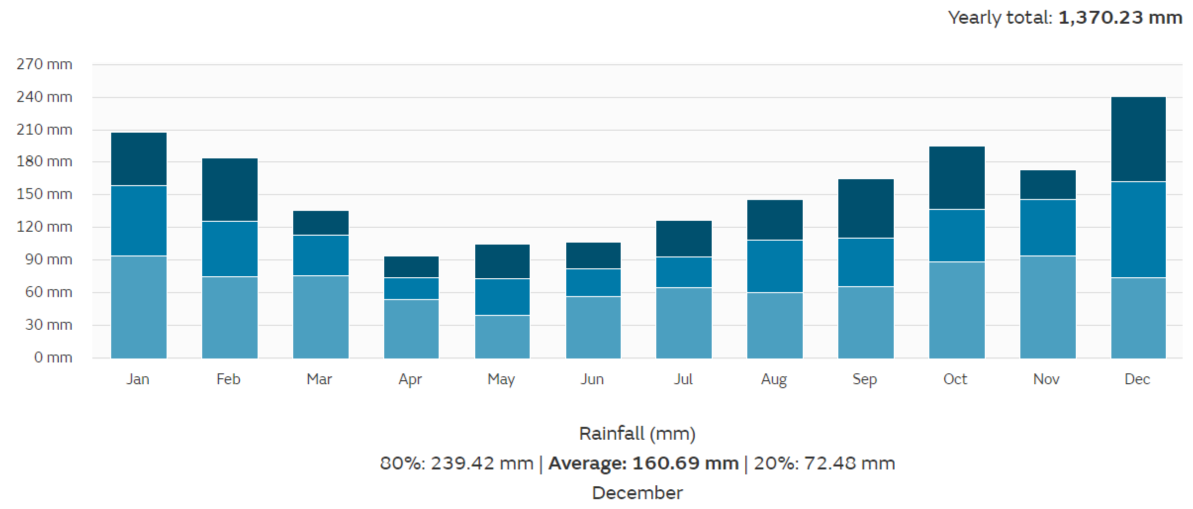
The model uses the following data for the hydrological modelling:

- Area of Assessment as defined in Chapter 5
- Numeric Value of rainfall depth (mm)
- Soil Hydrologic Map (raster)
- LULC
- Biophysical Table

11.2.1 Rainfall Depth

The assessment is based on (Met Office, 2020) data from the Glasgow/Bishopton station for the period 1991-2020, with the average rainfall depth for the wettest month of December being 160.69 mm (See Figure 23)

Figure 23: Rainfall, 1990-2020



Source 12: (Met Office, 2020)

11.2.2 Soil Hydrological Map Raster

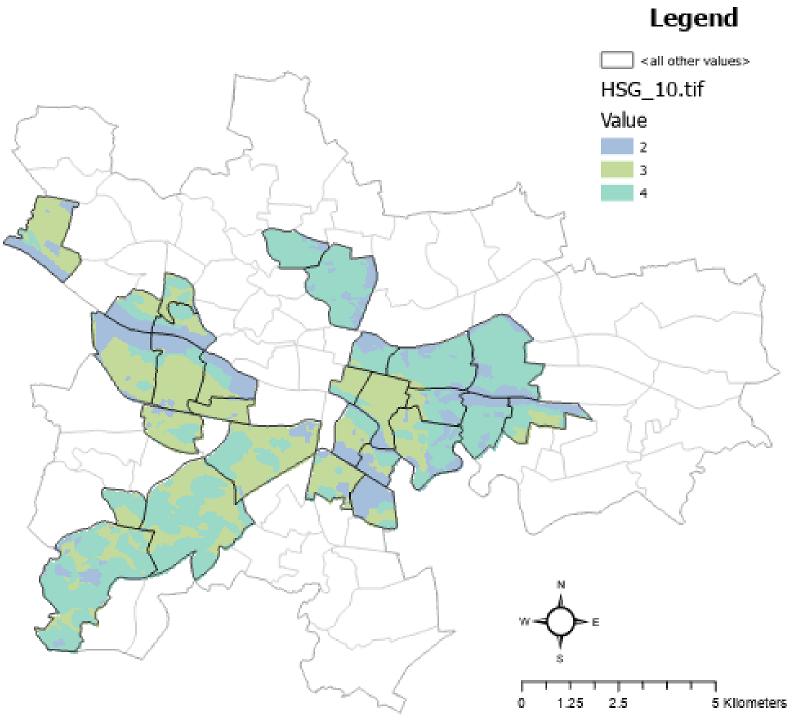
Hydrologic Soil Groups describes soil groups having similar runoff potential under similar flood conditions. Based on the four broad classifications provided by (USDA, 2007), three HSGs were identified (See **Error! Reference source not found.**) in Glasgow based on soil texture maps and the Global Hydrological Soil Maps (ORNL-DAAC's HYSOGs250m).

Table 20: Summary of Hydrological Soil Groups

Hydrological Soil Group	*Soil Texture Description*	*Hydrological Condition*
A	Typically, < 10 % clay and > 90 % sand or gravel and have gravel or sand textures.	Low runoff potential when thoroughly wet.
B	Typically, 10 – 20% Clay + 50 – 90% Sand + Loamy soils (loam, silt loam, silt, or sandy clay loam)	Moderately low runoff potential, when thoroughly wet.
C	Typically, 20 - 40 % clay + less than 50 % Sand + Loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Some soils having clay, silty clay, or sandy clay textures	Moderately high runoff potential when thoroughly wet. Water transmission somewhat restricted
D	typically, > 40% clay + < 50 % Sand + clayey textures.	High runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted.

Source 13: (USDA,2004)

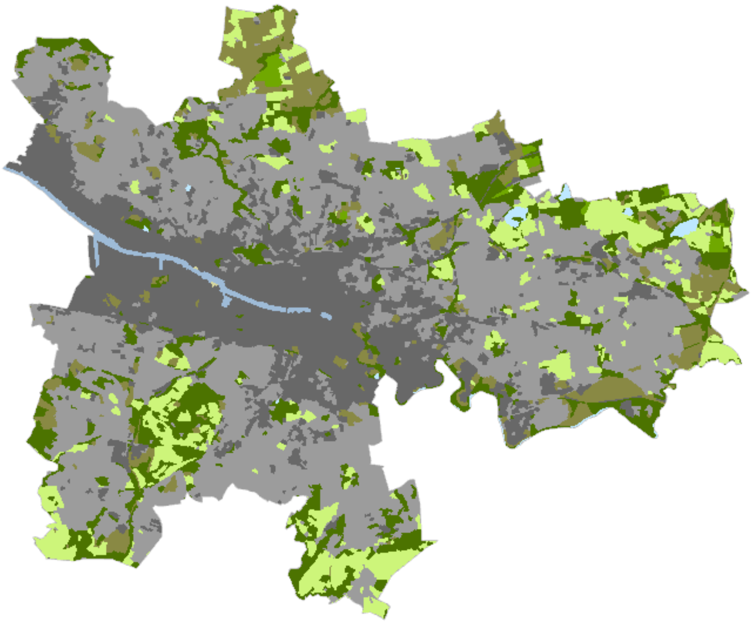
Figure 24: Spatial representation of HSGs in study area



11.2.3 Land use/land cover (LULC)

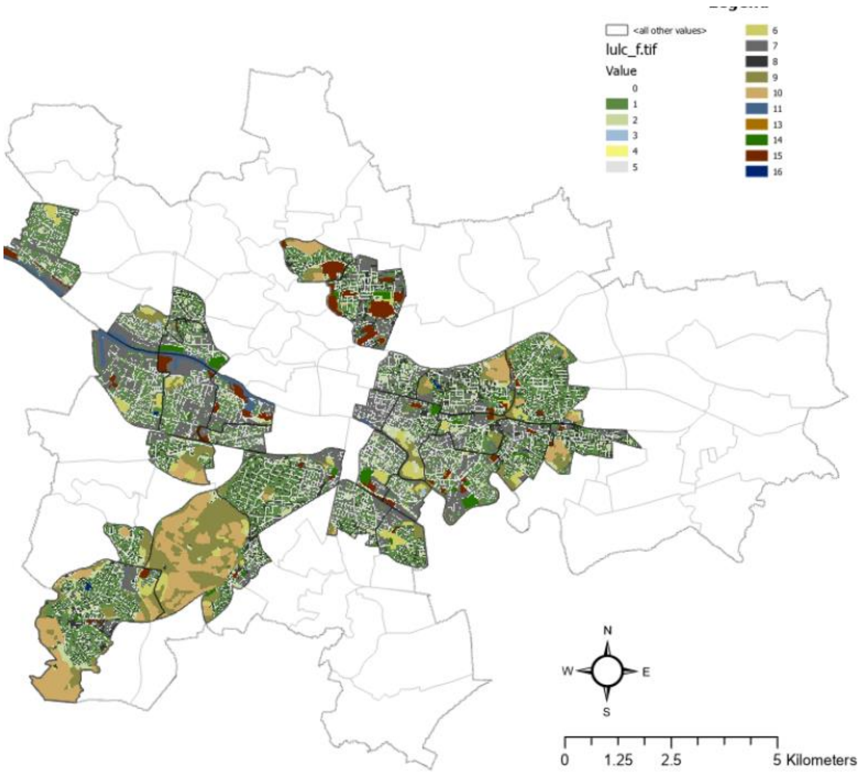
Land use along with the HSGs discussed above, also helps determine the soil's associated runoff CN. For the purposes of the accuracy of assessment, the LULC raster map for Glasgow (UKCEH, 2021) available with broad habitat classes (Figure 25), was broken into sub-groups with the use of topographic and green space maps to delineate permeability (See

Figure 25: UK BAP Broad Habitats Map for Glasgow,2020



Source 14: (UKCEH, 2021)

Figure 26: Improved map of Landcover classes, Study area



The finalised LULC classes within the study area are shown in Figure 26 with areas represented in Figure 27 and Figure 28. The total area of interest considered for this study amounts to 52206 ha of which potential area of intervention is 2258.8 ha, making up only 4.33% of the of total study area.

Figure 27: Distribution of land classes by % within study area

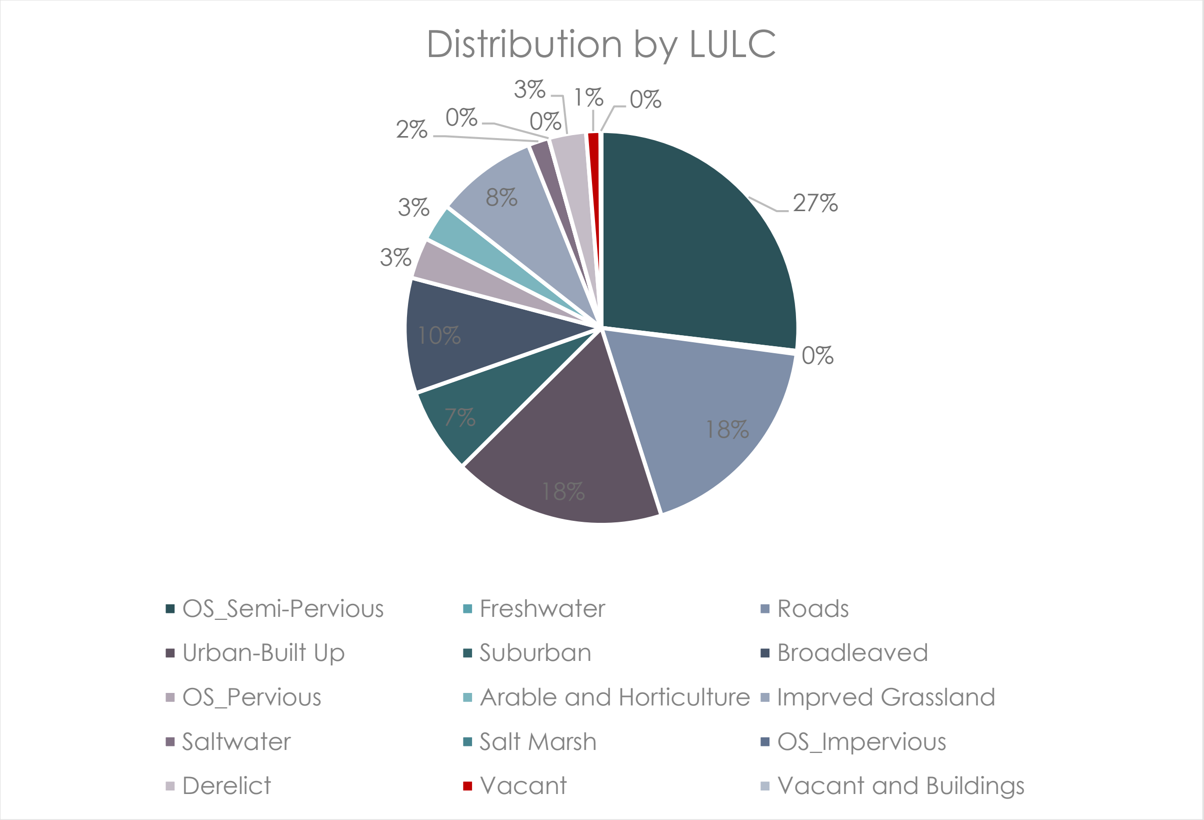
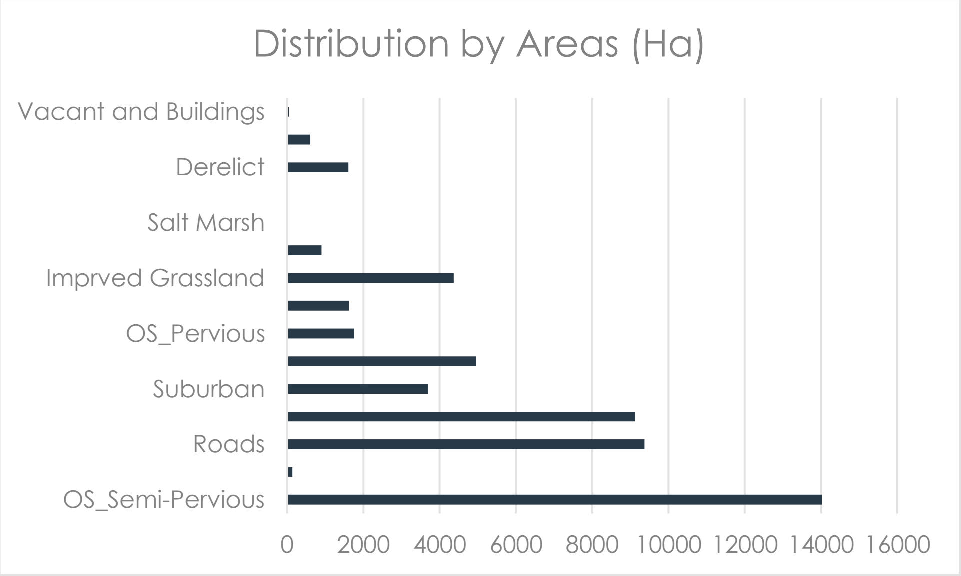


Figure 28: Distribution of LULC by Areas(Ha)



CNs (Curve Number) based on LULC for each of the four HSGs (A, B, C and D) have been estimated for the new classes (See Table 21), based on the review of relevant literature and the National Engineering Handbook Standards (USDA, 2004).

11.2.4 Biophysical Table

Following the preparation of a detailed LULC map, 16 land classes were categorised based on their hydrological soil conditions and a biophysical table prepared with CN values corresponding to each land use class (See Table 21). Land Use classes that have been introduced are indicated in red.

Table 21: Summary of Soil Hydrological Groups for Land Cover Types, Glasgow

LULC Code	*Classification*	*Description*	*HSG*				*Hydrologic Condition*
			A	B	C	D	
1	Open Spaces: Semi-Pervious	Open green spaces with established vegetation - Private Gardens, Rail Land, School, Religious Grounds, Allotments or Growing Areas	49	69	79	84	Fair condition (grass cover 50% to 75%)
2	Open Spaces: Pervious	[Public Park, Gardens, Parks, Cemeteries, golf courses, School Grounds, Playing Field)	39	61	74	80	Good condition, pervious urban areas are equivalent to pasture in good hydrologic condition (grass cover > 75%)
3	Freshwater/Open Water	i)Standing open water and canals ii) Rivers and streams	98	98	98	98	
4	Open Space : Mostly Impervious	Tennis Court, etc.	68	79	86	89	Poor condition (grass cover < 50%), possibly connected to a drainage system
5	Street and Roads	Paved; curbs and storm sewers (excluding right-of-way)	98	98	98	98	Impervious, poor
6	Arable and Horticulture	commercial horticultural land - nurseries, commercial vegetable plots and commercial flower growing areas; Scattered Trees	43	65	76	82	Wood Grass Combination Land cover values have been used
7	Urban – Built up	Residential districts by average lot size [2 acres] High densities	46	65	77	82	Average % impervious area - 12
8	Suburban	Low Densities	77	85	90	92	Average % impervious area – 65%

9	Broadleaved Woodland	drier soil than that of grassland depending on area and canopy cover. Broadleaved - characterised by stands >5 m high with tree cover >20%.	30	55	70	77	Good: Woods are protected from grazing, and litter and brush adequately cover the soil
10	Improved Grassland	Fertile, neutral soils, managed as pasture, non-agricultural contexts for recreation and amenity purposes, amenity grassland (Pasture)/Herbaceous	39	61	74	80	Not grazed - Good condition (ground cover >75% and lightly or only occasionally grazed)
11	Saltwater	Water Surface	98	98	98	98	Open Water
12	Heathered Grassland		39	61	74	80	Good Condition
13	Salt Marsh		0	62	74	85	Herbaceous Land Cover CNs have been used—mixture of grass, weeds and low-growing brush, with brush the minor element.
14	Vacant	May have some established vegetation (grass cover 50% to 75%)	49	69	79	84	Fair Condition (Same values as Semi-Pervious]
15	Derelict	any land "which has been so damaged by development, that it is unsuitable for development for beneficial use without rehabilitation."	77	86	91	94	Poor Drainage [(Same values for Bare Soil have been used)]
16	Vacant Lands and Buildings	Residential districts with an average plot size of 1 acre	51	68	79	84	Average percent - impervious area: 20%

Source 15: (USDA, 2004)

11.3 SCENARIO BASED DATA

11.3.1 Scenario One: Pre-Interventions

The first scenario is a preliminary assessment of the study area using existing soil and landcover conditions as discussed above (See Table 21).

11.3.2 Scenario Two – Using Rhubarb [New LULC]

For the scenario assessing crop potential in water retention, the land cover type of VDLs was assessed with values that corresponded as closely as possible to (USDA, 2004) "agricultural lands" classification with well-established crops and improved infiltration potential (Ebissa and Desta, 2022). The goal of this scenario was to determine how much runoff is retained with an agricultural land cover because, in addition to soil characteristics, hydrologic conditions also depend on several other variables, including the density and canopy of vegetative regions and the amount of year-round cover. Consequently, a new biophysical table with agricultural land coverage and related CNs was produced (See Table 22).

Table 22: Agricultural Hydrological Soil Conditions – Study Area

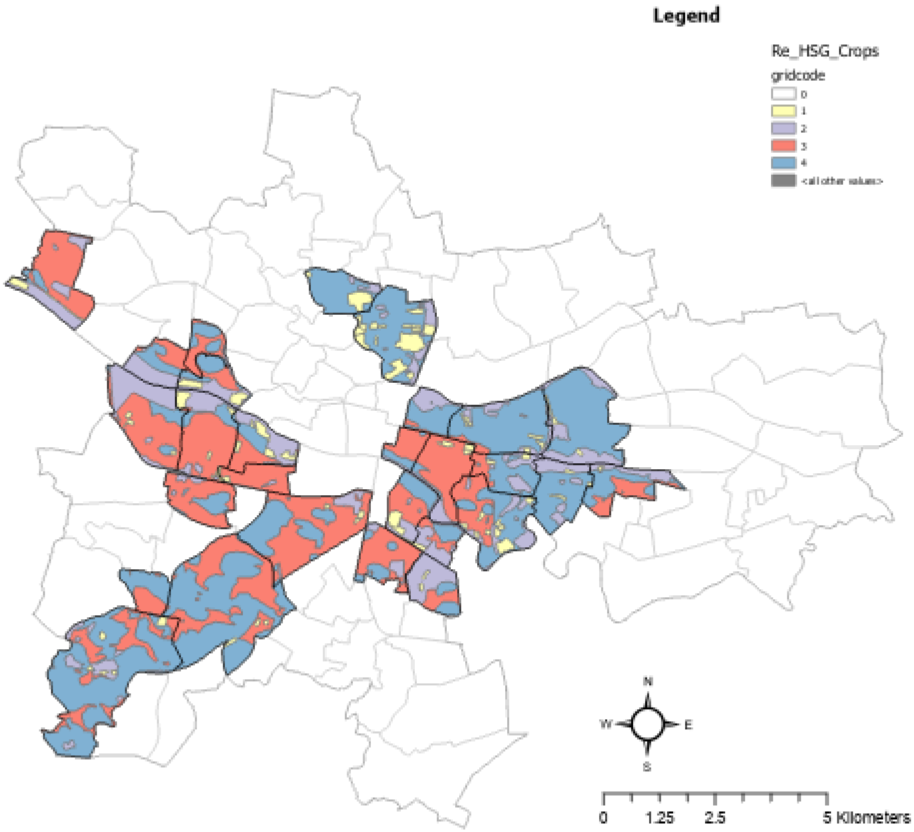
LULC Code	Previous Use	Cover Type	Description	HSG				Hydrological Soil Condition
				A	B	C	D	
14, 16	Vacant Lands and Vacant Lands and Buildings	Cultivated Land: Row Crops [Off-season]	Crops that can be grown in rows with space for tilling: sunflower, potato, canola, dry bean, field pea, flax, safflower, buckwheat, cotton, maize, soybeans, and sugar beets.	67	78	85	89	Good
15	Derelict Lands		As semi-pervious now	76	85	90	93	Fair condition (grass cover 50% to 75%)

Source 16: (USDA, 2004)

11.3.3 Scenario Three: Using LMP

While soil textures are a permanent feature of a place, hydrological soil conditions can be improved by improving hydraulic conductivity through land management approaches (aggregated soils, lower bulk density) (USDA, 2007). Any agricultural use of land would mean reconditioning of soil either in preparation of suitability (See Section 9) or improvement through introduction of vegetation (See Chapter 8). Since LMPs target urban soil characteristics responsible for enhanced runoff (See Section 9), new HSGs with low runoff potentials are assumed for this scenario for all VDLs (See Figure 29)

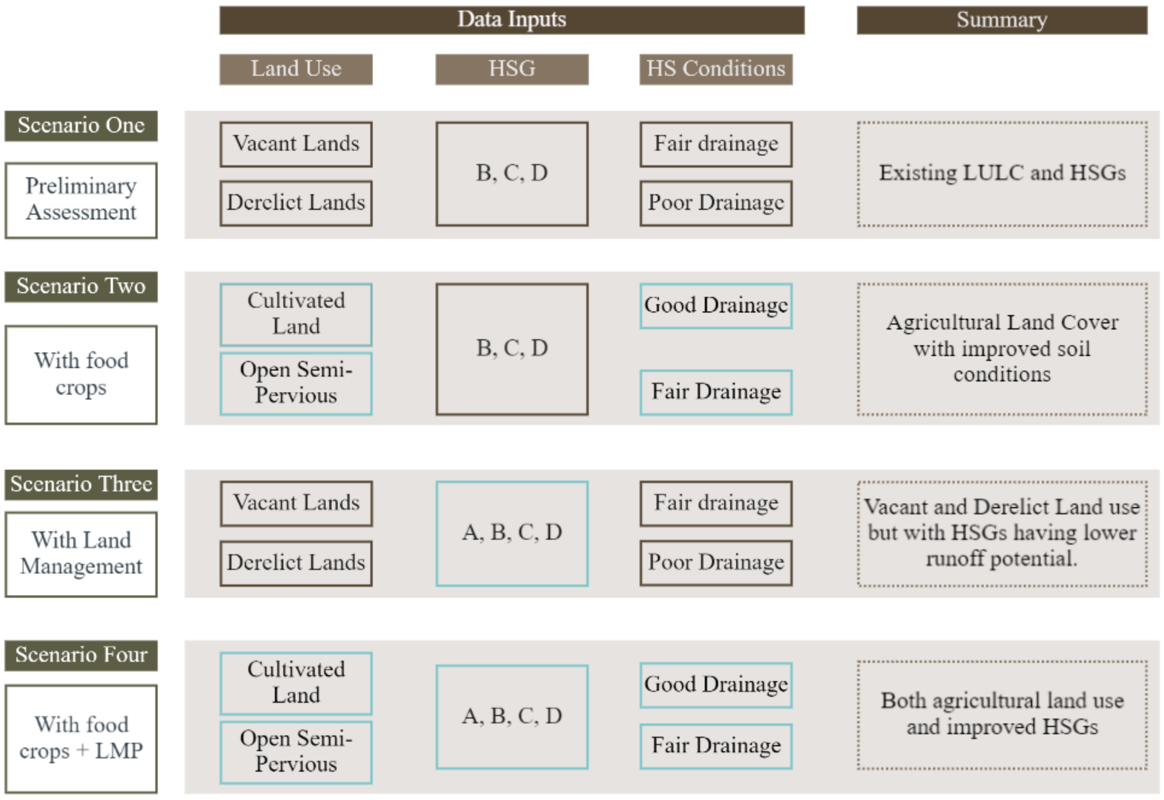
Figure 29: Improved HSGs with LMP



11.3.4 Scenario Four: A combination of LMP and Agricultural Land Cover

Finally, for the fourth scenario, the potential of UA is assessed in its entirety were both agricultural landcover and permeable soil groups from land management have been used for assessment.

Figure 30: Summary of flood assessment scenarios



	Data Inputs			Summary
	Land Use	HSG	HS Conditions	
Scenario One Preliminary Assessment	Vacant Lands Derelict Lands	B, C, D	Fair drainage Poor Drainage	Existing LULC and HSGs
Scenario Two With food crops	Cultivated Land Open Semi-Pervious	B, C, D	Good Drainage Fair Drainage	Agricultural Land Cover with improved soil conditions
Scenario Three With Land Management	Vacant Lands Derelict Lands	A, B, C, D	Fair drainage Poor Drainage	Vacant and Derelict Land use but with HSGs having lower runoff potential.
Scenario Four With food crops + LMP	Cultivated Land Open Semi-Pervious	A, B, C, D	Good Drainage Fair Drainage	Both agricultural land use and improved HSGs

11.4 CALCULATIONS

- **Total runoff produced [Q]**

Calculated from CNM for each pixel value ‘i’, representative of a unique land cover type and consequent soil characteristics, runoff quantity Q is calculated using Equation 1, where P is the ‘Depth of rainfall for the design storm of interest’ in mm, S_{max_i} the potential retention (mm), $\lambda . S_{max}$ rainfall depth needed to initiate runoff ($\lambda = 0.2$ for simplification) and S_{max} the function of CN in mm

Equation 1: Curve Number Method

$$Q_{p,i} = \left\{ \int \frac{(P - \lambda S_{max_i})^2}{P + (1 - \lambda) S_{max_i}} \; if \; P > \lambda . S_{max_i} \right\}$$

- **Runoff retention [R_i]**

The runoff retention per pixel or the fraction of total runoff (Q) retained, represented by R_i is based on Equation 2

Equation 2: Runoff Retention per pixel [R_i]

$$R_i = 1 - \frac{Q_{p,i}}{P}$$

- The runoff retention volume per pixel, represented by R_m3_i

Equation 3: Runoff Volume per pixel $\boldsymbol{Q_{m3_i}}$

$$Q_{m3_i} = Q_{p,i}.\, pixel\ .\, area.\, 10^{-3}$$

11.5 EVALUATION OF DATA

All data have been considered at the ward level. Flood Disadvantaged Index data was not ward wise, so that was converted ward wise in GIS. Thereafter, the results were normalised by standardisation for assessment.

Equation 4: Normalisation of Data

$$\boxed{x_{\text{norm}} = \frac{x - \min(x)}{\max(x) - \min(x)}}$$

12 Food Security Potential of VDLs

From literature review, it was clear that indicators common to both flood and food disadvantage were income and health aspects of indicators, affecting the four components of Food Security in Glasgow. Therefore, to evaluate the efficacy of the UA intervention to address these aspects, the production and nutritional value for each VDL is calculated at this stage.

12.1 Selection of Crops

Based on the agricultural census 2019 and (Hipkin, 1988) Rhubarb *(Rheum rhabarbarum)*, a common choice for market gardening and suitable for growing on soils around Glasgow was selected for the analysis.

Based on the priority weight evaluation of ecohydrological traits of vegetation, 'Rooting Depth' is being considered for an idealised calculation of total production and nutritional value of VDLs for each vulnerable council. Table 23 discusses its growth conditions and Table 24 discusses generic harvest estimations.

Table 23 : Growing conditions for Rhubarb

Rhubarb Suitability		**References**
Slope	Both gentle and steep slopes	(Hipkin, 1988)
Soil Depth	Deeper soils due to their extensive root systems	
Sun	Full sun	
Soil Drainage	Free Draining/ moist / well drained with high SOM content	(Atlantic Provinces Agriculture, 2022)
Soil Type	sandy loam to loam soil	
Ecohydrological Traits		**References**
Root Structure	underground portion consists of fleshy and woody rhizomes and a fibrous root system.	(Atlantic Provinces Agriculture, 2022)
Leaf Morphology		

Figure 31: Typical foliage of Rhubarb (Left) and Root Structure (Right)

12.2 PRODUCTION OF CROPS

Table 24: Production estimates of Rhubarb

Rhubarb Production		**References**
Harvest Months	Established Crops: From March - April	
Field Yields	15000 – 40000 kgs per Ha	(Atlantic Provinces Agriculture, 2022)
Plants per Hectare	17,220	
Nutritional Value per 100 gms	Calories - 21	(USDA, 2019)
LMP	Mulching from leaves (that are not consumable)	

Values tabulated in the table above/below have been used for estimating the production and corresponding nutritional values.

Equation 5: Total Yield of Crop Production

$$\boxed{\text{Total Yield (gms)} = \text{Total No. of Plants} \times \text{Land Parcel (Ha)}}$$

Equation 6: Total Nutritional Value

$$\boxed{\text{Total Calories (gms)} = \text{Calories per 100 gms} \times \text{Total Yield}}$$

Chapter 06

13 RESULTS

This section of the report summarises results from each phase directed to the three objectives set out in the beginning (See Chapter 1)

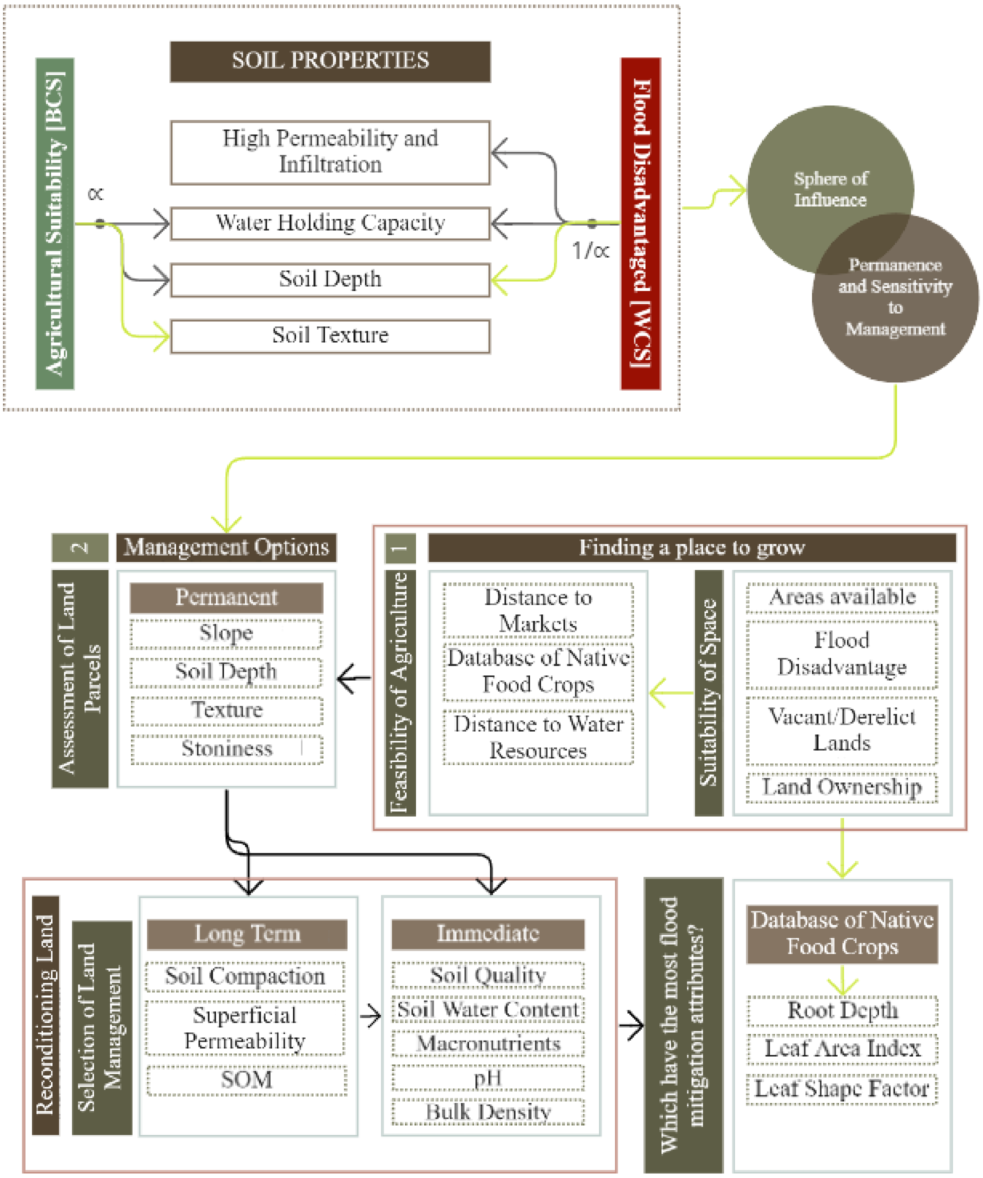
13.1 INDICATORS INFORMING THE FRAMEWORK

This section begins with a summary of the report in the form of a flowchart illustrating key stages of indicator assessment in a sequence, feeding into the larger picture of the methodology appointed for the framework development.

In the first section, indicators common to a best case scenario and worst case scenario is found to inform suitability analysis of the area of intervention. Indicators are then subjected to an assessment from the perspective of their sphere of influence answering the question, ‘ Which indicator influences the most number of indicators?’ and their sensitivity to management. The second aspect is necessary since the interventions are intended for flood prone areas, where soil permeability rates and hydrological conditions are understood to be compromised. Therefore, the indicator’s sensitivity to land management practices that comes as a result of agricultural interventions (either in preparation of land) or during the production period, is necessary.

The flowchart begins at the point of finding these locations, that are influenced by local policies, land values, etc. following which management options are reviewed before being assessed for local database of vegetation against ecohydrological traits.

Figure 32: Processes engaged in the final data for framework



13.2 Flood Retention potential [FRP]

Hydrological assessment of the study in section 11.5 are graphically presented here for the study area (See Figure 33 - Figure 35)

Figure 33: %change with Agriculture Practice and Crops

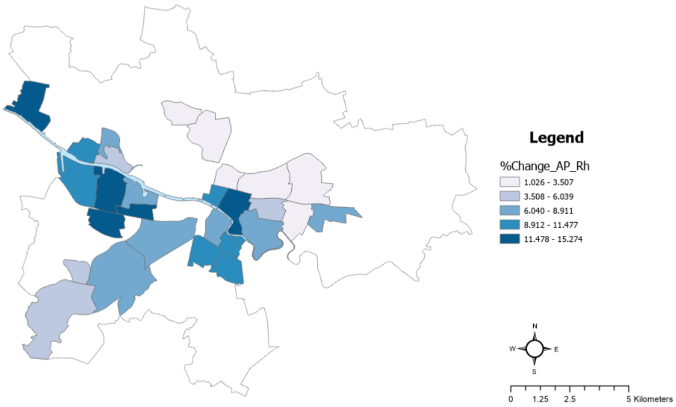


Figure 34: % Change with Land management Practice

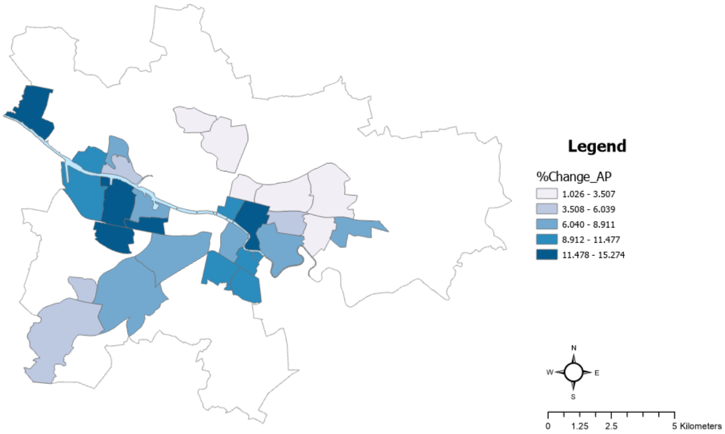
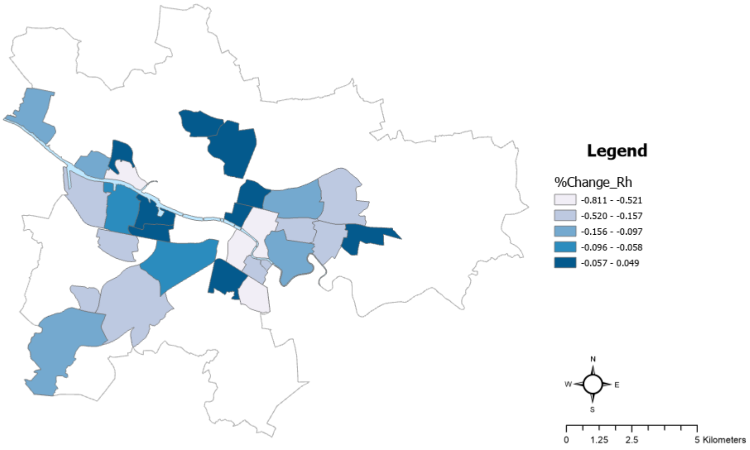


Figure 35: % Change with Crop Intervention



13.2.1 Flood Risk Service

The maps for flood risk service show ward wise the index of runoff retention values and consequent mitigation extent. 2 out of 27 wards show the highest values for the scenario Four where agricultural suitability has been the highest Figure 36 and only 1 ward with a crop intervention (See Figure 37).

Figure 36: Flood Risk Service for Land Management and Crop Intervention

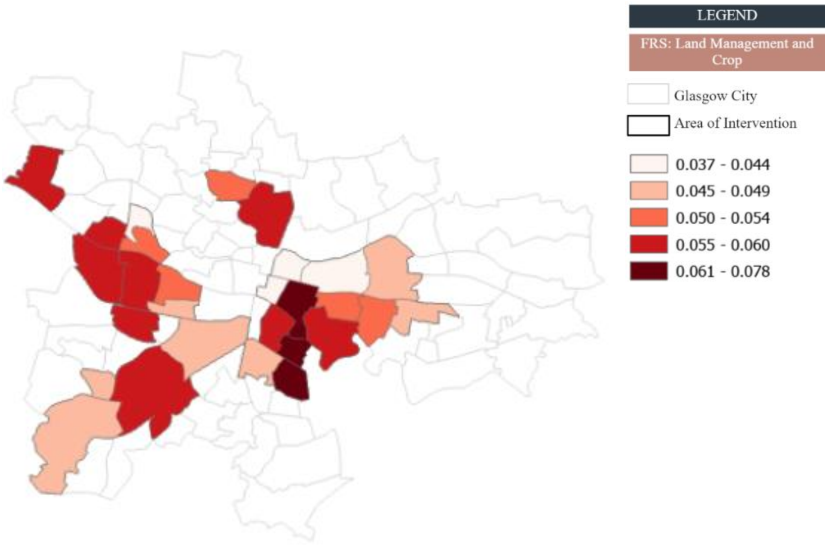


Figure 37: Flood Risk Service for Crop Intervention

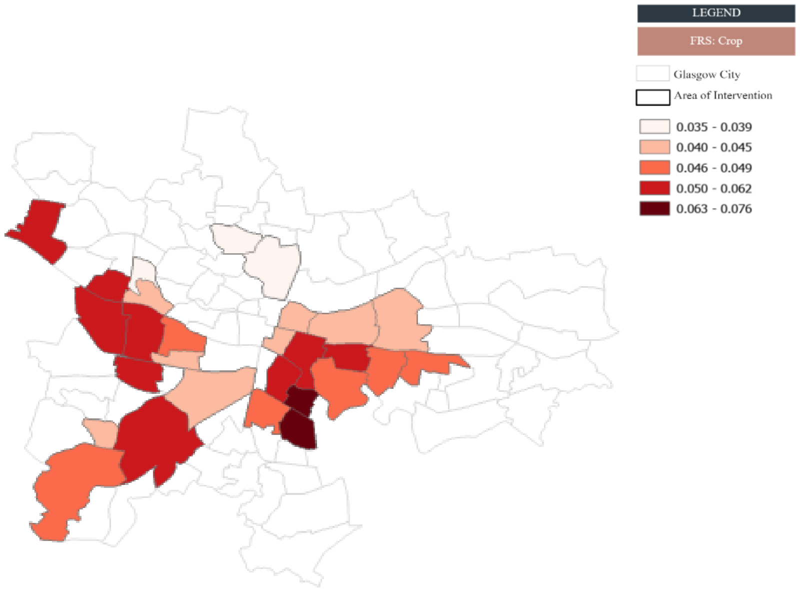
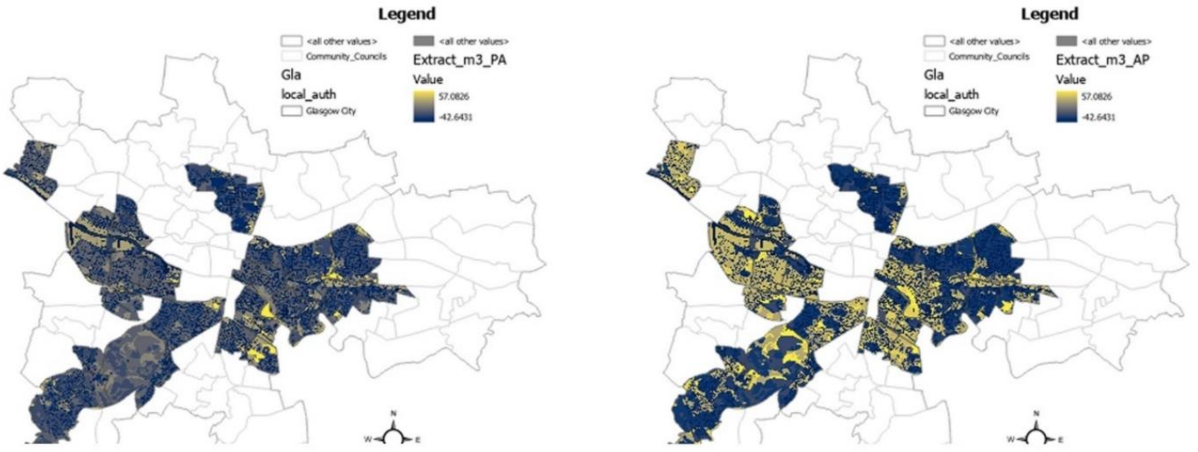
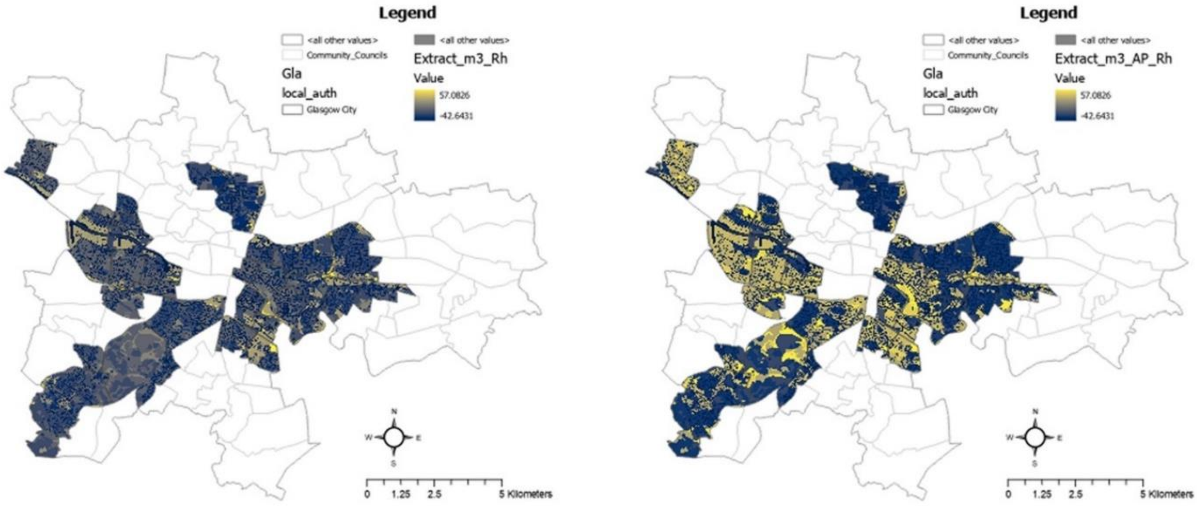


Figure 38: Quantity of Runoff retained [Rim3]



Initial Assessment

Using LMP



Using Rhubarb

Using LMP and Rhubarb

Spatial distribution of the simulated outputs for the 4 scenarios have been presented in the Figure 38. While the scenario using just crops exhibited little to none difference in the runoff retention, significant changes were seen in scenario 2 and 4. This has been represented by the increase in the area under yellow. The changes in scenarios 2 & 4 were mostly concentrated around the central part of the study area. This can be attributed to the combined effect of high VDL availability and LMP induced changes in the local hydrological conditions.

Table 25: Summary of Retention Values

	Scenarios	**Runoff Retention Index (%)** **[R_i]**	**Runoff Retention – Volume per pixel (i)** **[R_m^3_i]**	**Flood Volume (Total runoff produced in m^3)** **[Q]**
1	Pre-Intervention	1.37	3504359.71	68028912.37
2	UA land-use	**1.380**	**3523263.283**	**68010008.060**
3	UA land-use with management	1.487	3803806.795	67729464.049
4	Land Management	**1.492**	**3804725.883**	**67728546.107**

A 'Percentage Change' evaluation of the total volume of runoff produced is performed using Equation 7 to understand the extent of intervention for the scenarios, summarised in Table 26

Equation 7: % change in Flood Volume Produced

$$F_{\%} = [(F_o - F_i)/ F_o] \times 100$$

Where,

F_o = Original volume of runoff produced without intervention

F_i = Volume of water runoff produced after intervention

$F_{\%}$ = Percentage change in volume of runoff

Table 26: Summary of % Change in total volume of runoff produced

	Scenarios	***Total % Change of Q from Pre-assessment Values***
2	UA land-use	**0.55**
3	UA land-use with management	**11.71**
4	Land Management	**12.27**

Based on the results of the hydrological processing of each scenario, Land Management Practices along with Agricultural Land Use reflected the highest runoff reduction rates [Q] with marginal values for agricultural land use.

In the scenario using only Land Management Practices, the total percentage change in flood volumes is 12.27%, with Vacant Lands and Derelict Lands sharing the same hydrological functions (HSG A) contributing 5.49% and 6.77%, respectively, under the circumstances that the land has been reconditioned to the same capacity.

Similarly, for the scenario with only agricultural land use, the % change values of volume retention are significant at 11.71% reflecting effects on hydrological conditions (Section Land Management Practices) influenced by the density and canopy of vegetative areas, despite being allocated with soil groups showing higher runoff potentials values (USDA, 2004).

Within the study area, the number of lands that are vacant is only 7 compared to derelict lands 15 in number, Vacant Lands were converted to agricultural lands but not derelict lands. Six of the 28 wards in the research region do not have any VDLs, and their assessment does not take into account enhanced hydrological soil conditions. The percentage change in flood volumes for each scenario presented in Table 27, represent the ability of UA in the adjacent areas to reduce flood runoff in these wards as well.

Table 27: Summary of % Change in total volume of runoff produced in wards without VDLs

Scenario	%Change in retention volumes with LMP+UA
LMP	1.69
LMP+Agr	2.28
AGR	0.42

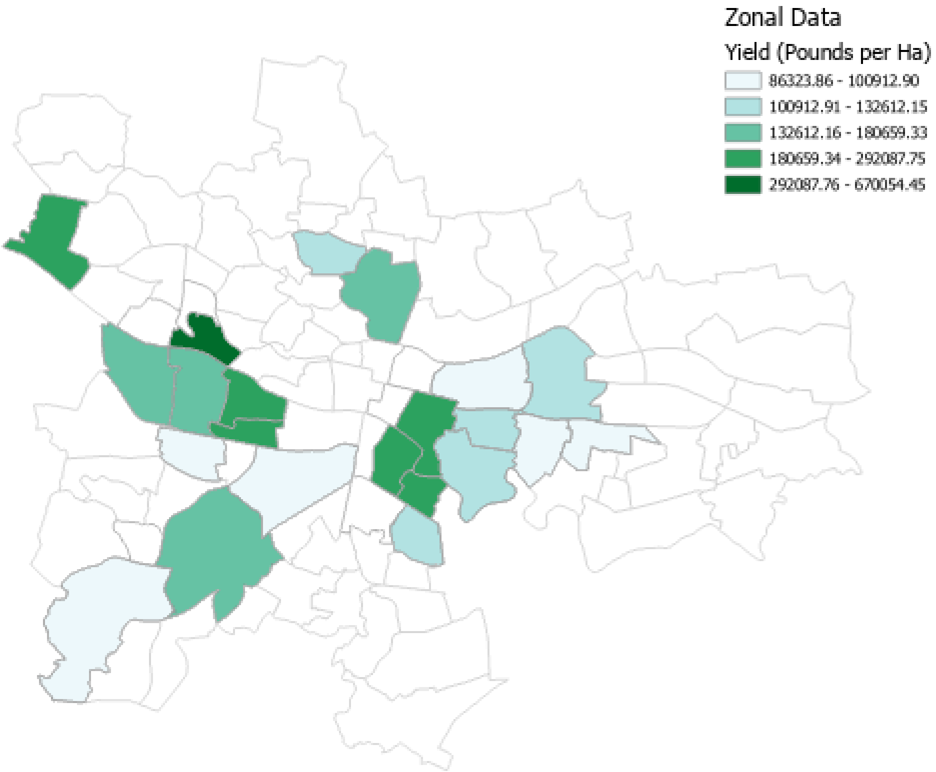
13.3 FOOD PRODUCTION POTENTIAL [FPP]

The total Yield of Rhubarb from all the VDLs in the 22 council areas was estimated to be 303931.33 Kgs based on the Table 28, whereas the nutritional value was found to be 63825.58 Kgs. 6 of the 28 councils do not have any food production potential and that aspect of reduced vulnerability is not addressed for them. A brief analysis of ward wise food production vs population shows, the largest % of households within the study area with ‘dependent children and no adults in employment’ produces only 86.32 Kgs per Ha, one of the lowest food production values. The wards producing the highest yields per Ha are mostly areas having the lowest income and health vulnerabilities.

Table 28: Ward wise analysis of social indicators of vulnerability and food production

Ward	Food production per ward (Yields per gram)	% Households with dependent children and no adults in employment	% People whose day-to-day activities are limited
Broomhill	86323.86	10.74	48.76
Govan East	1045545.49	10.24	37.05
Ibrox and Cessnock	777198.39	8.98	25.55
Thornwood	376124.38	8.82	53.36
Dennistoun	-	8.11	33.51
Gartcraig	1504798.67	7.23	35.85
Pollokshields	1117030.81	7.05	39.93
Townhead and Ladywell	-	6.94	40.20
Toryglen	768757.34	6.53	29.77
Bridgeton and Dalmarnock	-	5.98	46.15
Possilpark	384764.71	5.78	65.96
Ruchill	-	5.69	57.18
Parkhead	427087.97	5.64	33.41
Pollokshaws and Eastwood	588695.09	5.59	54.79
Shettleston	1814239.50	5.26	51.13
Oatlands	224113.90	4.38	47.43
Yoker	100912.90	3.37	50.34
Govan	357605.99	2.45	52.17
Yoker	5263362.83	2.27	52.65
Merchant City and Trongate	673642.98	1.79	17.44
Drumoyne		1.60	22.80
Barrowfield/Camlachie	1286996.56	1.12	18.99
Calton	355644.08	1.10	29.04

Figure 39: Rhubarb Production - Total Yield – (Gms per Ha)



The areas with highest production are not catering to the highest % of households inflicted with income and health vulnerabilities whereas the wards with the largest production yields are from derelict sites, since most of them fall into non-private ownership. This has potential for development but while there is space to grow, there also will be added costs of remediation, and that is why a cost benefit analysis is needed.

13.4 The Flood-Food-Potential Index [FFPI]

Therefore, for the development of the framework, key concepts relevant to the suitability of urban agriculture have been evaluated – i) Ecohydrological capacity of plants and ii) land management practices in agriculture. A review of the literature helped to identify the important themes. First, case studies and academic research were examined as a foundation for understanding how urban agriculture can reduce flood damage.

Using the conditions of retention and production values, an integrative assessment framework is developed for preliminary evaluation of suitability of UA in addressing challenges of flood and food production in a vulnerable community. The intent is to use the framework to identify areas where this intervention makes the most sense in terms of addressing flood risks and food insecurity. The detailed findings of framework elements are structured into separate categories (Land Management Practices, Plant Morphological Traits, Suitability of Space and Agriculture)

13.4.1 Summary of development:

- **For Food Production Potential [FPP]**
  - Establishing a co-relation between hydrological processes and crop traits to establish best crop trait scenarios
- **For Flood Retention Potential [FRP]**
  - Establishing a co-relation between hydrological processes and land management practices

13.4.2 Data inputs for the framework include

- For Food Production Potential
  - Area of Intervention
  - Yield per Ha for selected crop
- Flood Retention Potential
  - Hydrological Soil Conditions based on hydraulic conductivity, bulk density, on site data for extent of dereliction, surface sealing, etc.

13.4.3 How it works

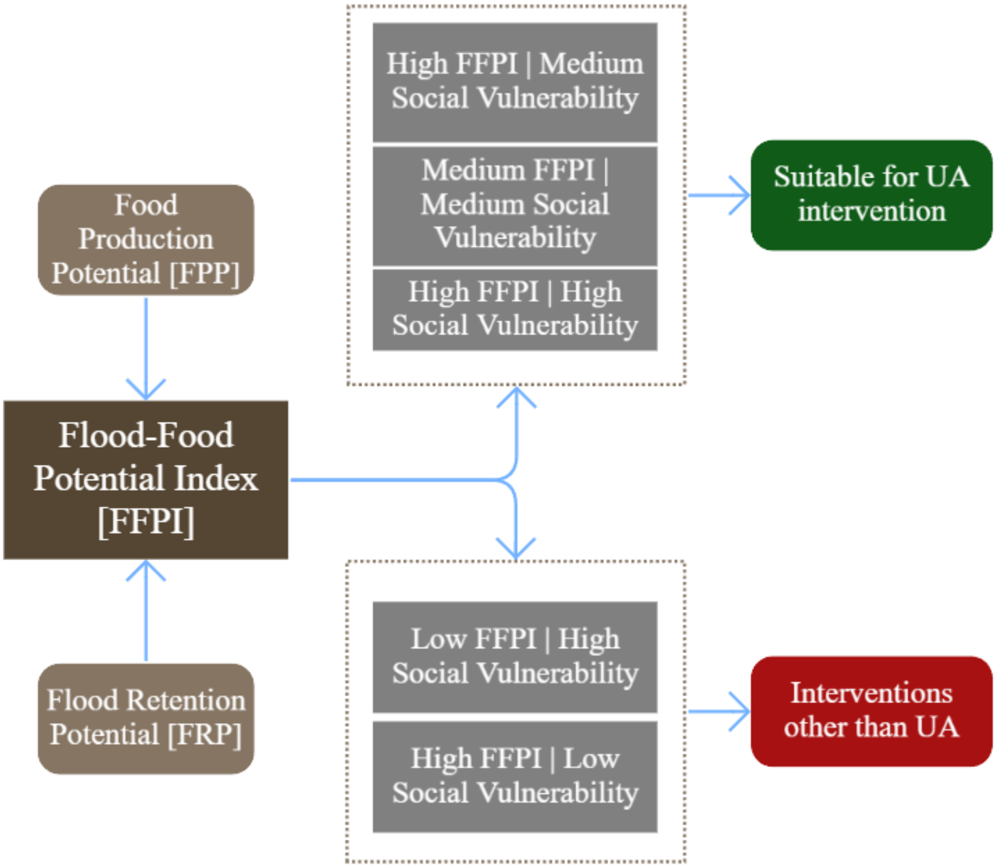
The Flood-Food Potential Index is calculated from two sets of values i) the Food Production Potential [FPP] and ii) the Flood Retention Potential [FRP] and fed into Equation 8 to get unique FFPI Values.

Equation 8: The Flood-Food Potential Index

$$\boxed{\text{FFPI} = f\,(\text{Average of Flood Retention \% Change, Food Production})}$$

The Food production values quantifying total yield per ha and flood retention potential providing values for % change in the total volume of flood retained. Based on the evaluation of land, various combinations of these sets of values can be achievers, guiding the decision for whether ward is suitable for a UA intervention or an alternative strategy.

Figure 40: FFPI Framework for UA Suitability



The framework (FFPI) developed reflects vulnerability components of each of the societal challenges of flood and food disadvantage as well as the overlap of components and that UA shows capacity to address these.

The average size of areas of intervention having the highest FFPIs were found to be 21.5 Ha, most of the lands being derelict, therefore more cost of remediation. Seven of the twenty-eight wards do not have any VDLs but are within a buffer of 500m of other significant VDLs in neighbouring wards. So, while it won’t have its ward wise production, it will partake in the benefits of %change in retention volumes.

Chapter 07

14 DISCUSSION

To adopt UA as a flood risk solution addressing more than one societal challenge, a holistic approach to its assessment is required, one that considers the interconnection of social vulnerabilities present in both high flood vulnerability and food shortage. This interconnectedness is examined in the next sections from the standpoint of UA implementation, with comments on the overall strategy and outcomes produced in the prior part. The chapter finishes by discussing the study's shortcomings as well as possible future directions.

14.1 SELECTION OF INDICATORS

The research summarised three main agricultural aspects that may contribute to hydrological processes in urban settings based on available knowledge. The aspects – i) Land Management Practices ii) Vegetation Traits and iii) Anthropogenic soils were viewed holistically via the lens of the Soil-Plant-Atmosphere Continuum, attempted to shed light on the interdependence of crops and anthropogenic soils in order to improve agricultural capacity in cities. Since the goal of this study was to develop a preliminary evaluation framework to determine whether the intervention provides maximum benefits within a community, A broad-brushed assessment was preferred over an in-depth one, and the indicator selection for the aspects was kept to a bare minimum with the goal of ease of use at a multi-stakeholder level.

Within the scope of the report, indicators influencing the effectiveness of the aforementioned aspects were viewed from two perspectives. First, its sensitivity to management and reconditioning, and second from the perspective of the sphere of influence they had on other suitability indicators. The analysis indicated that in untampered soil profiles, slopes had the largest influence dictating the formation of other soil indicators. Local anthropogenic influences, however, make these redundant by modifying the soil profile significantly, suggesting a local assessment of all available lands as a primary step for evaluation.

Vulnerability Indicators: From the discussion (See Section 2) two indicators were consistently common in Food Insecurity and/or Food Poverty and Flood Disadvantage. Income and Health while interconnected to each other also play key roles separately in shaping vulnerabilities.

14.2 FOOD SECURITY

Food Security from UA: For the assessment of Food Security, Rhubarb crop was selected due to its big root system, high Leaf Area Index values and suitability of soils in the study area. The results demonstrate production of food from both vacant and derelict lands in terms of area of production. The results are in accordance with the ability of UA's capacity to increase the quantitative access to locally produced sustainable food, thereby contributing to all aspects of Food Security - Accessibility, Availability and Utilisation, for low-income households of the global north. While UA plays a significant role in addressing the 'availability' component of food security, the results do not look at possibilities of crop diversification that can contribute to nutrition security.

Income from production: Furthermore, food production in the most vulnerable wards, imply an idealised representation of total produce in a year. Soil indicators used in the framework are indicators that are permanent in nature and not sensitive to management and change. So while, these indicators fit the production necessity of Rhubarb, the total yield per VDL determined is still dependent on numerous other factors such as the use of technology and the level of professionalism employed (Opitz *et al.*, 2016) and other soil conditions. Total yield even under idealised scenarios is not sufficient to meet the total food requirement of the entire population for each ward.

The assessment is done with the aim of consumption and not sale of production, in which case, distances to road networks and markets also have to be considered.

Income from Regeneration: According to (Setälä *et al.*, 2014), the soil usage in both urban and agricultural land use causes severe changes to the soil profile's biological, chemical, and physical components (See Chapter 6). Even if production capacities of individual plots of lands are not sufficient to meet the food requirement of entire communities, they offer urban regeneration opportunities having an 'economic multiplier affect' (Maantay, Park and West, 2017). The potential of crops in which case, prevents degradation of land post reconditioning and improvement in the long run, with some productivity benefits.

Food Quality and Safety: When considering land management, food safety is also a concern. Glasgow has seen industrialisation as well as the regular problems associated with urban soil degradation meaning there is a possibility of land contamination.

Sustainably locally produced food. Each community in the study area was able to produce a significant amount of food. While this may not be sufficient to feed the entire population in the council area, it takes of the burden to some extent.

Land Management: When assessing flood retention of the study areas, for the land management scenario, the vacant land cover type was assumed to have undergone land management akin to agricultural lands, with improved permeability. This scenario was the most effective in the amount of flood water it retained, an observation consistent with the understanding that both urban and agricultural soils have the ability to control hydrological processes when not compacted or sealed (Setälä *et al.*, 2014).

When only land management methods were considered, the total volume retained rose by 12.27%, which is consistent with findings from literature that indicates that UA absorbs 20% of precipitation and improves storage by 65% (Ebissa and Desta, 2022). Food production demands of the community besides being dependent on land suitability is also dependent on management intensities. One aspect of improving hydrological soil functions is the enhancement of soil aggregates by SOM amendments using crops residue. In the scenario that makes use of this cover type, with original HSGs as found originally in the study area, improved hydrological soil functions are not reflected. While these are effective practises, it is important to note that they are not without drawbacks, such as cover cropping potentially increases insects and pests, and so on and need to be supplemented with, crop diversification and cropping patterns, as well as a focus on land and water management in cities with agricultural zoning, are required in the face of climate change (Dubbeling and Halliday, 2019).

The results of water retention potential by UA opens the discussion for whether it makes for an efficient natural infrastructural system. Does agriculture make land management a long-term soil thing vs GI? Open green spaces used as a natural infrastructure can have issues of compaction (from people in parks) (Weil and Brady, 2015), something that is minimised in UA.

14.3 POLICY AND PLANNING IMPLICATIONS

UA is a soil-derived ecosystem and scale-dependent trade-offs present potential challenges between local and regional management

Data collection and Modelling: The simple data requirements of the InVEST software (Sharp. R *et al.*, 2015), makes it a suitable choice of suitability analysis of communities. While there are more complex models for assessing flood risk mitigation, this software's simple data requirements allow for the engagement of professionals from different backgrounds, thereby encouraging a multi-stakeholder decision making process. Furthermore, the software's multiple ecosystem service evaluation options can all use the same data format, which could facilitate the implementation of the practice (Sharp. R *et al.*, 2015).

Financing UA: Despite the fact that UA can improve food security regardless of a community's income levels (Artmann and Sartison, 2018), it does not take into account setting up costs - land reconditioning processes or infrastructure and support, which a community may be unable to afford. As a result, this intervention is suggested as a strategy for the local government in collaboration with local communities in a bottom-up approach

14.4 CONTRIBUTION OF UA TO CLIMATE RESILIENCE

Runoff Retention Values suggests a marginal improvement in the volume of water retained post intervention, and in between production periods. The results are in line with academic evidence for having the capacity to build resilience.

Soil Textures are largely permanent in an area, and they will influence the crop suitability. If these soils have high compaction (bulk density), then they are likely to have high runoff potential. But bulk density can be altered by land management practices. So, it really is the agricultural practice and not the vegetation contributing to the increased soil infiltration processes. So, adding rhubarb, protect the soil, improve conditions, prevent compaction and increase evapotranspiration. The influence of crops on water retention showed no results. Run-off generated is directly linked to the hydrological soil conditions, vegetation cover, slope and surface condition.

Influence of Crop Morphological Traits: According to the literature, there is a definitive relationship between vegetation features and the regulation of hydrological processes (See Chapter 8). However, the attributes selected for the most efficient plant morphological traits are not reflected in the hydrological assessment of agricultural land use where more generalised knowledge of density and canopy of vegetation (USDA, 2004) are used instead. The retention potential values for the scenario using agricultural land use definitely showed significant values of flood retention due to high permeability values of the land cover type. However, this does not map definitive understanding of the evapotranspiration processes for hydrological regulations.

Land Use: No independent category for UA in zoning plans but under local schemes, vacant lots in Glasgow have been allocated for green spaces. Growing food in spaces not designed for agriculture is a time consuming and probably expensive process. Towards this end, a cost benefit analysis is required. Beyond the crop suitability evaluated in the report in a city, urban agriculture is explicitly dependent on other urban conditions such as local policies, regulations, competition for land, urban markets, prices, and so on (De Zeeuw *et al.*, 2011). Local municipalities therefore need to tailor their own frameworks to evaluate the suitability of the intervention as a flood risk mitigation/ risk reduction tool. Because the effects of urban agriculture on climate change cannot be generalised, tactics and policy interventions for specific types or systems of urban agriculture should be examined (Dubbeling and Halliday, 2019), unique to Scotland.

14.5 CONCLUSIONS

As highlighted in the framework, there is interdependence between both vulnerabilities and ecosystem services necessary to reduce vulnerabilities in both the societal challenges of food and floods and thus, hypothesis stated in section 1.4 of the report is true and can be accepted. This is further substantiated through the scenario-based simulation exercises which exhibited substantial enhancements in flood retention and nutrition in the case study area.

Restructuring food systems and devalued lands: Glasgow is not suitable for agriculture. Whether VDLs are suitable for agriculture requires an in-depth understanding of the extent of dereliction, existing conditions (presence of vegetation, contamination, debris, etc.) and the consequent cost of reclamation (Broughton, 1985). Vacant and derelict lands observed was a specific area of intervention for Glasgow. For cities that do not have this option, (Dubbeling and Halliday, 2019) suggests “providing fiscal and tax incentives for land owners who lease out vacant private land to groups of urban poor willing to produce on this land”

14.6 LIMITATIONS

Overall limitations of the study involved reliance on a mix of primary and secondary data that can enable inaccuracy of results.

Assessment of Social Vulnerability: (SEPA, 2015) considers 34 indicators (Age, Health, Income, Information use, Insurance, Local knowledge, Social networks, Tenure, Mobility, Physical access, Crime, Access to services, Housing and Green space), for the development of the Social Vulnerability Assessment. Demographic parameters such as age, while an essential indicator for assessing flood disadvantage, is immutable and cannot be changed with flood risk intervention.

Land Management Practices (LMP): Effectiveness of LMPs such as BMPs depend on various other local indictors such as watershed characteristics, location and storm magnitude (Antolini *et al.*, 2020). The framework is simply a pre- assessment and thus cannot be deemed entirely sufficient in its evaluation of Urban Agricultural suitability. Furthermore, without taking into consideration adjacent ecosystems and the service trade-offs amongst them can instead cause a ‘disservice’. Poor management of UA land can result in complex impacts on urban soils.

Assessment of Flood Mitigation: The connection of impervious areas to either drainage systems or to other pervious surfaces has not been considered for the CN values nor site drainage conditions. The study also does not reflect values of evapotranspiration and does not inform the nexus of flood-food vulnerability in the study. This is necessary given Scotland’s low evapotranspiration rates.

Data Unavailability: Indicators that did not go into the development of the proposed framework are essential indicators worth looking but their incorporation was not feasible within the scope of this study owing to the unavailability of data.

Disturbed soils in urban areas despite their soil properties (texture, etc.) will have modified hydrological soil conditions and the groups assigned to them for the assessment was with the purpose of establishing a pattern of flood and food vulnerabilities. However, many assumptions had to be made for hydrological soil conditions as data for anthropogenic soils for Glasgow was largely unavailable. CNs used from ‘The National Engineering Handbook-Section 4, Hydrology (NEH-4)’ does not allow for an accurate evaluation but a more generalised one. The study also made assumptions of LULC categories for the hydrological modelling, as land cover types are unique to Scotland. Assumptions made towards this end are biased and compromised due to the extent of the researcher’s understanding of local conditions.

Scale of Intervention: Since there is no homogeneity in the concept of Urban Agriculture, there is limited data in understanding the scales of practices (Opitz *et al.*, 2016). Under an idealised representation, lands equal to or greater than 1 ha have been considered, but farming concepts such as small-plot intensive (SPIN) farming that require only 0.4 Ha and peri urban lands start from 2 Ha exist as well with a strong food production potential.

Availability of space will naturally dictate size of production, but usually in the global north, lack of category in zoning plans for agriculture makes it tough to find space to grow (Opitz *et al.*, 2016). Research in relations between scale of intervention for UA is necessary as plot sizes, proximity, and accessibility are all thought to have a direct impact on behaviour and harvest (Feola and Sahakian, 2020) contributing to the success of the intervention. Other indicators not considered but equally relevant are depth to water table, household nutrition data, etc.

14.7 RECOMMENDATIONS

Multi-stakeholder approach: The strongest benefits from floods are typically obtained by combining many different types of actions (Forbes, Ball and Mclay, 2015). Therefore, this intervention will benefit the most when based on social data, as this intervention opens avenues of skill development, livelihoods, and income from food sale. Towards which, a toolkit that informs the framework developed in the paper, will ensure its sustainability in the long run. It is also essential that the intervention is supported by legal and regulatory frameworks.

Plant Morphological Traits: The study aimed at identifying patterns in the soil-plant continuum to improve the efficiency of agriculture but within the scope of the report, only assessed flood regulation through soil characteristics with evapotranspiration benefits largely unexplored. There is an opportunity for a scientific assessment of plant traits to generalise them in terms of their traits, which not only benefits agriculture but green infrastructure in general for disaster risk strategies.

Detailed Assessment: The paper begins the process of identifying key elements using common indicators found in literature. Many indicators that were not considered are unique to individual sites, such as local drainage patterns, etc. Local runoff- rainfall data, evapotranspiration rate, and soil types can be used to calculate unique curve numbers for a more accurate assessment.

14.8 FUTURE RESEARCH

The study summarises key links in the field of agriculture that can enhance its efficiency in vulnerable urban communities. The study looked at provisional services (food) and regulatory services (Water management) to build upon the findings in Chapter 1. Literature suggests, and increase in biodiversity but also trade-offs and synergies of the UA ecosystem is not well explored (Artmann and Sartison, 2018). However, for it to be more efficient, a wider range of ecosystem services need to be researched to understand when linked with other urban ecosystems, which ecosystems will it deliver and which will it hinder such as Crop Health, Biological Hazards (Insects/diseases), etc. (Evans *et al.*, 2022)

Furthermore, while Glasgow has the provision of available land by way of vacant and derelict areas, high competition for resources whether land, or water, etc. requires further study on the resource management aspect of the intervention (Graefe, Schlecht and Buerkert, 2019). While suitable, land reconditioning practices based on the extent of dereliction as discussed in Section 14, suggests the need for a cost-benefit analysis, with inclusion of other aspects such as food production, labour, initial cost of investment to set up infrastructure.

This study is a step towards assessing the potential agriculture can have as a FMM and such requires an interdisciplinary research approach in a social – ecological framework

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16 APPENDIX A

List of Abbreviations

CCRA – Climate Change Risk Assessment

DRR – Disaster Risk Reduction

ES – Ecosystem Services

FFP – Flood Food Potential

FFPI – Flood Food Production Index

FMM – Flood Management Measures

FRM – Flood Risk Management

FRR – Flood Risk Reduction

FF – Fluvial Flooding

GCC – Glasgow City Council

GI – Green Infrastructure

HSG – Hydrological Soil Group

LMP – Land Management Practices

LULC – Land Use Land Cover

NFM – Natural Flood Management

NbS – Nature-based Solutions

OSS – Open Space Strategy

PAN – Planning Advice Note

PF – Pluvial Flooding

SEPA - Scottish Environment Protection Agency

SIMD – Scottish Index of Multiple Deprivation

UA – Urban Agriculture

VDL – Vacant and Derelict Lands

17 APPENDIX B

Table 29: Summary of Ecosystem Services (ES) provided by Urban Agriculture (UA)

	ES	**Aim**	**Mechanism**	**Ecosystem Dis-service**	**Reference**
Environmental	Regulating Services	Water Regulation and Erosion prevention and Soil Regeneration	Increased water storage, interception, infiltration, retention and transpiration Reduced stormwater runoff Groundwater replenishment Decreased erosion and topsoil removal Improved water quality		(Setälä *et al.*, 2014; Doherty, 2015; Dubbeling and Halliday, 2019; Sanyé-Mengual *et al.*, 2020; Evans *et al.*, 2022)
		Water Purification	Improved surface water quality through enhanced infiltration and retention		(Evans et al., 2022)
		Air Quality Regulation | Pollination, Carbon Sequestration and Storage, Disease Regulation, Noise Management, Biological Control	a wider base of plant and animal genetic diversity | more species of indigenous vegetables than in rural areas or smaller towns due to the diverse tastes of its residents.	Agricultural air pollution contributes to climate change in the form of greenhouse gas emissions and aerosols	(Aerts, Dewaelheyns and Achten, 2016; Evans et al., 2022)
		Human Health	By retaining pollutants		(Setälä et al., 2014)
	Supporting	Soil Regeneration			(Doherty, 2015)
	General	Resilience	By – Reduced vulnerabilities | increase food production resilience to extreme weather		
		Climate Mitigation	Capturing CO2 + dust Ecological Footprint: Food Miles and energy ;GHG emissions through climate compatible city development from less energy use in transport, cooling, storage, processing and packaging.		
		Urban Waste (Water and organic waste)	Reused and Reduced waste in landfills Reduced fertilizer use and energy consumption Reduced methane emissions Decentralised reuse of grey wastewater and organic waste à reduced competition for freshwater between sectors (agricultural, industrial, and domestic)		
		Urban Pollution + Temperatures	Shade + enhanced evapotranspiration more cooling + less smog		(Opitz et al., 2016)
Economic Development		Livelihood and Employment	Individual turnover and production levels low in many cases, but high no. of urban producers can make relevant contribution to the urban economy [DRR]: Diverse income sources à risk management + adaptation strategies		
	Provisioning	Influence on consumption wastage	Vested interest in production of a community reduces wastage, higher awareness of healthy food	Limited studies	
		Food Nutrition Security [Provisioning Services]	Diversification of food sources à resilience against rural flooding Reduced	Availability of l its suitability, l lease, zoning	Gulyas Edmondson, 2021)

		vulnerability of producers non-producers increased coping capacities against seasonality + disturbances in food supply + loss of income, etc.	laws, high costs of setting up	
		Reduced family food budget		
	Recreation Mental Physical Health/ Improved quality of life, Aesthetic Appreciation Inspiration for Culture, Art, Design, Spiritual Experience Sense of Place.	Recreational opportunities à increased participation for community development | a “driver of cultural aesthetics”+ “ethno-cultural identity” (Kingsley et al., 2021) Especially for elderly youth Sustainability of GI due to participation?		(Kingsley *et al.*, 2021; Evans *et al.*, 2022)
	Community Engagement for Sustainability of Projects	Communities to learn of their own ecological capability à health sustainable lifestyle		
	Skill development	Horticultural skills qualifications to ensure occupation, training career opportunities for locals.		

18 APPENDIX C

Table 30: Appendix: Challenges of implementation of UA

Constraint	Description	References
Availability of L	NbS in general requires large spaces such as floodplains for flood control; l ownerships opportunity costs (?) can also pose a threat	(UNDRR, 2021)
Access to safe irrigation of water	no clear consensus on whether it is safe or advisable to use stormwater on food gardens	(The Freshwater Society, 2013)
Access to credit [Financial Mechanisms]	For vulnerable farmers willing to invest in hazard resistant agricultural practices with high upfront costs.	(De Zeeuw *et al.*, 2011; FAO, 2018)
Access to Capital		
Soil	Urban soils have mixed soil profiles with contaminants, compaction, etc. due to human interference	(The Freshwater Society, 2013)
High rates of soil erosion	increase in the number size of urban farm sites could drive an increase in erosion from urban lots as it is in production agriculture	
Assessment of Benefits	multiple impacts of hydrology + nutrient cycling + soil fertility + other processes → BMPs	(Antolini et al., 2020).
Waste management	possible health risks related to the use of compost (accumulation of heavy metals in lettuce carrots)	

19 APPENDIX D

Table 31: Ward wise assessment of food production

Council Areas	Site Type	Food Production		
		F_Total no. of Plants	F_Total Yield	F_Total Yield(gms)
Thornwood	Vacant L	134010.89	150713.83	68362586.51
Bridgeton Dalmarnock	Derelict	22265.28	670054.45	303931339.7
Townhead Ladywell		0.00	292087.75	132488666.8
Govan East	Derelict	55979.86	279899.31	126960087
Craigton	Vacant L	20182.58	278899.42	126506548
Crosshill Govanhill		0.00	227326.52	103113492.8
Whiteinch		0.00	219973.23	99778097.49
Shettleston	Derelict	17264.77	219910.41	99749604.08
Pollokshields	Derelict	17626.90	180659.33	81945624.55
Yoker	Derelict	45465.30	141974.38	64398443.84
Ibrox Cessnock	Derelict	55779.89	139512.50	63281753.34
Ruchill	Derelict	22359.31	132612.15	60151809.51
Hutchesontown	Derelict	58417.55	124613.05	56523481.03
Levern District	Vacant L	19961.23	111796.54	50710018.44
Pollokshaws Eastwood	Vacant L	36131.86	111326.41	50496768.65
Merchant City Trongate		0.00	108854.76	49375647.25
Pollok		0.00	100912.90	45773282.06
Barrowfield/Camlachie	Vacant L	26522.43	99828.65	45281474.74
Dennistoun	Vacant L	19965.73	99806.16	45271276.7
Toryglen	Vacant L	21770.95	94339.32	42791562.65
Broomhill		0.00	88134.49	39977099.81
Calton	Derelict	43982.08	86323.86	39155812.31
Oatls	Derelict	43994.65	0.00	0
Possilpark	Derelict	30142.77	0.00	0
Drumoyne	Derelict	28394.88	0.00	0
Govan	Derelict	27902.50	0.00	0
Gartcraig	Derelict	24922.61	0.00	0

Parkhead	Derelict	18867.86	0.00	0

20 APPENDIX E

Table 32: FFPI Values for study area

FFPI Scores			Flood Disadvantage
Flood%Change_Normalised	*Production_Normalised*	*FFPI*	Relatively High
1.000	0.225	0.612	
0.076	1.000	0.538	Acute
0.435	0.436	0.435	Relatively High
0.182	0.418	0.300	
0.052	0.416	0.234	Relatively High
0.024	0.339	0.182	
0.045	0.328	0.187	
0.285	0.328	0.307	
0.014	0.270	0.142	Relatively High
0.031	0.212	0.121	Relatively High
0.000	0.208	0.104	
0.082	0.198	0.140	Relatively High
0.061	0.186	0.123	
0.042	0.167	0.105	Acute
0.070	0.166	0.118	
0.104	0.162	0.133	Average
0.173	0.151	0.162	Relatively High
0.132	0.149	0.140	Relatively High
0.735	0.149	0.442	Relatively High
0.108	0.141	0.125	Relatively High
0.068	0.132	0.100	Relatively High
0.115	0.129	0.122	
0.062	0.000	0.031	
0.160	0.000	0.080	Relatively High
0.096	0.000	0.048	
0.074	0.000	0.037	Relatively High
0.179	0.000	0.089	Average
0.049	0.000	0.025	

21 APPENDIX F

Table 33: Scenario wise Flood Retention Potential Values

Pre- Assessment			Using L Management				Using L Management Agriculture				Using Agriculture (Rhubarb)			
rnf_rt_idx	rnf_rt_m3	flood_vol	rnf_rt_idx	rnf_rt_m3	flood_vol	*%Change_AP*	rnf_rt_idx	rnf_rt_m3	flood_vol	*%Change_AP_Rh*	rnf_rt_idx	rnf_rt_m3	flood_vol	*%Change_Rh*
0.04	131822.68	3498875.88	0.05	190142.16	3440556.38	1.67	0.06	208833.48	3421865.00	2.20	0.04	142573.60	3488124.75	0.31
0.04	184865.89	3974878.53	0.05	192523.21	3967221.25	0.19	0.05	194493.87	3965250.47	0.24	0.04	185892.35	3973851.88	0.03
0.04	77405.05	1691836.13	0.05	85799.30	1683441.76	0.50	0.05	94370.11	1674870.98	1.00	0.05	82870.05	1686371.11	0.32
0.05	156028.35	2818604.10	0.06	164539.84	2810092.74	0.30	0.06	169187.96	2805444.49	0.47	0.05	159435.85	2815196.54	0.12
0.06	200705.20	3359152.58	0.06	206559.39	3353298.41	0.17	0.06	207154.64	3352703.16	0.19	0.06	201199.67	3358658.08	0.01
0.04	32226.20	878017.63	0.04	33391.25	876852.59	0.13	0.04	33391.25	876852.59	0.13	0.04	32226.20	878017.63	0.00
0.05	87405.20	1785836.40	0.05	90075.36	1783166.15	0.15	0.05	90557.94	1782683.65	0.18	0.05	87707.65	1785533.90	0.02
0.05	160217.53	3124635.13	0.06	190680.62	3094172.24	0.97	0.06	181618.14	3103234.36	0.68	0.05	159402.17	3125450.29	-0.03
0.04	50953.51	1186638.38	0.04	52262.79	1185329.13	0.11	0.04	52262.79	1185329.13	0.11	0.04	50953.51	1186638.38	0.00
0.06	85693.16	1379356.82	0.06	87702.77	1377347.17	0.15	0.06	87702.77	1377347.17	0.15	0.06	85693.16	1379356.82	0.00
0.04	35490.38	788428.97	0.04	36128.55	787790.81	0.08	0.04	36128.55	787790.81	0.08	0.04	35490.38	788428.97	0.00
0.04	137814.62	3192666.63	0.04	149772.59	3180708.64	0.37	0.04	145946.04	3184535.11	0.25	0.04	137282.61	3193198.52	-0.02
0.05	86349.98	1780725.56	0.05	90093.64	1776982.00	0.21	0.05	90093.64	1776982.00	0.21	0.05	86349.98	1780725.56	0.00
0.05	85280.32	1529398.75	0.05	88645.23	1526034.00	0.22	0.05	87895.10	1526784.13	0.17	0.05	85548.66	1529130.50	0.02

0.05	68297.29	1305906.56	0.07	89920.66	1284283.09	1.66	0.05	71303.31	1302900.47	0.23	0.04	61475.17	1312728.56	-0.52
0.05	101619.00	2032103.28	0.05	108604.25	2025117.97	0.34	0.05	107727.82	2025994.44	0.30	0.05	101870.38	2031851.86	0.01
0.04	45033.53	1024294.05	0.04	48063.19	1021264.33	0.30	0.05	49615.47	1019712.06	0.45	0.04	45772.51	1023555.06	0.07
0.05	353918.21	7437346.61	0.05	381304.32	7409960.33	0.37	0.05	380721.87	7410542.83	0.36	0.05	354718.17	7436547.11	0.01
0.04	60183.82	1602864.31	0.05	77763.62	1585284.63	1.10	0.05	86469.35	1576578.81	1.64	0.04	63272.54	1599775.63	0.19
0.04	49255.37	1069400.48	0.05	52575.90	1066079.86	0.31	0.05	52575.90	1066079.86	0.31	0.04	49255.37	1069400.48	0.00
0.06	434618.27	7262100.88	0.06	454050.75	7242668.38	0.27	0.06	450927.52	7245791.38	0.22	0.06	434250.08	7262469.13	-0.01
0.06	132606.20	2001253.07	0.07	142982.79	1990876.55	0.52	0.07	139089.51	1994769.88	0.32	0.06	132101.24	2001758.01	-0.03
0.04	209584.28	4631027.61	0.05	220549.74	4620062.13	0.24	0.05	219379.47	4621232.32	0.21	0.04	209574.65	4631036.96	0.00
0.05	85573.31	1527050.50	0.06	100792.92	1511830.88	1.00	0.06	91988.77	1520635.00	0.42	0.05	83434.51	1529189.25	-0.14
0.07	68293.91	969655.37	0.07	69804.33	968145.00	0.16	0.07	71052.78	966896.50	0.28	0.07	69157.98	968791.31	0.09
0.08	122125.13	1481318.03	0.08	126388.58	1477054.45	0.29	0.08	125651.44	1477791.70	0.24	0.08	122026.79	1481416.41	-0.01
0.05	160478.89	2908562.50	0.06	169781.02	2899260.50	0.32	0.06	173840.19	2895201.00	0.46	0.05	163213.63	2905827.75	0.09
0.05	100514.42	1786977.63	0.06	103827.13	1783664.75	0.19	0.06	103827.13	1783664.75	0.19	0.05	100514.42	1786977.63	0.00
1.37	3504359.71	68028912.37	1.49	3804725.88	67728546.11	12.27	1.49	3803806.80	67729464.05	11.71	1.38	3523263.28	68010008.06	0.55