Reorienting SUDS: An Integrated approach to Urban Regeneration and Flood Mitigation in Glasgow

Saloni Paudel

A thesis submitted for the Joint programme of

Master in Urban Climate & Sustainability

September 2022

Reorienting SUDS: An Integrated approach to Urban Regeneration and Flood Mitigation in Glasgow

Submitted by

Saloni Paudel

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

Student ID: S2038283

School of Engineering and Built Environment, Glasgow Caledonian University, UK;

LAB University of Applied Sciences, Finland;

University of Huelva, Spain

Supervisors: Prof Mickovski Slobodan & Prof. Jose José Enrique García Ramos

September 2022

DECLARATION

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

Saloni Paudel

September 2022

ABSTRACT

Existing post-industrial cities frequently face a conundrum between urban renewal, addressing the demands for economic resilience and community well-being on the one hand, and coping with the unpredictability intrinsic with climate change-related risks on the other. Glasgow has many derelict lands that need redevelopment and a long history of urban flooding. When water flows into a city faster than it can be emitted or absorbed by the soil, it overwhelms the drainage capacity. This thesis investigates the implications of an integrated approach to strategic urban planning based on the amalgamation of Sustainable drainage systems for urban regeneration and flooding for meeting polycentric needs of today.

First, through spatial analysis, sites most suitable for using SUDS for regeneration and flood mitigation are found, which was 3.17 % of the total area of Glasgow. Dalmarnock, which was one of the most suitable sites, is identified as a case study area and a microanalysis is performed. The rainfall of 30 years (1990-2020) is analysed with climate change allowance of 40%. Next, hydrological analysis in ArcGIS Pro to find the areas of highest flow accumulation. It was found that the rainfall will increase by at least 31% in the next 30 years, and Dalmarnock lacks the drainage capacity to incorporate that amount of change. So, a cost-benefit analysis was used the benefit transfer to compare incorporating SUDS and traditional grey drainage system. The kind of SUDS component to use for CBA was chosen based on SWOT analysis and consideration of the geo-morphology of the area. The result inclined with retrofitting SUDS as decentralized SUDS provided not only drainage benefits, but benefits related to community, economy, and environment in general. Moreover, expert interviews were conducted to understand the contemporary situation of SUDS and their opinion about its integration with urban regeneration in Glasgow. The result that there are technological means to achieve it. Glasgow is already at the forefront of implementing SUDS, compared to other Scottish cities. However, in contrast, it is not as extensively being implemented as it should be, engendering a contradiction in planning and practice, the main reasons being Lack of funding, Lack of public participation, Lack of ownership & commitment, to name a few, especially in low-income areas. As a silver lining, they seemed quite excited about the prospects of integration of SUDS with regeneration and suggested if we can show its combined economic, social, and environment benefits, the chances of funding will increase exponentially. Furthermore, this thesis suggests that the urban sectoral policies incorporate this idea of using SUDS for urban regeneration to change the tunnel vision of drainage into an unorthodox, more holistic planning to increase city resilience, especially in the income-deprived areas in the face of future uncertainties.

ACKNOWLEDGEMENT

As I come to end of these two years of MUrCS journey, I would like to express my gratitude to my supervisors Professor Mickovsi Slobodan and Professor José Enrique García Ramos for lending their time and input to this thesis.

Thank you, Professor Rohinton and Professor José Duenas, for letting me in in the MUrCS family and giving me an opportunity to have the experience of a lifetime.

Thank you mummy and thank you baba for always being patient with me and supporting me in every aspect. Thank you dii for always being a pillar of strength in my life.

Words cannot express my gratitude to my friends I made along this journey. Thank you, Abhijith, for your love and your constructive feedbacks, and bearing with me when the time got too stressful. My friend Samson, for being a GIS wizard and guiding me when I needed help. All my classmates, who I have learned so much from, professionally and personally over these two years.

Lastly, thank you with all my heart to the entire MUrCS family in Finland, UK and Huelva for devising this amazing program and my colleagues for tirelessly working towards trying to save the environment and making the cities and the world a better place to live in.

" I get by, with a little help, from my friends"

Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

1.INTRODUCTION

1.1. Background

Cities have become separate entities due to their unique biophysical, thermodynamic, and morphological characteristics. The permeable surface on natural land is substituted by impermeable surfaces such as pavements and roofs (Ercolani et al., 2018; McGrane, 2016), expanding regional impervious surface area, reducing hydrologic response time and eventually, increasing flood risk (Feng et al., 2021). This phenomenon is Urban Flooding. The matter remains troublesome as much of the current literature on climate change and cities focuses on mitigation rather than adaptation. (Bulkeley, 2013) has affirmed that, even as the effects of climate change are already discerned, international and national policy-making communities remain more inclined towards mitigating these effects than adapting to them, which had formed the focus of the international climate change agreement in Paris in 2015.

The transformation from an Agrarian world into a production machine brought a tremendous lifestyle change. After the industrial revolution, a drastic change in the world's economy ensued. Capitalism and neo-liberal markets prioritize the profit motive and are the dynamic force driving the system. An unjust social relationship is based on an asymmetry of power or unequal value exchange between workers and their employers, which leads to labour (GCC, 2018)exploitation and social inequality (Young, 2011). Widened income gaps, growing inter-city disparities, suburbs that have been re-sorted into a wide array based on class and race or ethnicity, and many central cities which have assumed renewed importance within metropolitan areas are some of the features of contemporary cities (Nijman&Wei, 2020). Despite this, the number living in urban centres has grown more than fourfold over the last 60 years; Today, the proportion of urban dwellers reaches 56.2%, compared to less than 15% in 1900 and 34% in 1960(Satterthwaite, 2021). The economy has shaped the environment and energy system, and the critical aspect of economy is, unfortunately, environmental destruction. People wanted modernization, and nothing says more modern than living in big cities. There is a rise in inequality in cities worldwide, and some geographical regions will experience harsher climate change consequences than others. The grim 2022 Pakistan floods are an example of this where one-third of the country is now submerged below water (Rannard, 2022). With more than half of the population dwelling in the cities, it is becoming imperative to design them in a way that the equilibrium between humans, natural ecosystems and socio-economy is uncompromised.

In the 2030 agenda for sustainable development by United Nations, SDG 11 advocates making cities and human settlements safe, inclusive, sustainable, and resilient. This thesis will look into two of the major issues in cities, urban flooding and urban regeneration; through spatial and temporal lens, a case study and interviews, using site specific physical and historic factors, to derive a common solution; Sustainable Urban Drainage Systems (SUDS). 61% of population in Glasgow live in 500m vicinity of vacant sites (GCC, 2018). Vacant lands are given main priority in process of site selection for transforming these barren areas into a physically attractive, environmentally safe, and socially sustainable lands.

1.2 Rationale

The city of Glasgow, the host of COP 26 has gone through substantial changes in history, stemming from its industrial background. Like many of the European cities after WW2, it has seen immense Urban decline. The recent decades have brought plethora of positive changes in the city; but there is still a wide consensus about its existing obstacles. Two of the major concerns are urban flooding and urban regeneration. As the effects of climate change intensifies, the consequences of such urban problems are being more severe and imminent, risking the welfare of urban dwellers, especially in the areas of highest social deprivation. Urbanized areas of the world are in a dire need of a more radical vision that can effectively reduce the effects of climate change. One of the emerging ideas is to see urban regeneration and flooding as different sides of the same coin, as two mutually inclusive challenges that can be dealt with one single solution. The solution being the establishment of a different paradigm through the transformation of the hard infrastructures in the city into more natural landscape for the reduction in the ecological vulnerability. Sustainable urban drainage systems (SUDS) are one of the most widely accepted Jargons for achieving the sustainability goals in the modern times.

1.3 Objectives

The overall objective of this thesis is to explore the surface water flood risk and urban regeneration to find their complementarity. Moreover, this framework can then be applied to other parts of the world with similar problems.

- To review and scrutinize the history of practice of SUDS and regeneration in Glasgow.
- To analyse the case of integrating SUDS with regeneration in Glasgow and develop insights
- To explore the commonality between urban regeneration and flooding.
- To advocate for a more equitable urban environment through wider SUDS implementation

1.4 Research Gaps

The following are the research gaps that were identified from the literature review.

1. There is not much existing literature about the benefits of integrating SUDS for Urban regeneration.
2. There is a lack of record keeping and monitoring of SUDS in Scotland and the organizations that monitors, do so on an irregular and expedient way.
3. How responsibilities of urban planning are considered and allocated raises a number of social justice issues that must be addressed at the intersection of FRM and urban regeneration.

1.5 Thesis structure

This thesis is divided into five parts. First chapter is Introduction, followed by Literature review, Analysis, Discussion and Conclusion. The case study is incorporated in literature review to provide a comprehensive, multi-faceted understanding of Dalmarnock related to its history and contemporary situation.

Chapter 2

2.LITERATURE REVIEW

2.1 Introduction to Regeneration

For creating urban environments that can eliminate their negative impacts for achieving sustainability on a global level, while supporting human wellbeing in every aspect; there is an urgency to better understand how characteristics of the environment form people's everyday experiences. In an urban space, as the environment changes, so do the affordances of a neighbourhood, both in terms of what the area offers physically, by way of amenities, and in terms of scope for social interaction (Gibson, 1979). Office of Disasater Preparedness and Management, ODPM (2004) defines regeneration as a ‘holistic process of reversing economic, social and physical decay in areas where it has reached a stage when market forces alone will not suffice’. Anderson asserted urban decay is usually connected with deprived areas, is a characteristic of working-class communes, exhibiting their low earning power and their vulnerability to the higher unemployment rates corelated with changes in the structure of the country's economy. The dilapidated buildings and their surrounding area are targeted for commercial signage and vandalism unless exposed to a new group of people or economic restructuring (Andersen, 2003). The redevelopment of dilapidated, run-down, or atrophied parts of urban areas is imperative and can bring a new life and economic vitality to maintain a market position in urban environment.

“Regeneration can help us make the best of our assets and our people. It can help areas adapt to new roles and improve the distribution of wealth and opportunity. It can restore social justice and reduce community tensions. And as the country adapts to a smaller state, regeneration can play a vital role for communities, by fostering a sense of solidarity and hope." (Ministerial statement at the National Regeneration Summit, 14 July 2010).

2.2 Changing hydrology and its effects

Three out of four global workforce depend on water either heavily or moderately (WWAP 2016), and water has an intimate relationship with all biotic beings. Climate change is anticipated to have a serious influence on the precipitation patterns and hydrological cycle resulting changes in freshwater resources (Tsanis et al., 2011). Human-induced increases in greenhouse gases released have contributed to the observed intensification of heavy precipitation and are projected to reinforce the path to critical flooding situations in the future (Min et al., 2011). Effects of climate change is already prominent today with parts of the world getting untimely rainfall and severe cases of flooding. The impact of climate change increases flooding vulnerability in many ways. Fluvial, surface, and groundwater flooding risks are anticipated to increase due to sea level rise, storm surges, and increased frequency of extreme precipitation events. These flooding events will have an impact on ecosystems, infrastructure, agricultural productivity, and livelihoods. (EEA, 2008).

When the precipitation distribution pattern is changed, the infrastructures designed for counteracting the flooding become superfluous; Hence, the risk for communities concerning flooding, property damage, and human safety escalates (Moore et al., 2016). While the tangible devastation to properties is usually obvious following a flood event, the intangible things such as its psychological impacts on people can be more obscure (Foudi et al., 2017). The pursuit of sustainability in urban water systems requires finding solutions that are valid now and are also able to accommodate future changes such as climate change or urban development, which is only possible through study and implementation of diverse adaptation measures(Lin et al., 2021).

There are several approaches to reach hydrological sustainability used around the world. Several standards and building codes exist now that require or encourage stormwater management, including California's Green Building Code (CALGreen), the US Green Building Council (USGBC) green building certification program LEED (Leadership for Energy and Environmental Design), and the International Green Construction Code (IgCC), to name a few (Mehdizadeh & Fischer, 2012). But, despite of these guidelines, handling of stormwater runoff seems rather ineffective.

2.3 Learning from the past

2.3.1 Surface water Management

Not until a decade ago, the international literature on flooding had tended only to focus on hard engineering as a flood defence measure to reduce the probability of flooding. Interestingly, one of the crises we face today is how a legacy of this kind of engineering intervention that sought only to constrain and channel runoff has failed to subsist at times of intense precipitation (Lennon et al., 2014). Drainage systems were designed to ensure rapid runoff discharge into adjacent waterways.

Thames river pollution in London is a shining example of the city's expanding population and rapid economic development from the beginning of the Industrial Revolution to the twentieth century. The river Thames's water quality and ecology were severely harmed as residents' human waste was dumped directly into the river. This caused regular outbreaks of cholera and resulted in the infamous “The Great Stink” of 1858, during which the smell from the river even forced the Parliament to close (Hillier & Bell, 2010). Similarly, the river Clyde in Glasgow, Scotland, has been infamous for a long time because of its constituent pollutants. It was found that under lower intensity human activities, beyond the Glasgow urban area, the concentrations of dissolved chemicals were low while the water flowing in urbanized areas such as the city center had high traces of chromium and lead particles. Other pollutants, making it one of the most polluted rivers in the UK (Bearcock et al., 2017). Surface water flooding is defined by the Department of Environment, Food, and Rural Affairs (DEFRA) in the context of urban catchments as flooding from sewers, drains, small watercourses, and ditches that occurs during heavy precipitation in urban areas and includes overflows from sewers and watercourses due to inadequacy or raised water levels downstream. Moreover, it also comprises spring flow and groundwater infiltration into urban drainage systems. It is insufficient to conceptualize runoff only as an "infiltration surplus" because of the hidden deeper flow routes into the streambed; even if a region does not appear to produce local surface runoff, it still influences storm flow in the downstream stream network. (DEFRA, 2010)

2.3.2 Regeneration Schemes in Glasgow

Following WWII, Glasgow's population was bursting at the seams with people looking for work. The situation was concerning for the government because Glasgow suffered from massive physical, social, and economic decay, particularly in the inner city, where the ruins of long-gone industries remained. As a result, Glasgow could not make the consumer leap into the next stage of urban industrial growth" and eventually entered a period of recession in which all of the factors that had successfully combined in the growth phase were reversed (Checkland, 1976). The Scottish government, inclusive of private and public sectors, devised plans and policies to address the situation's needs. Because of the physical decay of the housing stock, which consisted primarily of substandard tenements (Alan, 1997), a full-scale housing crisis had developed, and the strategy ahead was large-scale population and industrial overspill in the city's periphery areas. Although initially sceptical, the City Corporation recognised the need for overspill. In addition, the decision was made to rebuild the inner city. Furthermore, by 1957, the city had identified 29 comprehensive development areas (CDAs) for immediate redevelopment, with a decision to demolish dwellings at a rate of 4500 per year (Pacione, 1995). Residents of these dilapidated areas were to be displaced to peripheral housing schemes in Easterhouse, Pollock, Drumchapel and Castlemilk.

Policymakers are increasingly accepting that two distinct types of social indicators can be used to assess societal and individual well-being. The first is made up of objective indicators that describe the environments in which people live and work (for example, housing standards, crime rates, infrastructures, or provision of health care facilities). The second, on the other hand, is made up of subjective indicators that describe how people perceive and evaluate their surroundings (Pacione, 1986). The reality of the situation was diametrically opposed to the expectations. As Pacione put it, "capitalism with a social conscience" was a chimaera in the periphery estates (Pacione, 1990).

To start with, these locations were characterised by poor building construction and compromised building systems. The rent levels were insufficient to cover the maintenance costs, which exacerbated the situation. The sites lacked a sense of community. Many long-established communities across the city were quickly torn apart in the name of regeneration, with neighbours and extended family frequently re-housed far apart (Paice, 2008). Tenants were also dissatisfied with the lack of schools, public places, shops, public houses, hospitals, recreational sports, and cultural facilities. Even after these amenities were provided after a certain time, dissatisfaction remained as the state did not provide the promised employment opportunities. As Miller put it, "The scheme, however, is not particularly effective, for many of the designated reception areas either cannot offer employment to Glasgow people or wish only skilled operatives, precisely the type of Glasgow dares not lose." (Miller, 1970). The transportation cost of having to travel to other towns for employment was high. A terrible cycle of poverty and crime had resulted from a lack of jobs. From their onset, Easterhouse and Drumchapel were perceived as 'problem' areas. Initially, the focus was on youth violence, with gang fights in Easterhouse and vandalism in Drumchapel receiving extensive press coverage (Mitchell, 1987). As time progressed, the council and government came to the realization that they may have overestimated the project's optimistic aspects. It was result of poor decisions made on the planner's side. Later, these peripheral schemes were to pose some of the most severe social, economic, and environmental problems faced by urban policy in the 1980s in Glasgow and the whole of Scotland (Keating, 1988).

2.3.3 Potential Reasons for past failures

Philosopher Mikhail Bakhtin, in his theory of the world as a “Shared Territory,” -Life is dialogic, and a shared event; living is participating in the dialogue. Meaning comes about through dialogue at whatever level that dialogue takes place (Coghlan&Miller,2014). Even though different actors can share meanings to an extent, their unique position will always create partially different interpretations. Similarly, the governments and businesses cannot solely determine the kind of infrastructure to use in any area for any purpose; Invention and collaboration must be present and transparent between the national, regional, and public levels for sustainable development. Because the old ways did not work out for either urban flooding or urban regeneration, we must start looking for new ways, and that starts with having a holistic view of the environment and society in general.

(Evans &Jones, 2008) argued that we need to avoid the meaning of sustainability to the assessment of predetermined benchmarks or policy goals, both within the regeneration literature and across studies of sectoral planning policies and begin a more wholesome practice. One of the major reasons SUDS type approaches was not a priority was simply because there was no pressure from the government for using redevelopment as an opportunity to reduce drainage load on conventional systems. Even with a personal interest in these kinds of systems, no organization or person would push the matter if it were not a matter of compliance and was not a priority for the client.

On the one hand, as SUDS research grows among researchers, so do its numerous acclaimed benefits. The technical performance of SUDS has been thoroughly studied in scientific literature and has proven beneficial in reducing the risk of flash flooding and watercourse pollution (Fletcher et al., 2015, USEPA, 2013). Moreover, the advantages of incorporating SUDS into conceptual and methodological frameworks of urban planning and design, including urban regeneration, to create an attractive, functional and "environmentally-friendly" urban environment (Vasilevska, 2018).

However, we lack a starting point; an integrated strategy for using SUDS for urban regeneration that would provide the evidence document required to support any potential application for funds from national or international sources, either for broader use or for funding individual pilot schemes (Breton, et al., 2013). For the longest time, the urban planning sector had a tunnel vision, rather than a comprehensive and transdisciplinary vision that can collaborate with a variety of sectors to create a sustainable environment. This thesis aspires to portray SUDS as a new era changemaker, capable of restoring the natural balance on Earth and creating a more sustainable future for future generations.

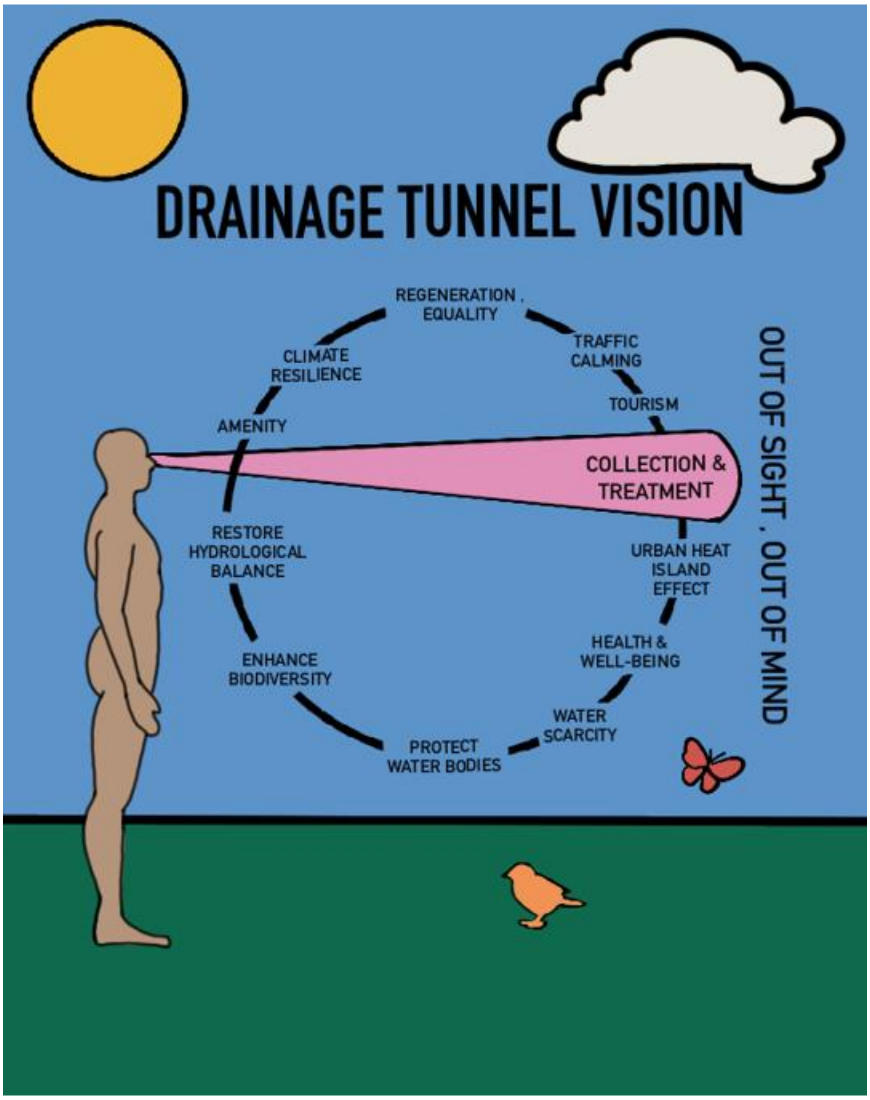

Figure 1: Drainage Tunnel Vision (Source: Author,2022)

2.4 Green infrastructures

GI is defined by the European Commission (2013) as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services". In the UK, GI is a broad term from green roofs and private gardens to the larger scale such as wetlands, forests, and agricultural land, according to the UK Green Building Council (2015).The United States Environmental Protection Agency has defined Green Infrastructures as "the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspiration stormwater and reduce flows to sewer systems or to surface waters (EPA-USA, 2019)." While doing so, stormwater gets collected where it is necessary to support urban vegetation; and this vegetation prevents the future runoff while engendering a range of environment, economic and social benefits. It is known by different names in various parts the world. In the United Kingdoms it is referred to as Sustainable Urban Drainage Systems (SUDS), by Low Impact development (LID) in North America and New Zealand, Water Sensitive Urban Design in Australia but they all have the same purpose; to promote drainage using green infrastructures (Fletcher et al., 2015). The term SUDS is more commonly used to describe stormwater control techniques that are mainly associated with structural measures (e.g., ponds, swales), whereas the Sponge City Program (SCP) has a more dominant ideology in that it manages waterways, quality, and ecology on a larger scale, which can include cities, regions, and river basins.

SUDS falls in broader principles of GI, which encourage multiple benefits by integrating drainage designs and natural waterbodies to provide better amenities for public (Li et al., 2020) , enhance natural environment and support regeneration. (Carter et al, 2018) mapped the flood risk management functions offered by SUDS situated in England and found it to be significantly helpful in runoff management.

2.5 Grey infrastructure

Conventional stormwater infrastructure, which is grey infrastructure, is designed to prevent flooding by transporting rainfall and snowmelt through drainage and engineered water treatment systems such as tanks, pipes, or underground storage facilities. It finally discharges the water at sea or the available largest watercourse. In some areas, the sewers and drainage pipes have separate conduits for their flow, but in others, Sewers and drainage pipes are both collected in the same conduit. They are referred to as combined sewer systems. This diluted sewage either gets channelled into a treatment plant or directly spilled into watercourses when the treatment plant's capacity is exceeded. The process is referred to as combined sewer overflow (CSO). This is imprudent regarding the aquatic ecosystems, particularly the freshwater ecosystems, that are exposed to supplementary contamination from industrial practices as well as release of discharges commencing from urban growths (Demirak et al., 2006). Moreover, At the time of flash flooding, when the urban runoff is too high, these combined systems sometimes get overloaded and burst. This is known as pluvial flooding, a rainfall-generated overland flow before the runoff enters any watercourse. Because these Gray infrastructures were built a very long ago, most of them are now ageing or at the end of their lifetime.

It has been under scrutiny for a while now and it gives no benefits other than directing stormwater from one location to another. There is a plethora of research conducted in scientific literature(Fu et al., 2019; Sarkar et al., 2018; Shafique & Kim, 2017; Tavakol-Davani et al., 2016) that has claimed the use of sole gray infrastructures is already or going to become redundant in the future.

2.6 State-of-the-art literatures

2.6.1 Health Scenario

Today, new stressor combinations are contributing to deteriorating runoff quality. Climate change, new pollutants and pathogens, and the exploitation of the subsurface for alternative energy sources are all part of it. Furthermore, land use is becoming more concentrated as a result of rising food costs, increased demand for biofuel, and growingly varying targets for food production and energy generation for the ever-increasing population.(Wang et al., 2021)detected significant differences in the physiochemical conditions and particle characteristics of rainwater, urban runoff, and rivers. It was found that runoff constituted a higher proportion of nano-scale particles than in rivers. This mismanagement of water network can have a significant impact on the waterbodies. Rainfall and runoff have also been implicated in site-specific waterborne disease outbreaks. According to (Gaffield et al., 2003) more than half of the documented waterborne disease outbreaks since 1948 in the United States have followed extreme rainfall events while between 1991 and 2000, 123 documented outbreaks of waterborne illness in 30 different states were linked to pathogens from waterbodies. At least 50% of UK groundwater used for public supply is showing significant deterioration in quality (Counsell, et al., 2017). The groundwater gets more rapidly exhausted when instead of infiltrating the stormwater, it is tried to get removed as the surface runoff (Arnold & Gibbons, 1996). Carolyn M in (Johns, 2019) asserted “Provision of water and wastewater services, something that many urban residents in developed countries have taken for granted in the past 100 years, will be seriously tested in the coming decades”.

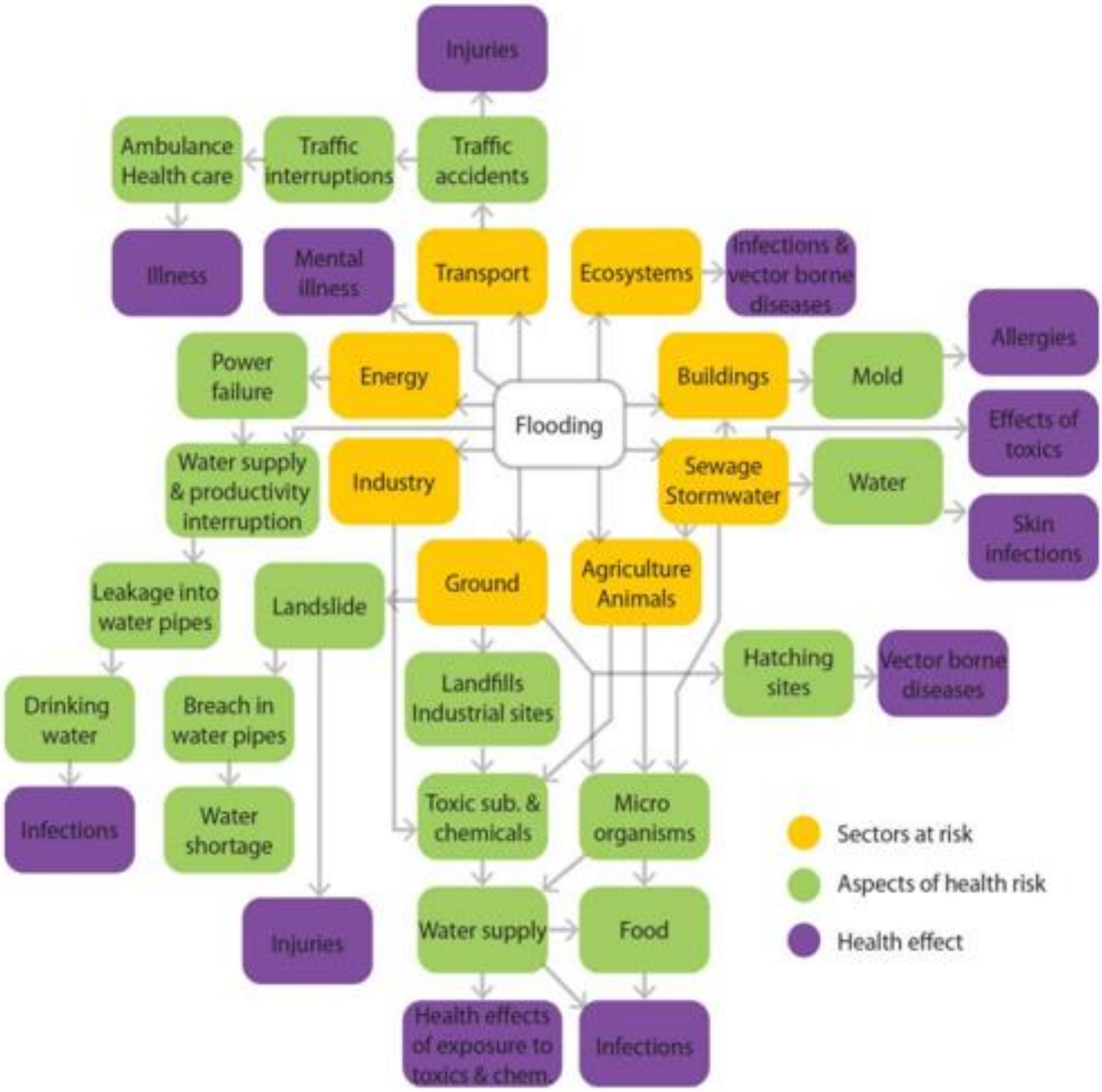

Figure 2: Health effects of flooding Source: (Justic et al, 2020)

2.6.2 Energy scenario

The manufacturing of concrete and metals that is used in production of components of grey infrastructures releases an enormous amount of greenhouse gases (Flower & Sanjayan, 2007), while its transportation and treatment of the wastewater incurs additional energy. On the contrary, green infrastructures are found to increase energy efficiency. Green roofs are on average about 60 degrees Fahrenheit cooler than black roofs in summer and hence reduce annual energy consumption for heating and cooling, shaded surfaces from street trees are 20-40 o F cooler than the non- shaded ones ; rain barrels and cisterns reduces energy use by saving on the need to use treated water for outdoor and non -potable activities(Odefey et al., 2012).Temperature reduction happens through sequestering carbon from atmosphere, reduction of urban heat island effect and removing atmospheric pollutants. Moreover, SUDS enhance biodiversity and ameliorate the surrounding, promoting air and water quality which was found to enhance the physical and psychological well -being of its residents (Tzoulas et al., 2007).

2.6.3 Social scenario

While conducting a social survey of these infrastructures, disparities in public attitudes were discovered. (Scarlett et al., 2021) investigated the link between social and economic marginalisation and stormwater management and discovered that people of colour, minorities, women, and less-educated respondents were more willing to participate in stormwater management than White, male, and more-educated respondents, and it was their concern about local stormwater conditions & hazards that drove their willingness to participate. Moreover, (Apostalaki, 2005) confirmed that the public prioritized a good aesthetic, recreational values of site and amenities and hence were in favor of green infrastructures, (Johnson & Priest, 2008) found out around the same time that due to the media that favored structural defense system and because the flood insurance compensating the flooding victims, citizens were not ready to accept green infrastructures yet. But in the recent studies by (Jarvie et al., 2017) it was clear that citizens liked living around pond because it invited biodiversity, open spaces for children for playing and perceived safety in the area.

2.6.4 Economic scenario

Both grey and green infrastructures offer a very different profile with respect to the cost of implementation, flexibility at the end of their life and other wider scopes beside the obvious flood protection purpose. For ranking the efficiency of both types while including their economic and social benefits, one should provide the highest ratio of benefits to cost compared with other feasible types of stormwater management system in a specific sub catchment(Xu et al., 2021). Creation of job opportunities was an economic scope for installation and maintenance of green infrastructures but what is so contrasting about it is that this study also found that the most important barrier to increase the implementation of GI was related to finance, both in upfront costs and maintenance costs(Li et al., 2020). Because there are no immediate profit returns, the investors were found to be reluctant when investing for GI infrastructures.

- *Economic Valuation*

The application of SUDS retrofitting has been low due to lack of understanding of true costs and benefits and its maintenance. Even though the biggest part for total cost of SUDS is usually the capital cost, it also demands a long-term operation and maintenance cost. Cost and benefits of any SUDS scheme is highly contextual and will differ depending on the SUDS type, location, and site characteristics (CIRIA, 2015) The cost of installation, maintenance and opportunity will be compared to the benefits, tangible and intangible provided by the green infrastructure. because SUDS benefits are often determined based on transference from seemingly equivalent or comparable scheme

- *Hedonic Pricing*

Hedonic pricing is a method used in several benefit valuations that is based on the observation of fluctuations of price of houses, caused by various factors, such as how much is the environment around the house worth? In numerous surveys conducted in high-density environments around the world, this approach has been used to investigate the economic value of urban green space (Kestens et al., 2004; Luttik, 2000), and has generally demonstrated the positive impact of green spaces on property value. Despite the positive results, hedonic valuation of environmental benefits is a difficult exercise because it requires significant data on precise property values and the authors' choice of variables is subjective in nature.

- *Contingent Valuation*

The Contingent Valuation approach to quantifying benefits entails asking respondents, using a structured interview framework, what price they would be willing to pay for market or environmental goods. In some cases, people are asked how much compensation they are willing to accept in exchange for giving up certain benefits (CIRIA, 2015). In comparison to hedonic pricing, the CV method requires less information about the environment but is heavily dependent on respondents' willingness to participate.

- *Benefit Transfer*

  To carry out CV requires specific amount of time and materials which was a limiting factor in this research. Hedonic pricing was also not an option since the required data was another factor restricting criteria in this research. Therefore, the benefit transfer method was chosen in this study for the valuation of benefits provided by SUDS. An increasing number of studies have been carried out in the UK to value amenities such as water quality improvements, the benefits of reduced air pollution and the value of ecologically important species (biodiversity) make use of other contingent valuation studies using a benefit transfer approach. When the characteristics of two study areas are similar, properties of one area can be a good indicator of the range of possible values another area could have, had the CV was performed in that area (CIRIA,2015).

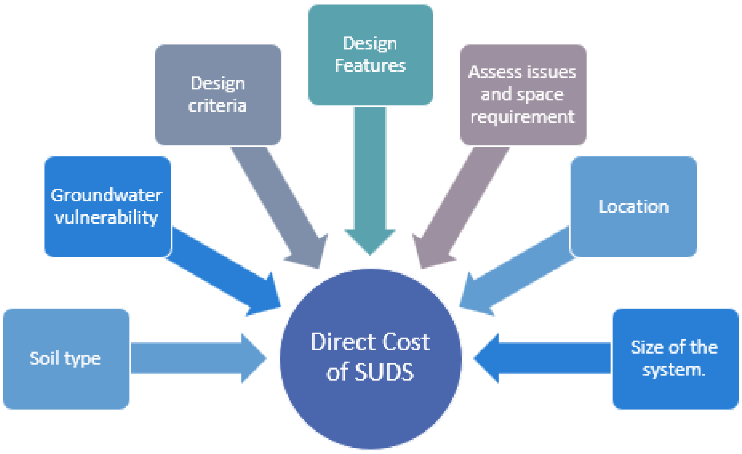

Figure 3: Factors affecting cost of SUDS Source: (Albert et al, 2020)

2.7 Drainage Scenario

Modern stormwater management should aim at both flood control and pollution control rather than just the collection and treatment of water. The EU Water Framework Directive (WFD) focuses on the control of diffuse pollution as a key factor in qualifying good ecological status. "Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such." (WFD, 2000)

Various studies (Gersonius et al., 2012; Miller & Hutchins, 2017; Saraswat et al., 2016 Khan et al., 2022) have assessed the resilience of existing urban stormwater infrastructure in the current built environment under projected climate change and urbanization scenarios. All of them portrayed the efficiency and effectiveness of innovative technologies, the combination of green infrastructures with existing Grey infrastructures to maximize the stormwater management potential of an area. Rainfall Analysis.

(Pamungkas & Purwitaningsih, 2019) found that when they combined grey and green infrastructures, it reduced the floodwater by 45.5% and (13), Another study conducted in Australia combined SUDS and grey systems which resulted in reduced stormwater runoff by over 124 ML/yr compared to that of the conventional SUDS model in accommodating future development. However, SUDS were found to be more effective on flood mitigation as the rainfall duration increases, but it is less effective in shorter and heavier storms (14). In one hand, the effectiveness of water-sensitive designs on stormwater runoff mitigation for a larger catchment area is still not well understood, especially for a catchment area (>1000 ha) have not been investigated (13). On the other hand, applying only grey infrastructures is not viable economically and environmentally feasible as it required more than twice the current drainage capacity. The scenario with green space, permeable pavement, green roof, and stormwater detention cell outperformed other scenarios in urban residential drainage and flood control, but it did not guarantee long-term flood control. In the coupled green and grey scenario, however, no flood occurred during the ten-year return period rainfall. When comparing green and grey infrastructures, most studies concluded that green infrastructures are more environmentally friendly than grey ones. However, studies show that in some cases, combining green and grey infrastructures can improve environmental performance (Alves et al., 2019).

This was an interesting revelation to follow that grey infrastructures are not entirely unproductive. However, we cannot deal with effects of climate change, nor we can regenerate cities with using them.

2.7 SUDS components

Some of the Green Infrastructures we will be looking at in this paper are Swales, Bioretention cells and Permeable Pavements.

2.7.1 SWALES

Swales use vegetated open channels, designed for conveyance of water. They are shallow with a flat bottom. They also provide aesthetic and biodiversity benefits. Mostly, they are used to drain a stretch of roads where it is convenient to collect the distributed runoff inflows. It can be used in place of the conventional pipework. A standard swale will facilitate sedimentation, filtration, evapotranspiration to further decrease the velocity of runoff flow.

Figure 4: Swales Source (CIRIA Manual)

The current best practice employs the design life of 25–30 years for swales. Furthermore, a comprehensive understanding of maintenance requirements for a swale beyond litter removal and grass cutting is limited which has led to uncertainty in defining maintenance needs, long-term design efficiencies and best possible practice in deploying them(Allen et al., 2015)

2.7.2 Bio-retention Systems

Bioretention systems are shallow depressions which are landscaped and often used in urban environments for treating water quality and to combat hydrological impacts of stormwater. A selective designing of the system is imperative to achieve the aforementioned goals, which includes correct type of vegetation at the top, which is planted on an engineered media with drainage system and if required, a possible underdrain at the bottom.

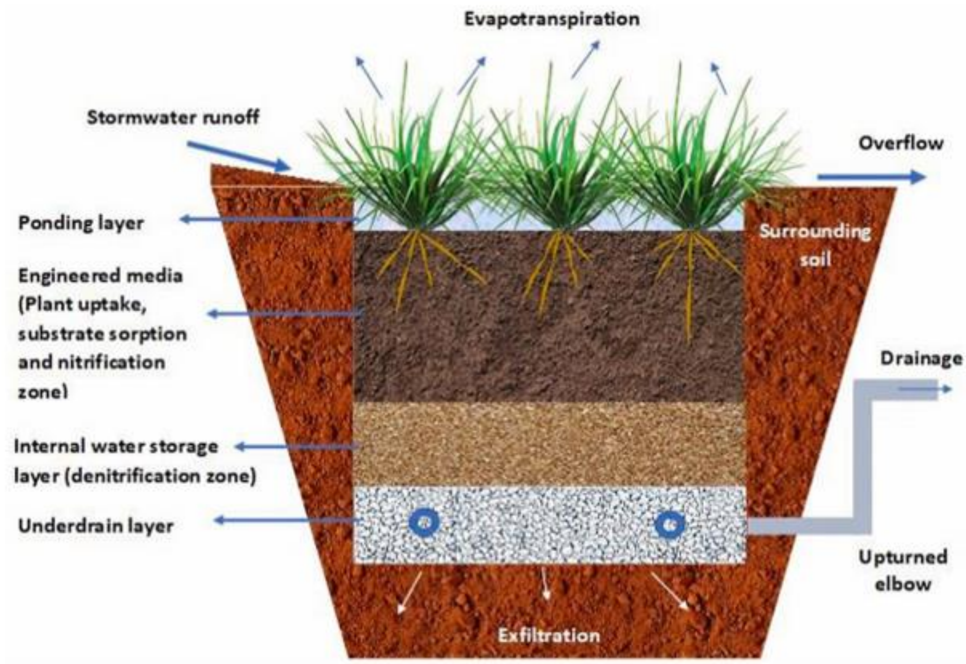

Figure 5: A typical Bioretention system **Source(Vijayaraghavan et al., 2021)**

(Source: CIRIA manual)

They are very flexible with their size and therefore can be integrated into a wide variety of landscapes, ranging from a small area to a larger catchment area. They are also applicable to most developments, from residential to non-residential and even industrial. They can be used for supplying treatment for water before it gets used for harvesting, disinfection of the discharge is imperative, especially when the water contains deadly pathogens. A wide range of rainfall systems can be managed by various designs of bioretention systems when there is a extensively accepted rule that systems are designed near the source of runoff and should drain relatively small areas.

2.7.3 Porous pavements

Porous pavements provide the solution in creating a suitable parking/footpath area where the water when falls, infiltrates through the pavement and can be stored in the reservoir inside, causing no environmental consequences to the environment in times of heavy rainfall. Fully permeable pavements are characterized as that in which all layers are permeable. Water infiltrates the entire surface material, which are composed of any of these materials such as reinforced grass or gravel surfaces, porous concrete, resin bound gravel and porous asphalt (Ballard, et al., 2015). Despite the high initial construction cost, their cost effectiveness is perceived through its design life of 20-30 years more than the asphalt/concrete pavements. (Rehan et al., 2018; Wang et al., 2010).

Figure 6: Examples of porous pavement implementation

2.8 Flood risk in United Kingdom

It is projected that the UK will see warmer and wetter winters, Hotter and drier summer, and more frequent and intense weather extremes. (Office, 2020). Therefore, cities should be designed to be resilient to extreme climates. The description of the causes and consequences of global climate change are presented in IPCC (2021). The accessibility and reliability of daily rainfall data worldwide has made it one of the most scrutinized variables in hydrology, even more so than the sub hourly or hourly rainfall data (de Michele, 2019).

Flooding incidents can be the cause of great public concern and anxiety, especially when they are unusual sequence incidents, or unusual sequences of floods. It might not be environmentally and economically sustainable to improve defences to further reduce the frequency of inundation in some places. However, flood risk assessment is required to support the decision. The 3.33% annual probability (once in 30 years event) is of importance as it is linked with the level of service requirement of the standard government manual, Sewers for Adoption 7th edition (SfA7). It requires that surface water sewers should be capable of carrying the 3.33% annual probability event within the system without causing damage due to flooding in any part of the site. (Scottish, 2018)

Rainfall is the principal driver for identifying the most sustainable infrastructure. The duration, intensity and frequency of rainfall events are affected by long-term fundamental alterations in climate patterns on Earth. Another important driver considered for selecting infrastructure is pollution load influenced by the land-use of the catchment area (Ingvertsen, 2011). Spatial developments have important influences on the pollution loads of runoff, especially when the future developments of the land-use are characterized by uncertainties surrounding it.

2.8.1 Stormwater management in Scotland

The process of governing surface water is quite complicated in Scotland because there are multiple authorities that are responsible for different parts of drainage systems. The Scottish water, under the Sewerage (Scotland) Act 1968 has the responsibility of management provide and maintain public sewers to effectively drain surface water. Road authorities have duties to maintain and manage public roads under the Roads (Scotland) Act 1984. Under the FRM Act, local authorities have general powers to manage flood risk (from all sources, including surface water flooding) in their area. Moreover, SEPA and homeowners/landowners also have their share of responsibility. The source control vision and agenda are fragmented due to different stakeholder drivers and funding mechanisms in Scotland (Duffy et al,2013). SUDS was first implemented in Scotland in the mid 1990's and is also regarded as a trailblazer in implementing SUDS in the UK. Despite an early start, Scotland seems to have not utilized its full potential in SUDS implementation.

Surface water will typically require a dedicated sewer network for new developments, but existing surface networks with suitable conditions and sufficient volume may be used. Surface water discharges into Scottish Water's combined sewer networks are generally prohibited. Because the ultimate receptor of any surface water system is the water environment, treatment with Sustainable Drainage Systems (SUDS) will be required in most cases. Greater Glasgow has over 600 sewer overflows, which should only spill during heavy rain to avoid sewer flooding in homes and gardens. Many overflows in Glasgow are not properly designed for modern drainage systems, polluting smaller tributaries in the Clyde catchment with sewage and litter. (SEPA, 2017) Scottish Water and SEPA reports over 400 overflows across Glasgow are in an unsatisfactory condition and Scottish Water is delivering a phased programme of improvement over the period 2010-2027 to remedy the situation.

Today, Scotland has a growing sewage spill problem. The data reveals that at least 120 million cubic metres of waste has been spilled from combined sewer overflows between 2016 and 2020 (Marc, 2021) . To avert wastewater backing up into households during heavy rain, storm water and waste that would typically go to Scottish Water treatment centres are released into the nearby watercourses via the 3,697 Combined Sewer Overflows (CSOs) dotted across the country.

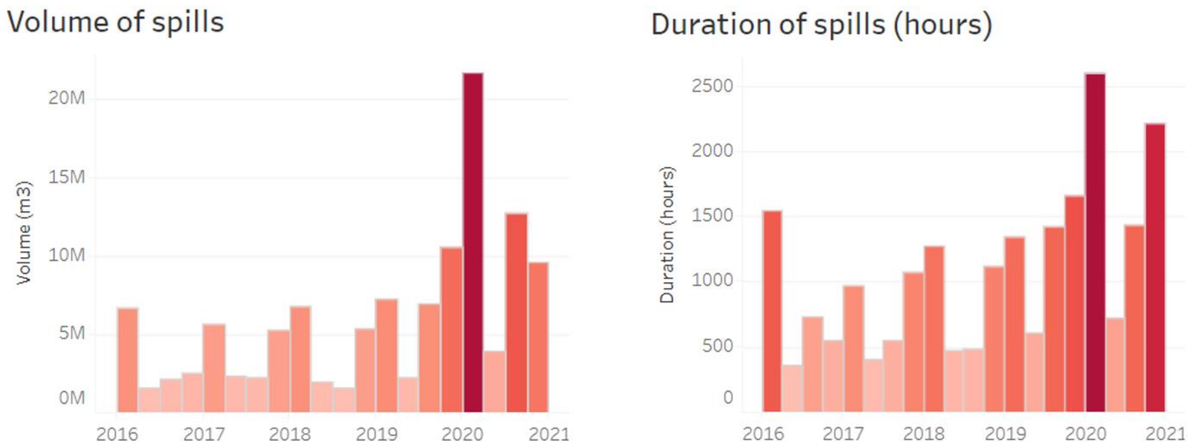

Figure 7: Volume of CSO spills and its hourly duration Source (Marc, 2021)

2.9 Industrial legacy of Glasgow

The advent of industrialization in Glasgow began when James Watt, an artisan inventor and producer of mathematical instruments for Glasgow University, reformed the workings of steam engine which increased the efficiency and power of the steam engine. Trade coupled with Industrialization brought big money and huge employment opportunities that led to a boom in the city's population. As Pacione put it, the polarization of urban society, with the workers and factories in the east end and the middle-class housing and business quarter in the west end, maybe interpreted as the spatial expression of 19th century class consciousness in Glasgow (Pacione, 1979).

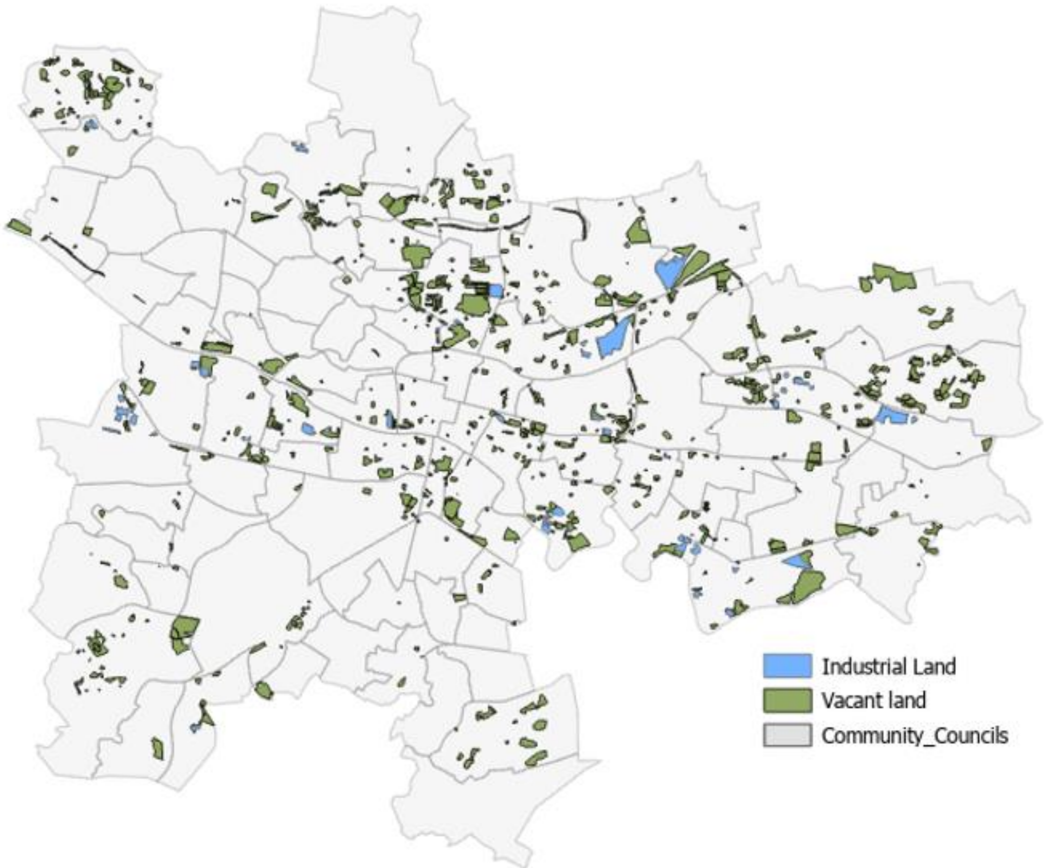

Figure 8: Vacant and Industrial lands in Glasgow Source (GlasgowGIS maps)

2.9.1 The Need for Regeneration

As a result of post-industrial decline and previous housing policies, Glasgow has a large amount of vacant and derelict land within the city boundaries and neighbourhoods with significant levels of deprivation (Kintrea & Madgin, 2019). This vacant and derelict land has been an issue for Glasgow as the city has consistently had the highest concentration of vacant and derelict land than any other local authority in Scotland. A £2.316 million funding had come from the Scottish Government's Vacant and Derelict Land Fund in 2020, which aims to bring vacant and derelict land into beneficial and productive use, in line with Glasgow City Council and Scottish Government objectives. These objectives including tackling long-term (more than 15 years) vacant and derelict sites; supporting communities blighted by such sites; stimulate economic growth and the creation of job opportunities; and the development of a diverse sustainable environment (Glasgow City Council,2021).

2.9.2 History of Flooding

Perhaps two of the most devastating floods in the history of Glasgow would be the freak flood of 1994 and 2002 Glasgow floods. Out of them the 2002 Glasgow flood stands out because it was the first flood in which the impermeable surfaces due to dense urban built up acted as a catalyst for flooding. As Doug Bertram of University of Strathclyde puts it:

"Up to that point, most large-scale flooding events in Scotland were river-based. Traditionally, upland slopes would see water gather in water courses where they would be transported down to the sea. Rivers would burst their banks if the water course wasn't large enough to accommodate the volume of water. "Our traditional response to this was to build concrete structures, but one of the key outputs of the 2002 floods was the realisation that the structural measures we put in place to manage drainage weren't always the optimum solution." (Scotsman, 2016).

2.10 Spatial Analysis Tools

Spatial analysis tools were used to find site suitability of SUDS. Land suitability mainly deals with a large amount of data and involves multifactor, therefore the determination of suitable sites for any projects involves multitude of factors such as Elevation, land use and land covers, cost factors, geographical factors, and so on. There exists a number of methods employed for a sound decision making such as Analytic Hierarchy Process (AHP) and Weighted Sum Model (WSM), Weighted Overlay

Method (WOM), Weighted Linear Combination (WLC) and Fuzzy Logic, Machine Learning (ML) and many more(Ali Ahmad et al., 2015).

2.10.1 Analytic hierarchy process (AHP)

It is a classical land suitability analysis procedure, which gives a systematic approach in making proper decisions for site selection. It also suggests the integration of the GIS-based land suitability model for site selection (Mendoza, 1997). AHP is a tool used for Multicriteria Decision for eliminating environmentally prospective risk areas, a GIS-based AHPs can provide a blueprint at the beginning stage for commissioning any kind of development projects to the urban planning decision makers(Chandio et al., 2013).

2.10.2 Weighted Overlay (WO)

It is another method of modelling suitability. WOA is performed by overlaying classified datasets (using reclassify tool), such as soil type, land cover, or topography, for a defined area, assigning a weight to each dataset, summing the values of each vertical cell stack, and then evaluating the resulting composite map (COLLINS et al., 2001). This tool allows the calculation of a multiple-criteria analysis between several raster. WO includes different weights in the multicriteria spatial analysis, and it is considered different from conventional MCE techniques evaluating the influence of each criterion and assigning values within a defined range of classes (Mayfield, 2016).

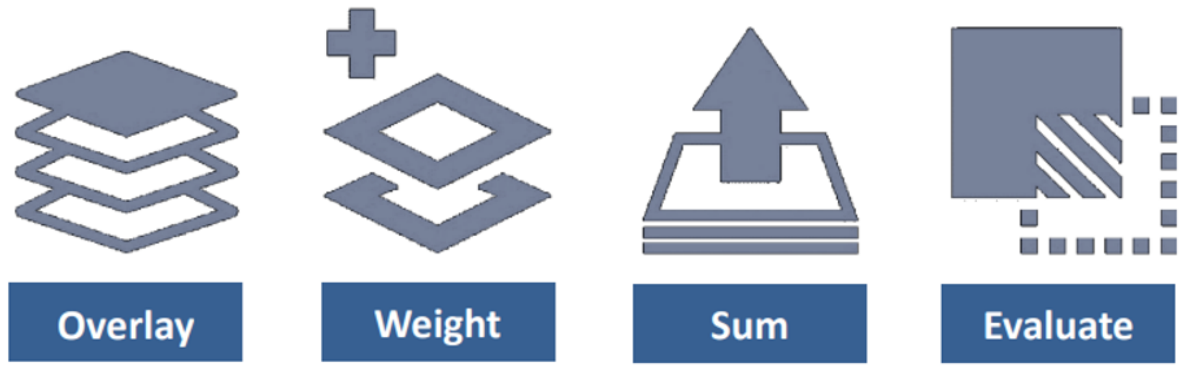

Figure 9: Weighted Overlay process

Table 1: Chosen criterions to find appropriate SUDS areas for flooding and regeneration (adopted from Charlesworth et al,2016)

Map Layers	Description	Source	Reasons
Slope	Digital cartographic dataset that represents a continuous topographic elevation surface, through a series of cells that represents the elevation (Z) of a feature at its location (X and Y). It was converted into slope. Then, it was reclassified. The areas with the greatest slopes had a lower rating of 1 because when SUDS receive water from high slope areas, it can cause the surface of SUDS to erode due to its high speed.	LIDAR phaseV, Scotland	Steeper slopes contribute to generating major floods, while areas with a lower slope have higher probability of inundation. (Kandilioti & Makropoulos, 2012).
Groundwater Vulnerability	It shows the relative vulnerability of groundwater to contamination across Glasgow. Groundwater vulnerability is the tendency and likelihood for general contaminants to move vertically through the unsaturated zone and reach the water table after introduction at the ground surface.	British Geological Survey (BGS)	Deadly contaminants when mixed with the surface water runoff, can penetrate through highly vulnerable sites, toxifying water in deep aquifers, affecting all existing flora and fauna(Mooney et al., 2020)
Distance from Industrial sites in Glasgow	The Scottish Vacant and Derelict Land Survey (SVDLS) is a data collection undertaken to establish the extent and state of vacant and derelict land in Scotland. The survey has been operating since 1988 and is managed by Scottish Government.	ArcGISWebmap,GlasgowGIS	Even if the site isn't redeveloped, they would improve the look and amenity value of the site.(Jin et al., 2021) Reduce diffuse pollution (Krivtsov et al,2021)
Distance from Vacant sites in Glasgow	Same as industrial sites. They consist 10% of total area of Glasgow and 61% of total population lives within 500 m them((Health, 2015)	ArcGISWebmap, GlasgowGIS	54.7% of population in Glasgow lives in the vicinity of 500 m from vacant sites. (Health, 2015), which is highest in Scotland.

Multiple deprivation maps of Glasgow.	SIMD analysis is the key measure of deprivation in Scotland and is published at approximately four yearly intervals by the Scottish Government (Scottish Government). This includes the deprivation in general that includes employment, Income, Health, Education, Skills and Training, Geographic Access to Services, Crime, and Housing. For this study, income-based deprivation criteria is used.	Scottish Government Website https://simd.scot/	SUDS systems should address stormwater mitigation by increasing on-site infiltration and evaporation through enhanced greenspace whilst also improving various components of societal well-being, such as physical health, mental health, social cohesion, especially in areas which already suffers from deprivation(Castro, 2022) (Majekodunmi et al., 2020) found that the deprived communities within Glasgow city would most likely be more negatively impacted in the event of a heatwave or flooding incident than residents in affluent areas.

2.11 Case Study Area: Dalmarnock

2.11.1 History

Back in the early 1900s, Dalmarnock used to be Glasgow's industrial spine. The Deindustrialization after the second world war made this once thriving place, a ghost town. The population exponentially decreased from 50,000 in the 1950s to around 2000 because of post-industrial decline and dereliction. Years later, when Glasgow was chosen as a host City of the Commonwealth Games, Dalmarnock got its second "big break" as it was to be the main development site.

Figure 10: Dalmarnock power station Source (Wiseman,2015)

Figure 11: Tram passing through old Dalmarnock Source (Wiseman, 2015)

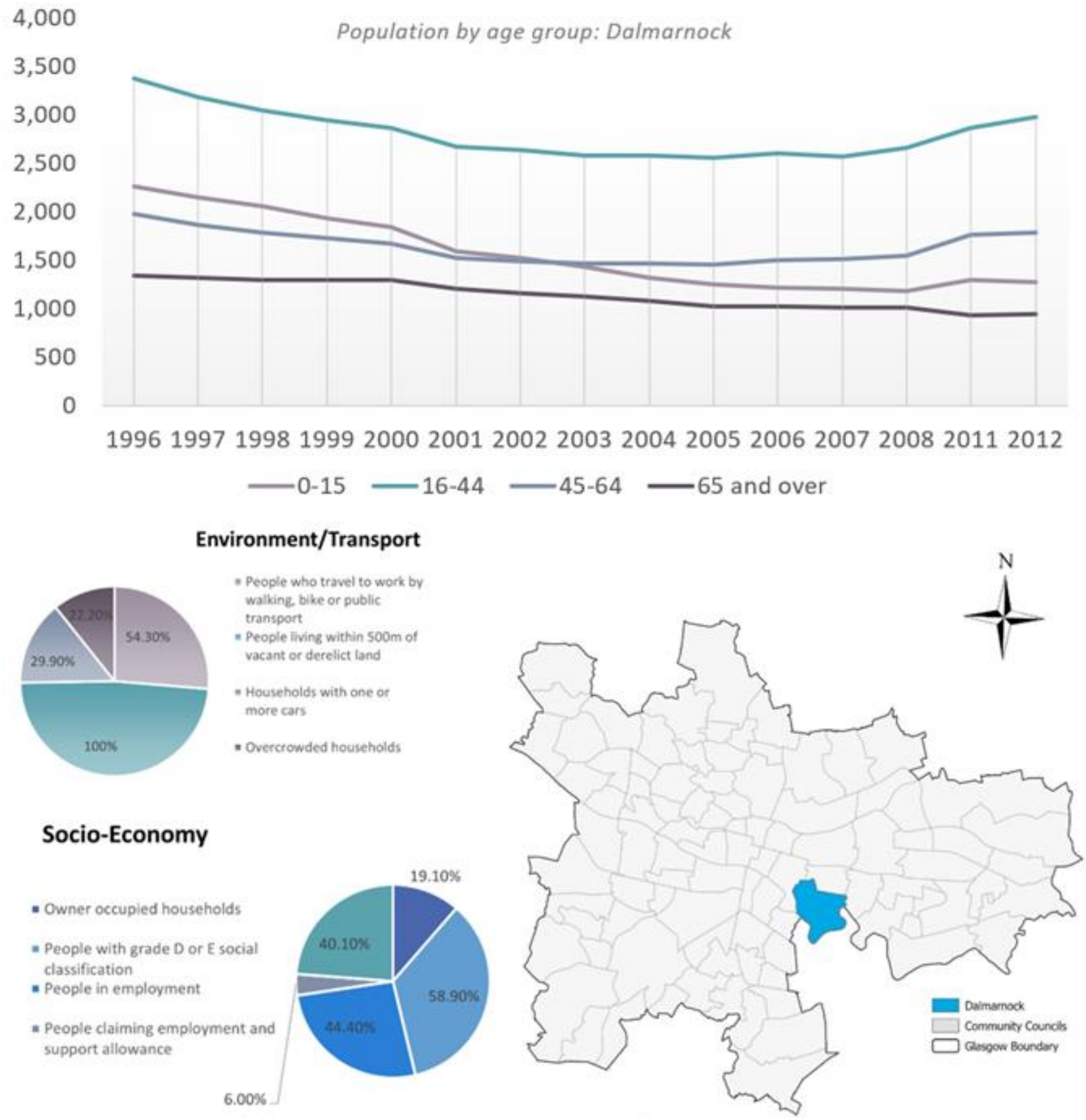

Figure 12: Dalmarnock at a glance Source (Glasgow Indicators)

2.11.2 Geography

Dalmarnock Power Station was, for decades, a landmark structure whose chimney dominated the skyline of the east end. Dalmarnock is situated in the East of Glasgow and North from the meandering river Clyde, opposite to the town of Rutherglen. Its geographical coordinates are

55° 50′ 32.24″ N, 4° 12′ 40.93″ W. According to the flood map data provided by SEPA, this region has a medium to high likelihood of river and surface water flooding.

Figure 13: Industrial past of Dalmarnock Source (Scotland, 1937)

Figure 14: Pharmaceutical pollution in Polmadie Burn Source(Craig,2021)

2.11.3 Socio-economic

Dalmarnock ranks in top 5% of the most deprived areas of Glasgow (Government, 2020). Estimates of male and female life expectancy here is lower than the Glasgow average. It was interesting to know that 100% of people in Dalmarnock live in the vicinity of 500m to a vacant or derelict land. Furthermore, 37.9% of people were income deprived in this area.

2.11.4 Infrastructures

As a part of Commonwealth Games works leading up to 2014, many infrastructures including Dalmarnock Station, SMART bridge, Police station was reconstructed. Moreover, redevelopment projects was implemented through South Dalmarnock Integrated Urban Infrastructure Framework (Commision, 2022) as a part of Clyde gateway regeneration which delivered the key public spaces and pedestrian routes in and around South Dalmarnock .

Figure 16: SMART Bridge Dalmarnock

Figure 15: Police Station Dalmarnock

2.11.5 Stormwater Infrastructures in Dalmarnock:

Current State

Dalmarnock wastewater treatment works was the first biggest sewage treatment work in Glasgow. The drainage system in Dalmarnock is a combined sewer system where the surface runoff gets mixed with the foul water and gets treated together. On days of excessive rainfall, the surplus sewage is released to the river Clyde as CSO. Its capacity would be a limiting factor for allowing any significant number of new developments in the area (Sheppard, 2014), therefore requires decentralised drainage areas. The presence of the wastewater treatment plant can exacerbate the CSO problem as when it rains, the raw sewage can sometimes overspill and cause stench in the surrounding area causing nuisance and diseases (Jonathan, 2022).

The city council of Glasgow has attempted to solve this problem through decentralizing drainage with the help of SUDS. As a part of regeneration in Glasgow highway raingardens were built from

Dalmarnock Station in the north down to Colvend Street, discharging to the river Clyde adjacent to the Shawfield Smart bridge. Moreover, The South Dalmarnock Regional SUDS Pond was designed and built to receive flows from a large area (c.36ha), removing approximately 27,000m3 of surface water from the combined sewer and providing a more efficient and effective approach to surface water management as well as reducing capacity constraints to enable development.

(a) (b)

Figure 17: Existing SUDS in Dalmarnock (a) Raingardens in Colvend street (b) South Dalmarnock Regional Pond

City Development Plan Dalmarnock

In 2017 March a citywide development plan for Glasgow was adopted for land use, placemaking and sustainable spatial strategy. The Glasgow city council's tactical vision in CDP is to turn Dalmarnock into a strategic Economic Investment location. The area north-west to the Wastewater treatment plant is designated as a strategic economic investment location.

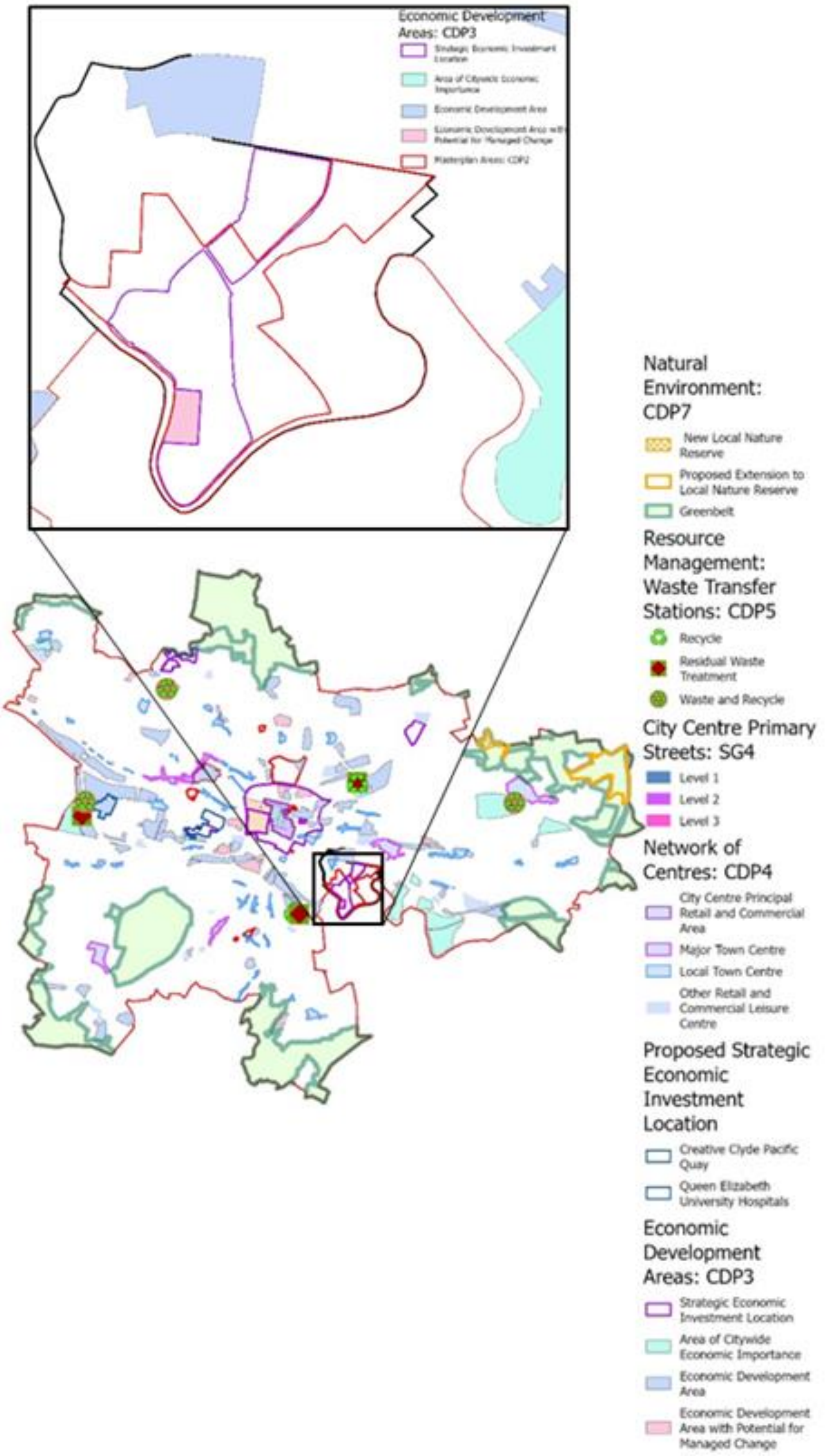

Figure 18: City Development Plan, Glasgow & Dalmarnock (Source GlasgowGIS)

3 METHODOLOGY

3.1 Research Design

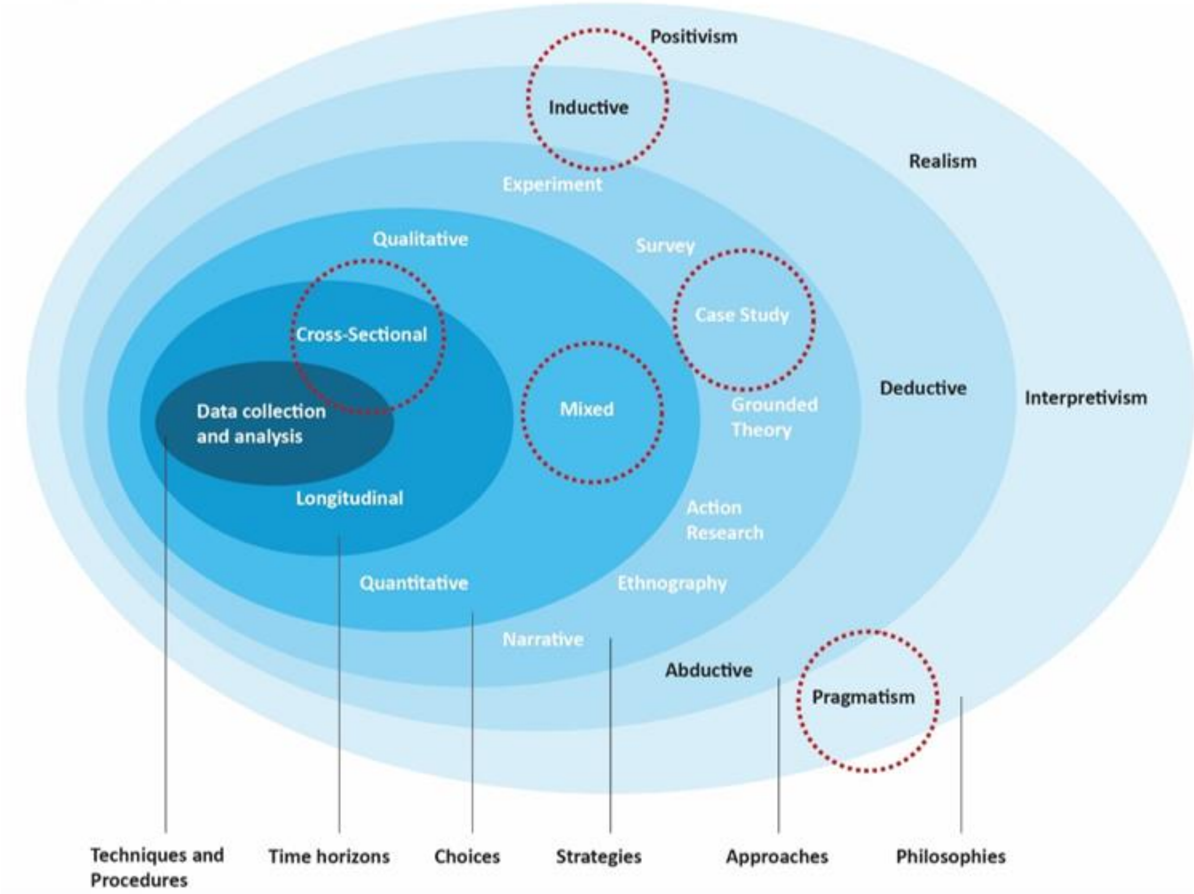

Figure 19: Research onion showing the key choices

The research onion developed by Saunders et al. (2007) describes the stages when formulating a practical methodology for this thesis. This thesis uses pragmatism as a philosophy that uses words and thoughts to predict, solve problems and act while rejecting any idea that describes, represents, and mirrors reality (Vinod, 2022). Furthermore, it helps clarifying the meaning of hypotheses by tracing their practical consequences and implications for experience in specific situations. This philosophy is more elastic in devising methodology and design, as qualitative and quantitative analysis comes under its scope.

An inductive approach is followed, which generates meanings from the data set collected to identify patterns and relationships to build a theory; and learn from experience. Mixed methods allowed the use of qualitative and quantitative methods. Literature review and interviews helped curate existing research and expert advice; which informed the quantitative studies-spatial analysis, rainfall analysis and cost benefit analysis. The research followed a case study strategy, with Dalmarnock to give a definitive answer to the research question- can we make a more sustainable Glasgow by using SUDS as a common solution to urban regeneration and urban flooding? Figure 20 illustrates the sequence of analysis.

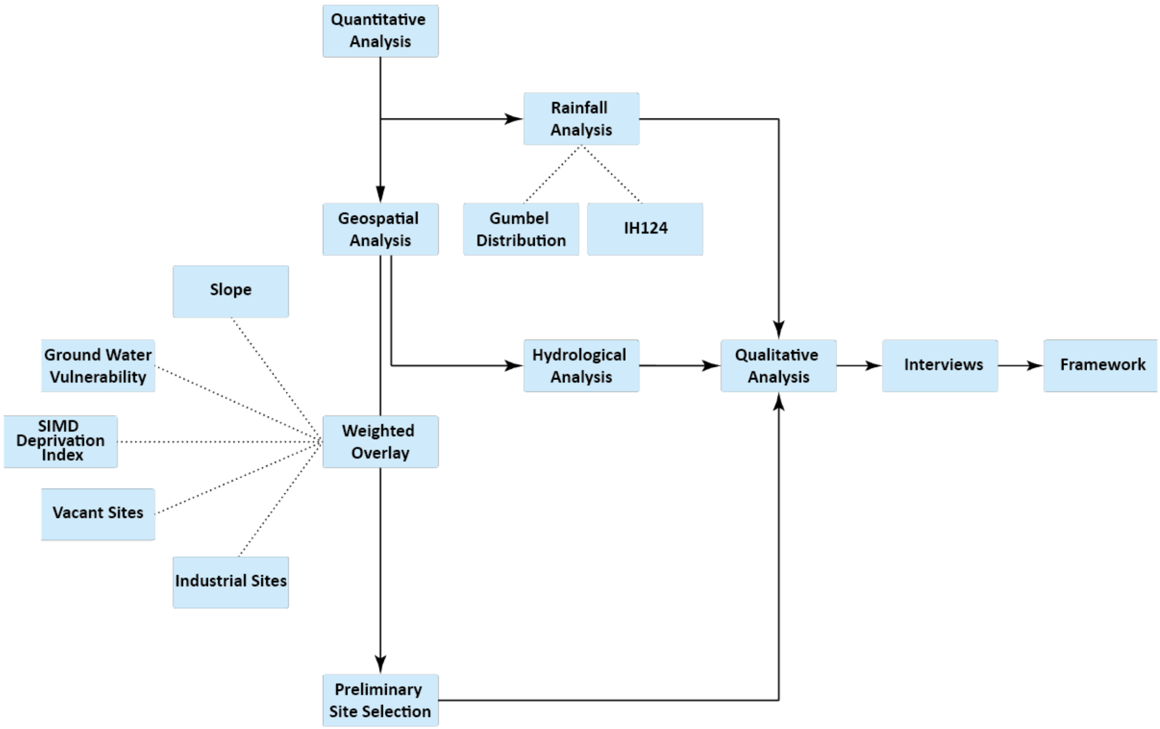

Figure 20: Methodology

2.1 Quantitative Analysis

2.1.1 Macroscale

Weighted Overlay

As explained in the chapter 1, Weighted overlay tool is used to do a Multi-Criterion Decision-Making Analysis in which there will be multiple alternatives and we must determine the best alternative based on multiple criteria. Multi-criteria decision analysis is a method for evaluating and comparing measures that differ in many ways. Measures are assessed against a number of predefined criteria. Criteria in this case could include flexibility and path dependency (Hiller, et al., 2019).

The objective was to find the Priority Areas for Sustainable Urban Drainage Practice for urban flooding and urban regeneration. Geographical Information system was used for the preliminary assessment to find the appropriate sites for SUDS for flood management in Glasgow. The characteristics of the criteria influenced the site's suitability. The weighted overlay overlaps all thematic layers in GIS and multiplies the weight value with the cell value of each raster in the ArcGIS model builder.

Each individual raster cell is reclassified into units of suitability and multiplied by a weight to assign relative importance to each and finally add them together for the final weight to obtain a suitability value for every location on the map; this can be interpreted by Eq. (1) (Eastman, 2001).

$s = \Sigma w_i x_i$ .... (1)

where, w_i = The weight of ith factor map

x_i = Criteria score of class of factor

s = Suitability index for each pixel in the map

The total weights of each pixel of the final integrated layer were derived from the following equation.

S= $DI_f DI_C$+$SL_f SL_c$+$IL_f IL_c$+VL_f +∨ L_C+GV_f + GV_c......... (2)

S= dimensionless quantity that helps in indexing suitable sites for SUDS implementation in the area.

DI=Deprivation Index; SL=Slope; IL= Industrial Lands; VL= Vacant Lands; GV= Groundwater Vulnerability; f= weight of each criterion; c= weight of each class of individual factor

Criteria

Several readily accessible industry standard georeferenced data have been used during the selection process which has been mentioned in Table 1: Chosen criterions to find appropriate SUDS areas for flooding and regeneration (adopted from Charlesworth et al,2016). Five criterions were considered in the study. According to (CIRIA, 2007) Land use, Site characteristic, Quantity and quality of water is most important aspects. Moreover, the wider community benefit from it to transform derelict and vacant sites into a more aesthetically pleasing areas, who has a high social value. (Charlesworth et al,2016) performed a GIS analysis to design SUDS for a small-scale regeneration. Having this in mind and trying to relate SUDS with urban regeneration of Glasgow, 5 main parameters were transferred from her study which were factors driving SUDS design.

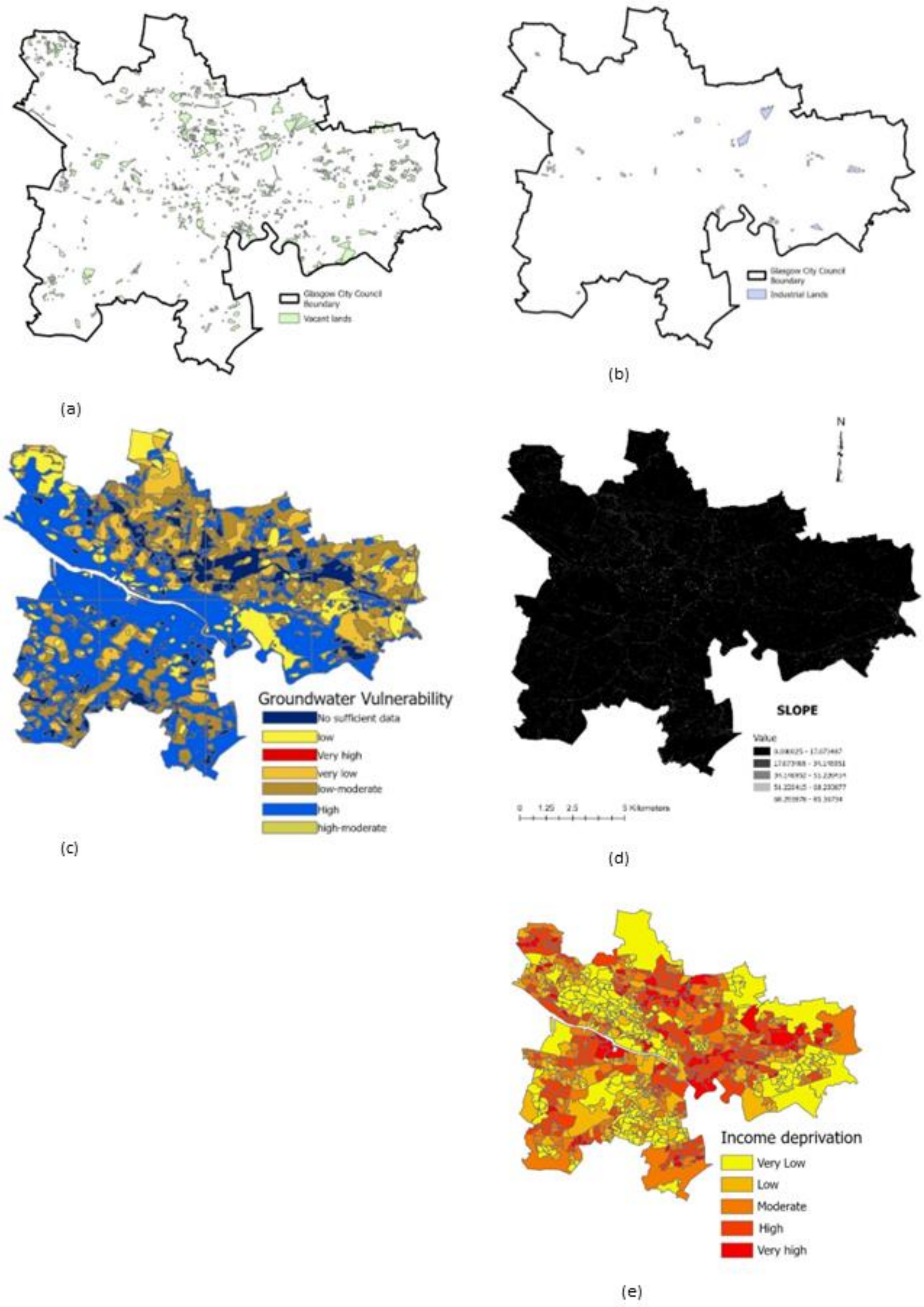

Figure 21: Criteria used for weighted overlay (a) Vacant sites (b) Industrial sites (c) Groundwater vulnerability (d) Slope (e) Income deprivation (SIMD)

Reclassify – This tool provides a variety of methods that allows to reclassify or change input cell values to alternative values based on the preference of users. When the input raster is a layer from the table of contents, the default reclassification table will import the unique values or classified break values as specified by the layer symbology. Categories were created with interval ranges manually that are a proportion of the standard deviation from the mean.5 classes are created for each parameter. The weighting of layers and the basis for reclassification is justified through the expert interviews conducted and literature analysed. Interviewees were given a sheet of questionnaire and were asked to rate layers according to the numbers they find suitable, from the range of one to five.

Weighted Overlay

Externally and internally, weights are assigned to each raster layer based on their relative importance as determined by expert opinion. Internal weights or rating values are referred to as class values, and external weights or weight values are overall weights of all layers that must equal 100.

Table 2: Defining importance for reclassification

Strength on an Absolute scale	Definition
1	Very weak Importance
2	Weak importance
3	Moderate importance
4	Strong importance
5	Very strong importance

Table 3: Table of criteria, variables & weights

Main Criteria	Weight	Description	Class	Score
Slope	15%	Slope must not be too high as it causes erosion in SUDS due to high flow of water should not be too low as well as gravity flow wouldn't work. (Susdrain, 2020)	0-0.38 0.38-0.935 0.935-20.45 20.45-26 26-75.98	Restricted Restricted 5 4 Restricted
Distance from vacant sites	20%	The distance nearest to vacant sites are most suitable and furthest are least. (In metres)	0-1857.99 1857.99-3715.98 3715.98-5573.97 5573.97-7431.96 7431.96-9289.95	5 4 3 2 1
Distance from industrial site	20%	The distance nearest to industrial sites are most suitable and furthest are least (In metres)	0-1378.87m 1378.8-2757.74 2757.74-4136.61 4136.61-5515.48 5515.48-6894.35	5 4 3 2 1
Social deprivation	25%	Represents number of income deprived individuals in an area. Area with highest number of individuals with income deprivation is the most suitable.	0-48.98 49-102.25 103-261.98 262-368.48 369-636	1 2 3 4 5

Groundwater vulnerability.	20%	1 Only vulnerable to conservative pollutants in the long term when continuously and widely discharged. 2 Vulnerable to some pollutants, but only when they are continuously discharged 3 Vulnerable to some pollutants; many others significantly attenuated. 4 Vulnerable to those pollutants not readily adsorbed or transformed. 5 Vulnerable to most pollutants, with rapid impact in many scenarios.	1 2 3 4 5	5 5 4 3 1

2.1.2 Microscale

Micro scale analysis was performed in ArcGIS Pro to obtain a comprehensive view of hydrologic features of our case study, Dalmarnock and use it as an input factor in the design of SUDS. It comprised of runoff analysis and rainfall analysis. Runoff analysis was performed to find area of highest runoff accumulation using hydrology tool in ArcGISPro while rainfall analysis was done using two different methods, Gumbel distribution and IH124 method. They are described below.

Flow Accumulation: Hydrology Tool in ARCGIS

One of the design features of Suds is to harvest and use the rain close to where it falls, i.e. source control (CIRIA, 2015). With the in-built hydrology tool in ArcGIS, the areas with highest flow accumulation during the precipitation can be generated.

Steps for analysis

1. Obtain **DEM**
2. **Fill** DEM to filled to ensure that there are no irregularities that could affect the layer's outcome.
3. The **Flow Direction tool** is then used to calculate which direction water will flow along the topography using the Filled DEM as input data.
4. **Flow Accumulation** is observed using the newly developed Flow Direction Raster, which shows where water collects to form streams and basins.

The result of Flow Accumulation is a raster of accumulated flow to each cell, as determined by accumulating the weight for all cells that flow into each downslope cell. To separate the high flow concentrations from the flow accumulation results, a threshold for the main flow paths is calculated. The root mean square flow accumulation is calculated according to the following equation, considering all flow accumulation values:

$$x_{RMS} = \sqrt{\frac{1}{n}(x_1{}^2 + x_2{}^2 + \cdots + x_n{}^2)}$$

where xn is the flow accumulation value in grid cell n and xRMS is the root mean square used as flow accumulation threshold. Higher values are given larger weight by the RMS, due to the squaring of each value. This is necessary since there is many low values which are slightly higher than 1 (which is not of interest for the calculation) and only a few high values (of interests for the calculation)

Rainfall Analysis

In probability theory, extreme value distributions namely Gumbel, Fréchet and Weibull are generally considered for frequency analysis of meteorological variables in most parts of the world(Tudunwada & Abbas, 2022)(Syafrina et al., 2019) (Min & Halim, 2020).In the UK, however two theories FSR and FEH are most widely used. The Gumbel distribution is used to model the largest value from a relatively large set of independent elements from distributions whose tails decay relatively fast, such as a normal or exponential distribution. As a result, it can be used to analyse annual maximum daily rainfall volumes. In this way, it can be used to predict extreme events such as floods, earthquakes, or hurricanes.

The rainfall data of 30 years for Dalmarnock, Glasgow, was subjected to a Gumbel distribution to interpreting the past data for making predictions about the future. The need for implementation of SUDS can be reflected in the rainfall scenarios of the future.

The Intensity Duration Frequency relationships can be used in conjunction with the rational method to determine peak discharge from a catchment area for design of hydrological structures. The quantity of storm runoff or discharge may be computed based on the correlation between rainfall intensity and surface flow using the expression in equation 1 equation below

Q=CIA………… (1)

Where Q = the design peak runoff rate in m3/s, C = the runoff coefficient, I = rainfall intensity in mm/hr for the design return period and for a duration equal to the “time of concentration” of the water shed, A = the watershed area in hectares.

Firstly, The Gumbel distribution was used to model the largest value from a relatively large set of independent elements from distributions whose tails decay relatively fast, such as a normal or exponential distribution. As a result, it can be used to analyse annual maximum daily rainfall volumes.

$$Pt= P24*(t/24)^{(1/3)}$$

$$Xt=Mean+STD*kt$$

$$K=(Yt-Yn)/Sn$$

$$Yt= -[Ln.Ln(t/(t-1)]$$

Pt= required rainfall depth in mm at t-hour duration; K = Frequency Factor is a function of return period and sample size; Sn=Standard deviation; Yn= Expected mean (Sn and Yn can be found from Gumbel variate table using sample size of 30 years)

Indian Meteorological Department (IMD) use an empirical reduction formula (equation (1)) for estimation of various duration like 1-hr, 2-hr, 3-hr, 5-hr, 8-hr rainfall values from annual maximum values. Chowdhury et al (2007), used Indian Meteorological Department (IMD) empirical reduction formula to estimate the short duration rainfall from daily rainfall data in Sylhet city in Bangladesh and found that this formula gives the best estimation of short duration rainfall.

United Kingdom has its own runoff calculating methods

Table 4: Runoff Calculation methods in United Kingdom

Development size	Method
0 – 50 ha	One of two approaches can be used: 1. The Institute of Hydrology (IH) Report 124 Flood Estimation for Small Catchments (1994) method can be used to estimate the greenfield site flow rate. 2. The Index Flood, QMED (the median of the set of annual maximum flood peaks) regression equation that forms part of the FEH statistical method .
50+ Ha	1.I H Report 124 or the FEH QMED equation from the statistical method can be used to calculate the greenfield site peak flow rates. 2.FSSR 2 and 14 regional growth curve factors can be used to calculate the greenfield peak flow rates for return periods greater than 100 years.

2.2 Qualitative Analysis

2.2.1 Bibliometric result

The first goal of the study was to find out more about the characteristics of different SUDS. Therefore, it started with the review of academic databases, scientific articles and journals written in English language. Scopus search engine was most widely used, followed by science direct and other websites. The search focused on the different thematic areas. The abstract part of papers that got generated with different keywords were perused to find out about the relevant studies. Then, an in-depth review of articles that have established the effect of water quality improvement by different NBSs, such as bio-retention cells, vegetative swales, constructed wetlands, green roofs, rain barrels, porous pavements, detention basins, retention basins, was performed. Articles covering topics such as sophisticated hydrological and statistical methods were omitted and not considered as a part of this study as they were beyond its scopes. Finally, 100–110 papers were analysed. The CIRIA manual (Ballard, et al., 2015) was most widely used for the scope of this thesis. Moreover, expert interviews were held who were working in the field of SUDS and regeneration in Glasgow. Finally, SUDS analysis was done to choose the best site-specific SUDS.

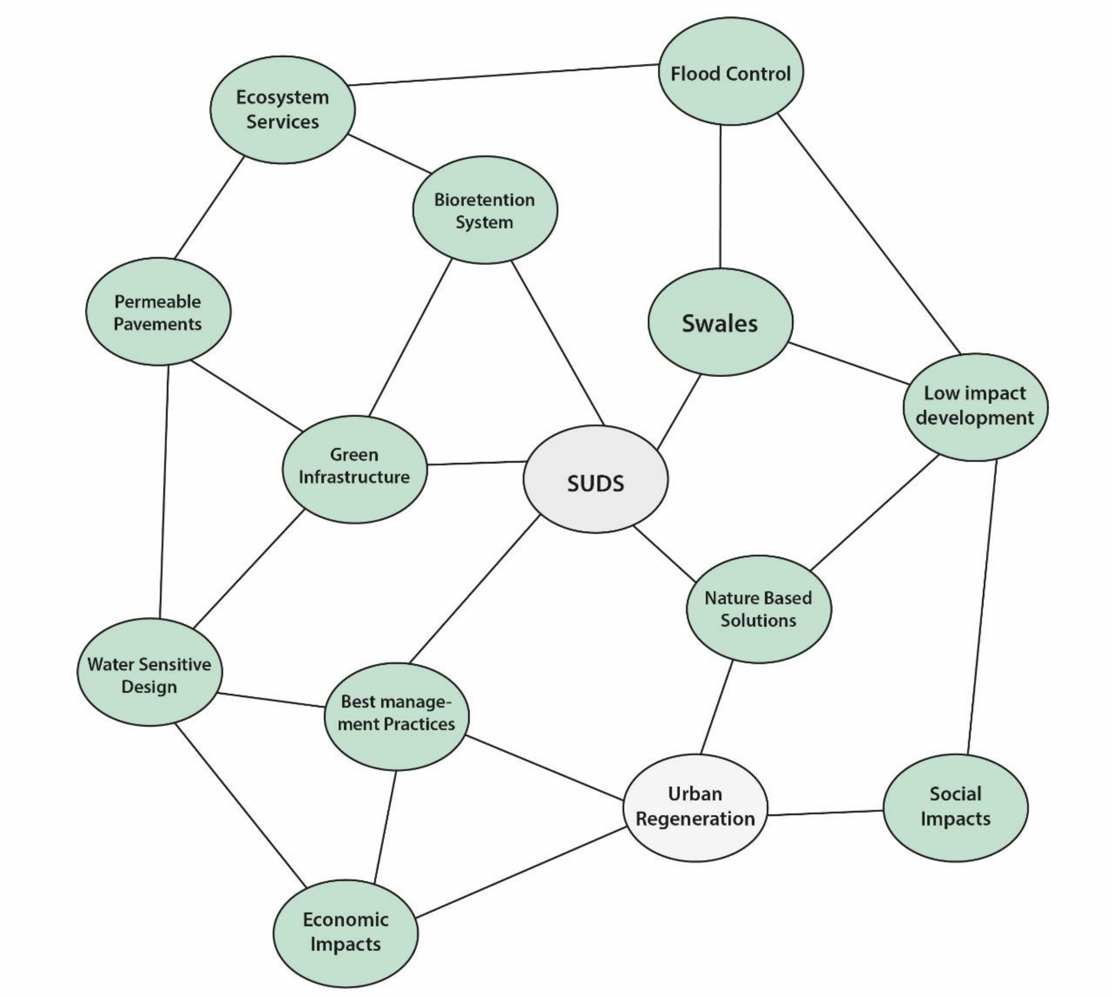

Figure 22: Cluster Diagram of bibliometric analysis

Adaptive approach to Urban flooding & Urban Regeneration

This thesis aims to relate urban flooding with urban regeneration through the expansion of work by (Hudson et al., 2022) in Czech Republic. According to Hudson, this holistic perspective of planning is an important concept to transfer to Urban sectoral planning efforts, especially within flood risk management. SUDS retrofit opportunity has the potential of multiple benefits. The first is urban regeneration or site reconstruction, where the primary goal is not necessarily drainage improvement, but rather site development, building stock replacement or regeneration, enhanced urban environments, and small local incremental improvements. (Breton, et al., 2013) tried to help address the problems of CSO that was contributing to significant decline in the bathing water quality of Blackpool, UK through use of SUDS for urban regeneration to find integrated solutions for surface water pollution in the area Surprisingly, this field of integration of SUDS for urban regeneration has a very limited literature. A spatial analysis and cost-benefit analysis is performed to elucidate the understanding and possible enhancement of land use planning decisions, from the integration of SUDS with urban regeneration for a holistic flood Risk Management in contemporary period in Glasgow Decision- making in Urban Planning increasingly requires comparing alternatives to achieve multiple and competing goals, such as reviving cities while addressing needs of vulnerable communities, and possibly fostering economic growth. Adaptive planning approach set out sequences of multiple actions and define 'trigger points' where planners can flexibly switch between courses of action based on new information (Hiller, et al., 2019). Figure 23 shows the process of adaptive planning followed in this thesis.Figure 21

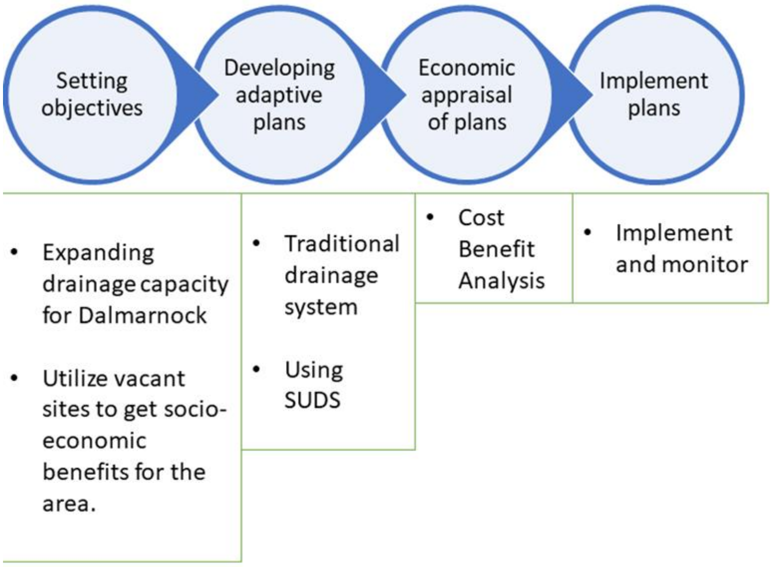

Figure 23: Adapted planning approach Source (Hiller, et al., 2019)

2.2.2 Cost Benefit Analysis

One way to develop adaptive plans is to view each component of a development project as providing a set of benefits that outweigh the potential increased flood impacts (Hudson et al., 2022). Therefore, a cost benefit analysis is performed for our site in Dalmarnock.

Various guidance documents including (Ballard, et al., 2015), (DOEE, 2018), (Keating, et al., 2015), were used to generate unit costs while benefits were qualified by scouring previous literature on SUDS, a benefit transfer approach and a PESTEL Analysis. CBA needs to mirror different drainage area conditions and circumstances, where these would properly reflect the local cost-benefit situations. (Gordon-Walker, et al., 2007).

Cost Analysis

- Net Value for project in N years= Net benefit in N years – Net cost
- Net cost (NC) =Present cost of Installation + maintenance cost (MC)
- Net benefit in N years= Total benefit/annum * N

Present Value (PV)

$$\boldsymbol{PV = C * \frac{1}{(1+i)^{n}}}$$

N= time horizon in years; C= monetary cost (or benefit); i=discount rate (discount rate of 3.5% is recommended by UK Government other discount rates are used commonly in evaluation projects)

Net Present Value (NPV)

$$NPV = \sum_{0}^{t} \left[\frac{B_t - C_t}{(1+i)^t}\right]$$

Bt= total monetary benefits in each year from zero to the end-of-life t; Ct= total monetary costs in each year from zero to the end-of-life t; T= design life or planning period covering the entire life cycle.

If Cost/Benefits > 1 = The project is lucrative and there is a green light shown.

2.2.3 Interviews

Expert interviews were conducted to get an insight into SUDS and urban regeneration. Interviewees were asked semi- structured questions and analysed, bridge the relationship between urban regeneration. All interviews were conducted virtually and recorded and transcribed with the permission of the interviewees according to standard process. The transcripts were used to identify codes which where clustered into themes to distil key ideas.

Table 5: Interviewees in a glance

Affiliated Organizations of Interviewees	Designation
NatureScot	Project & Funding Officer, Green Infrastructure
NatureScot	Project Manager
Metropolitan Glasgow Strategic Drainage Partnership	Manager, Neighbourhoods, Regeneration & Sustainability
University of Strathclyde	PhD researcher on SUDS

3 ANALYSES

3.1 Spatial Analysis

The figure below summarises whole process, macro and macro of spatial analysis used in this study. The final output is a flow accumulation raster which shows the areas of the highest flow accumulation.

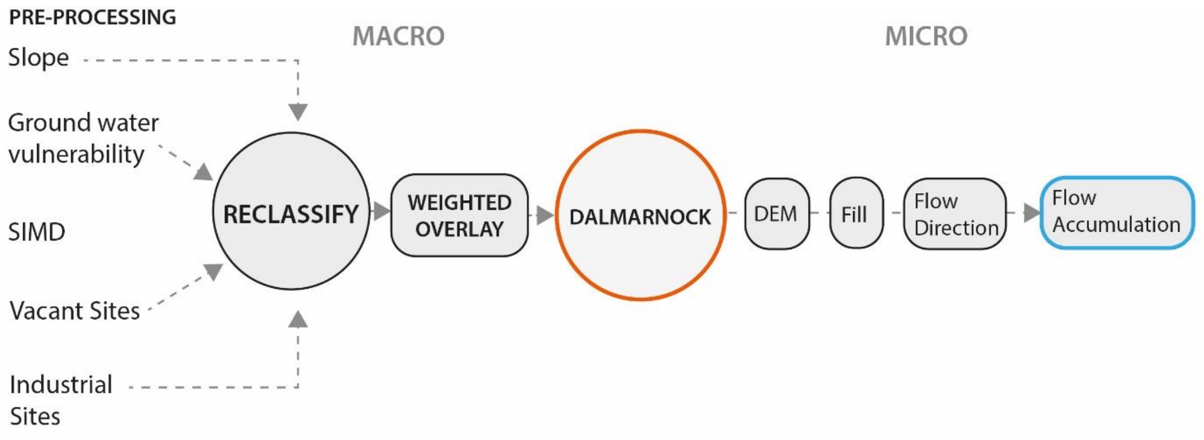

Figure 24: Summary of Spatial Analysis

3.1.1 Weighted Overlay using Model builder

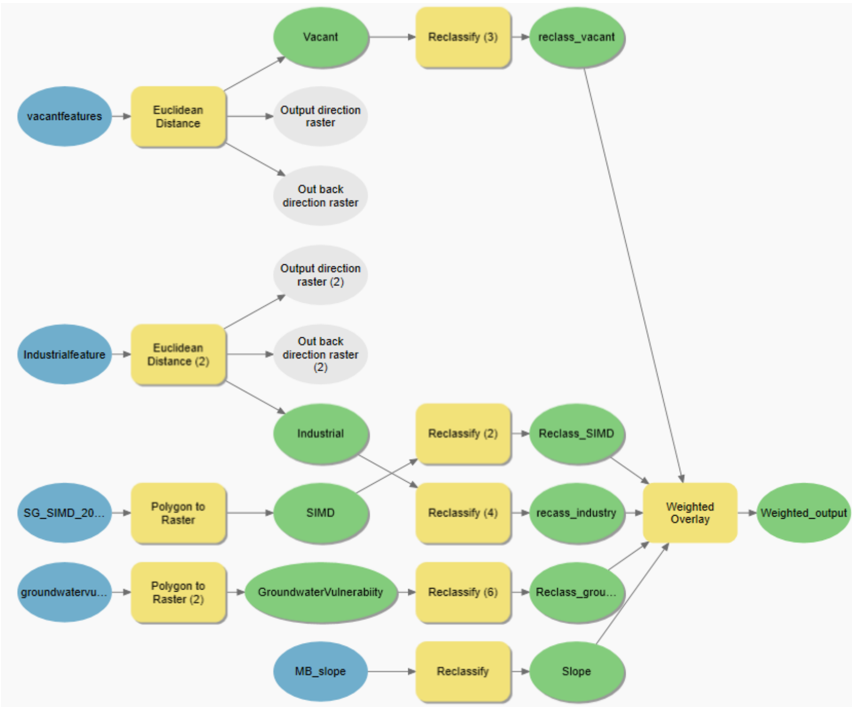

Figure 25: Process of weighted overlay in model builder

All the criteria were classified into 5 classes so that the weighted overlay tool could be used to extract the cells according to the weight assigned to each number of the group. Some groups were restricted too because they did not fit in the criteria, some values were too high/too low to fit in. Then, a result was extracted from weighted overlay tool. These areas of Glasgow were the results of our preliminary assessment for SUDS site selection.

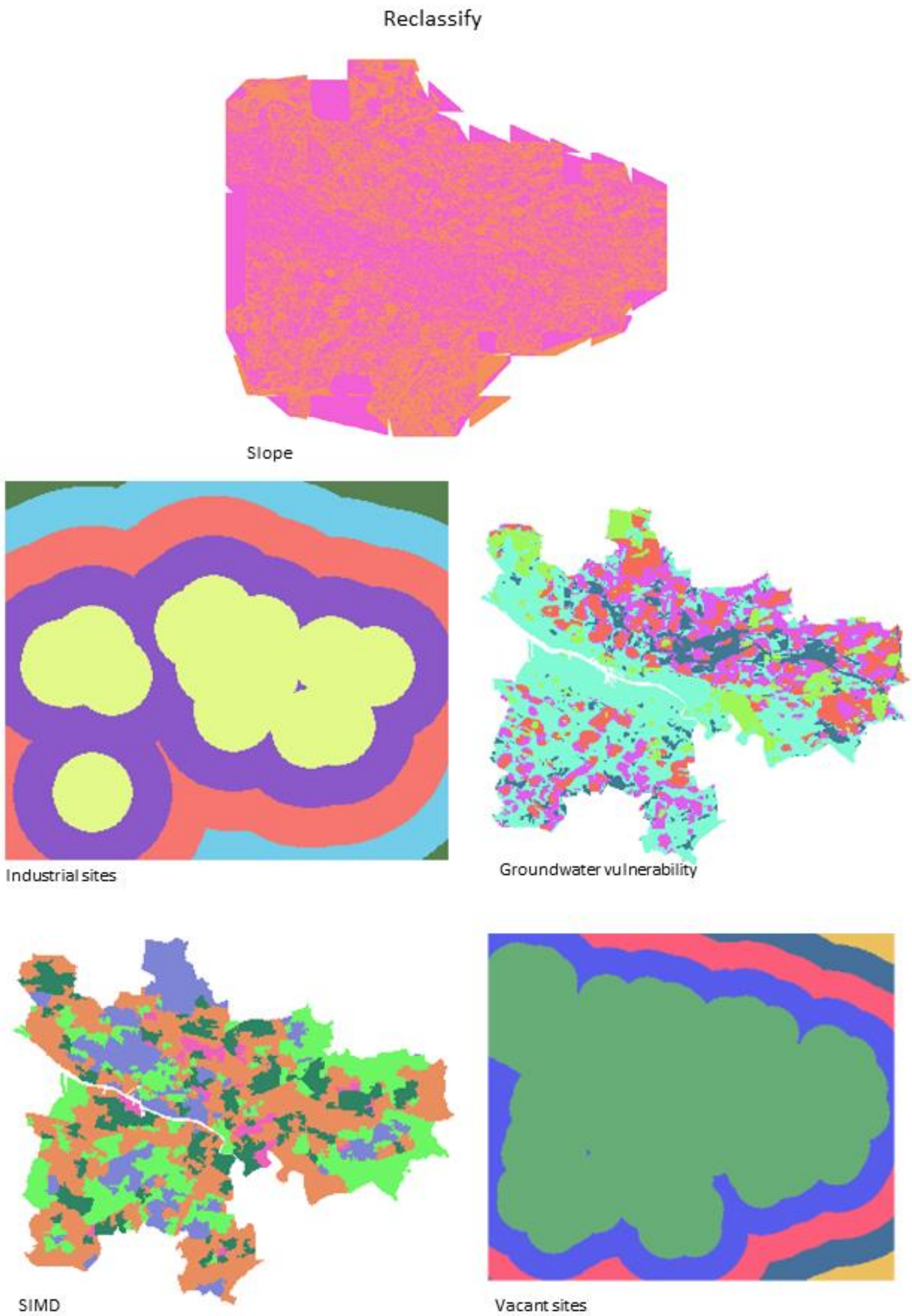

Figure 26: Reclassed criteria

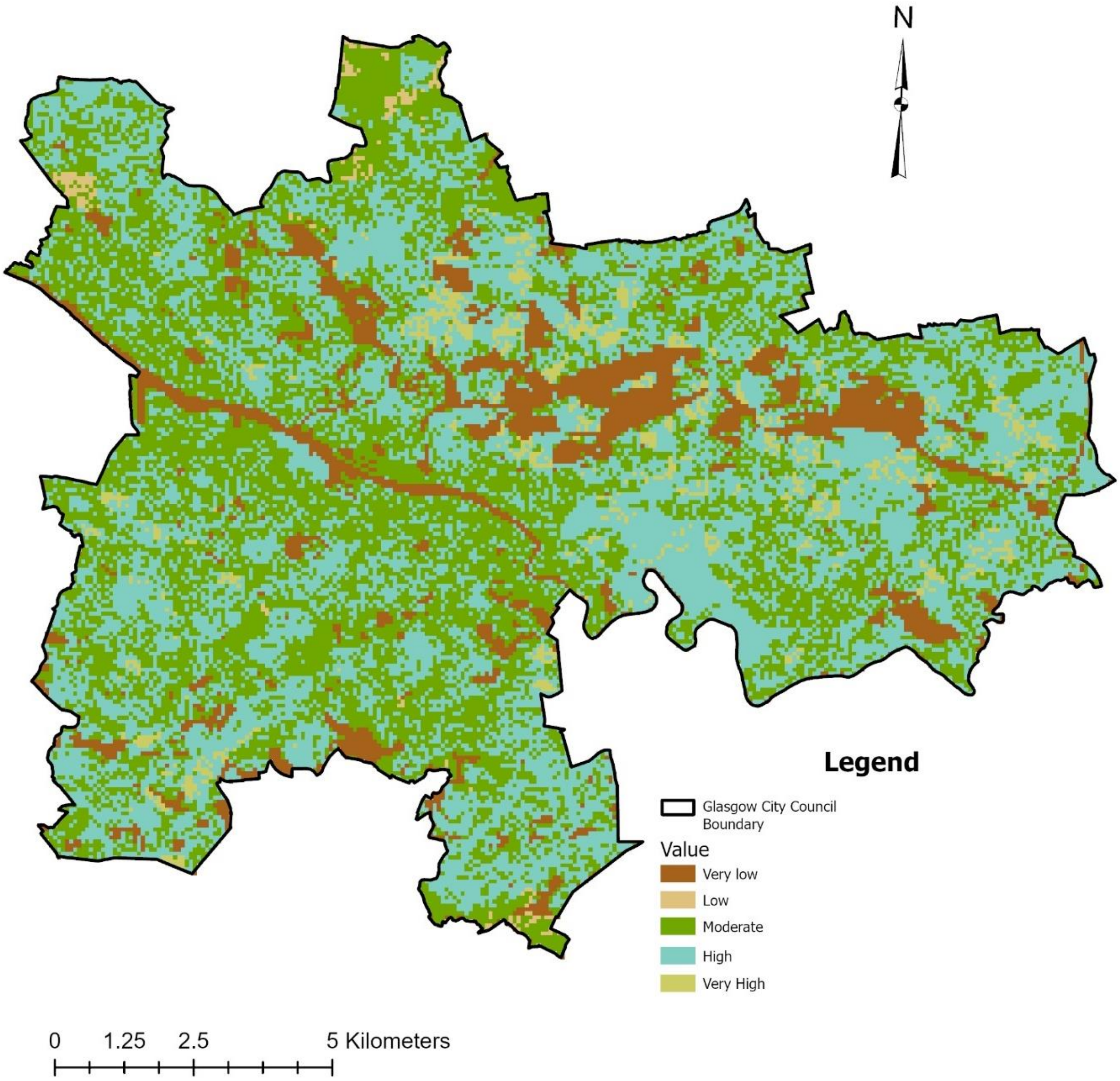

Figure 27: Suitable areas for SUDS from macroanalysis

One of the suitable areas for site selection is our case study: Dalmarnock. Initial assessment proved it has high potential for SUDS implementation. 100% of population in Dalmarnock lives in the vicinity of vacant sites. Figure 21(e) shows it is one of the most deprived areas in Glasgow. Next, micro spatial analysis showed the highest flow accumulation area which are the most suitable for SUDS implementation to diffuse source runoff and pollution.

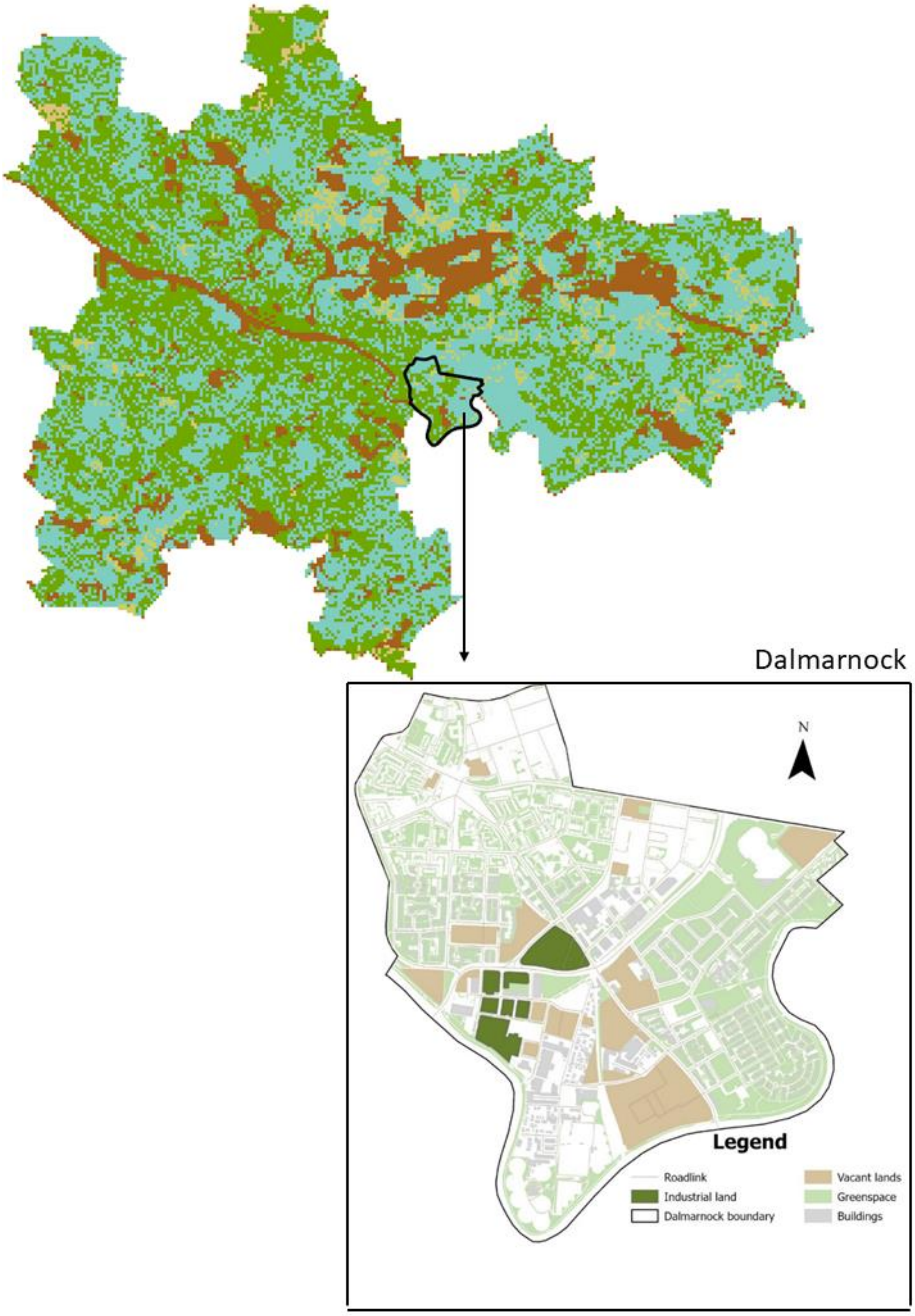

Figure 28: Landuse Map of Dalmarnock

3.1.2 Flow accumulation

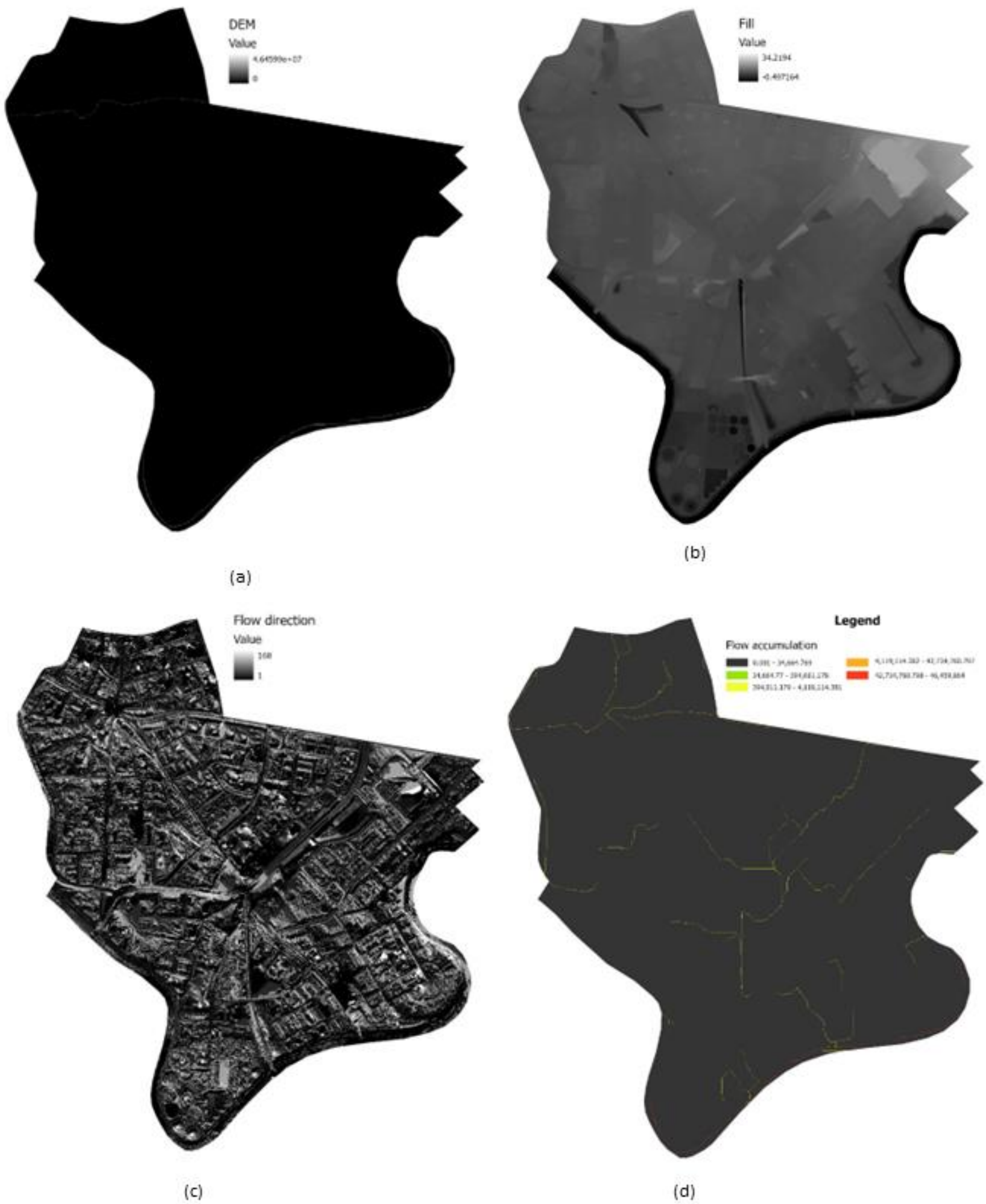

Figure 29: Rasters from hydrology analysis (a) DEM Dalmarnock, (b) Fill (c) Flow direction, (d) Flow accumulation

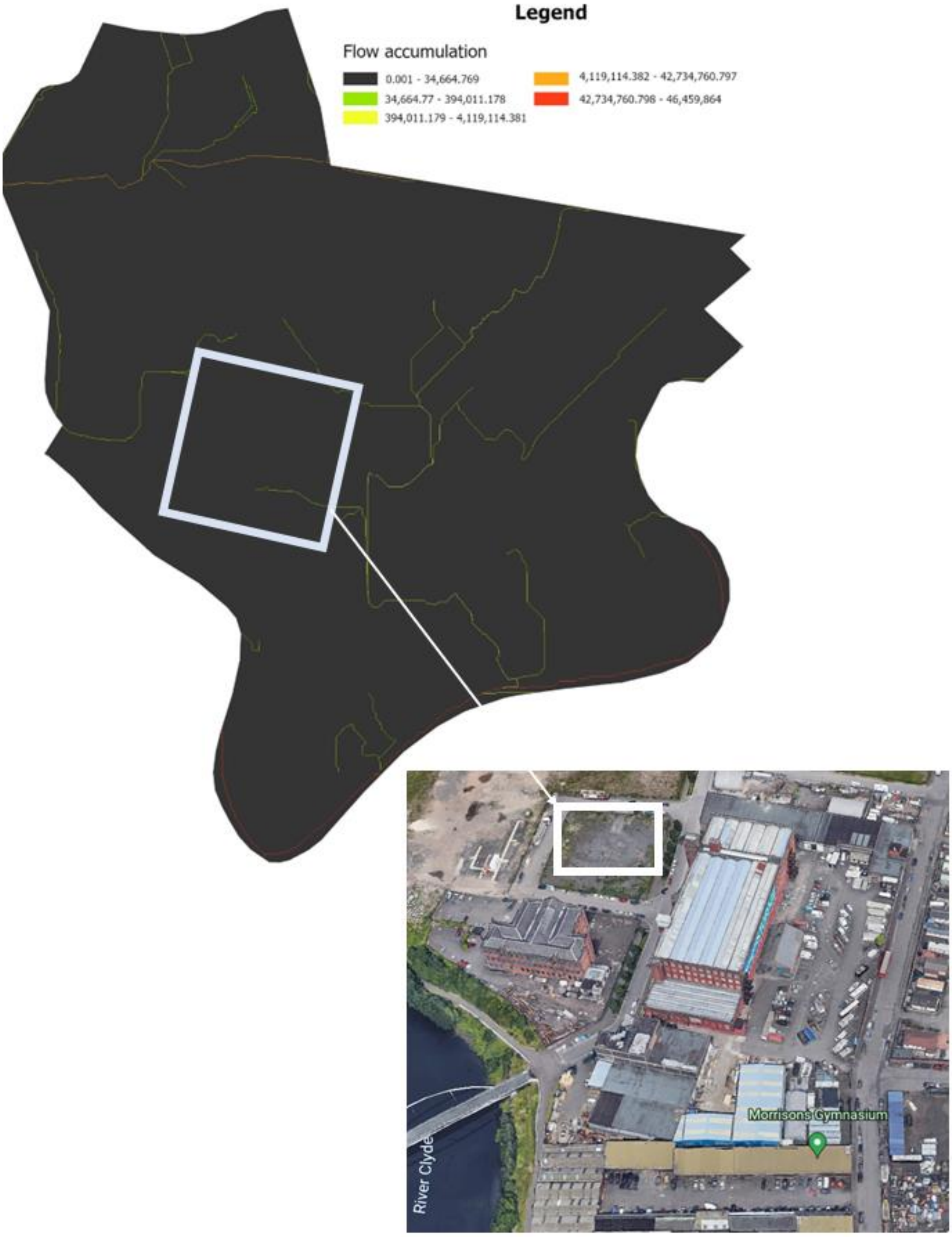

Figure 30: Final site obtained from flow accumulation raster Dalmarnock

3.2 Rainfall analysis

The most important driver for identifying suitable infrastructure for stormwater management is rainfall. The duration, intensity and frequency of rainfall events are affected by long-term fundamental alterations in climate patterns. Another chief driver considered for selecting infrastructure is pollution load that is influenced by the land-use of the catchment area (Ingvertsen, 2011). Spatial developments have important influences on the pollution loads of runoff. Future developments of the land-use are characterized by uncertainties. The hydraulic performance, treatment, maintenance, technological development, cost, and efficiency concerning the different infrastructures are also most of the major future uncertainties. Moreover, it is also not possible to find the exact runoff rate for rainfall at any site. The general objective of using an agreed method is to provide a consistent, reasonable, and ubiquitous estimate upon which storage design can be based (CIRIA,2015).

The surface water system should be designed and constructed so that flooding does not occur in any part of the site in a 1-in-30-year return period design storm flood frequency, with a 1-in-200 year overall minimum flood resilience assessment check, as may be required, by the Local Authority and SEPA for developments in flood vulnerable areas. (SEPA, 2013). Moreover, Sustainable Urban Drainage Systems should be designed for 1 in 30-year rainfall events in Scotland. For the design rainfall, the volume of precipitation required to be attenuated must be predicted for getting the right sized hydraulic/ drainage infrastructures. The overall objective of using an agreed method is to provide a consistent and reasonable estimate upon which storage design can be based, rather than finding the exact runoff rate for any specific site, which is not possible because of too many parameters. (CIRIA,2015) First, Gumbel distribution was applied to the precipitation data to get 1 in 30-year rainfall. The study investigates the maximum daily rainfall data of 30 years of Dalmarnock using the Indian Meteorological Department (IMD) empirical formula to calculate the short durations rainfall intensity for 5, 10, 20, 30, 60, 120, 360 and 1440 minutes, and with return periods of 2, 5, 10, 30 and 100 years. Then, the IH124 rainfall method was used. The method which gave the highest precipitation intensity for 1 in 30-year rainfall, was finally chosen as the design precipitation.

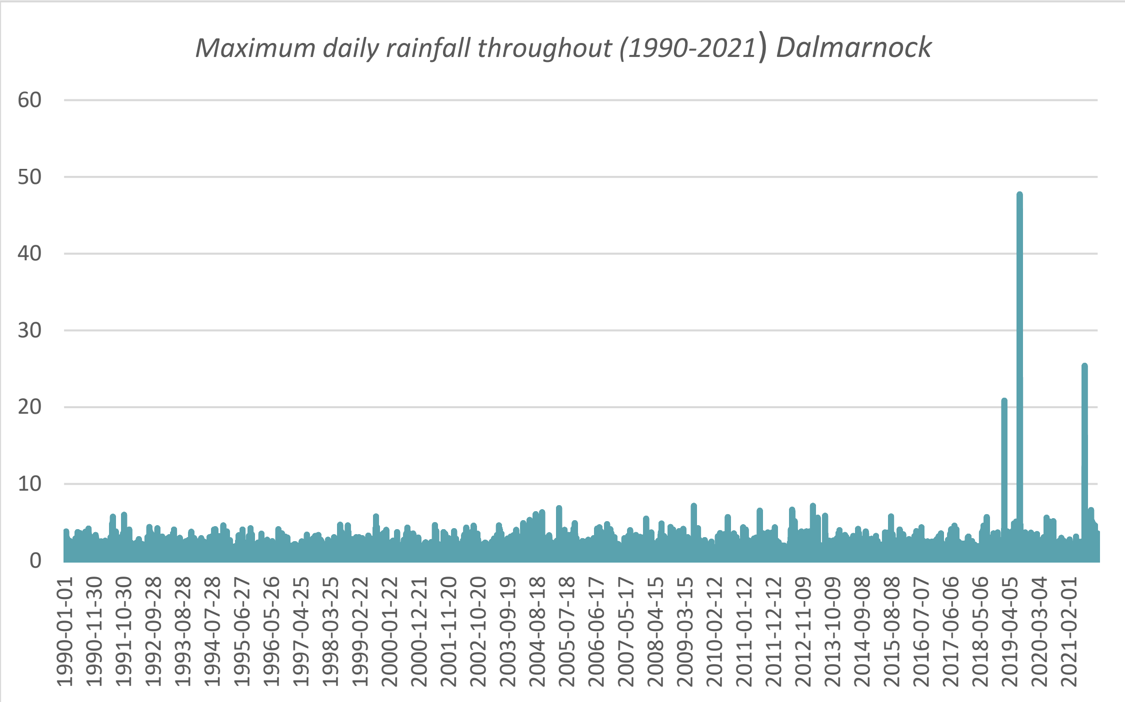

Figure 31: Maximum daily rainfall Dalmarnock (1990-2021)

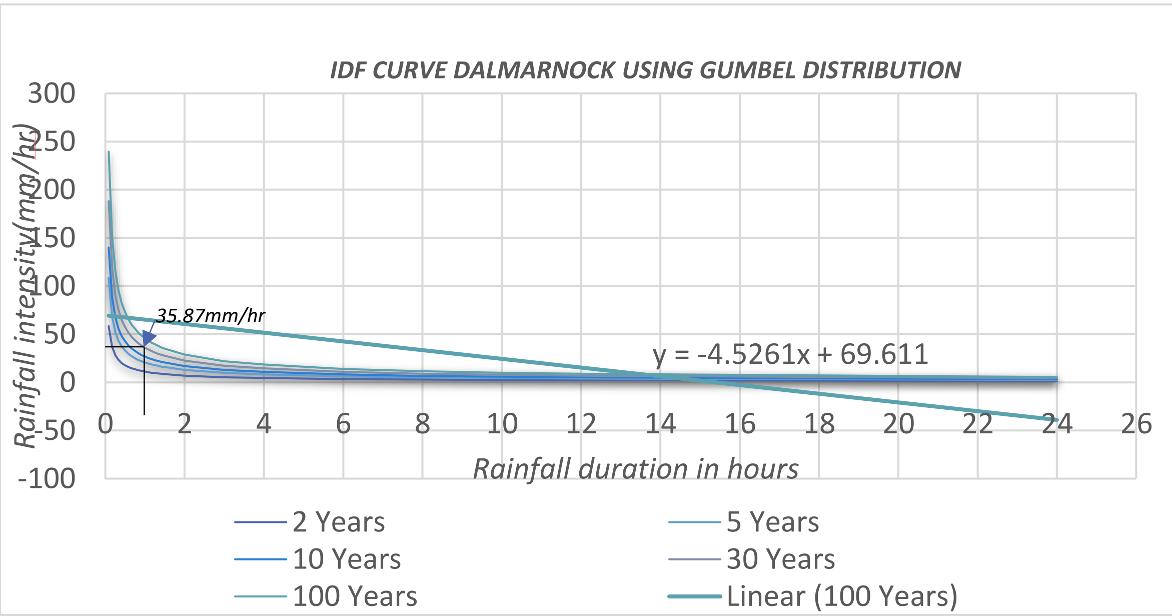

Figure 32: IDF curve from Gumbel distribution

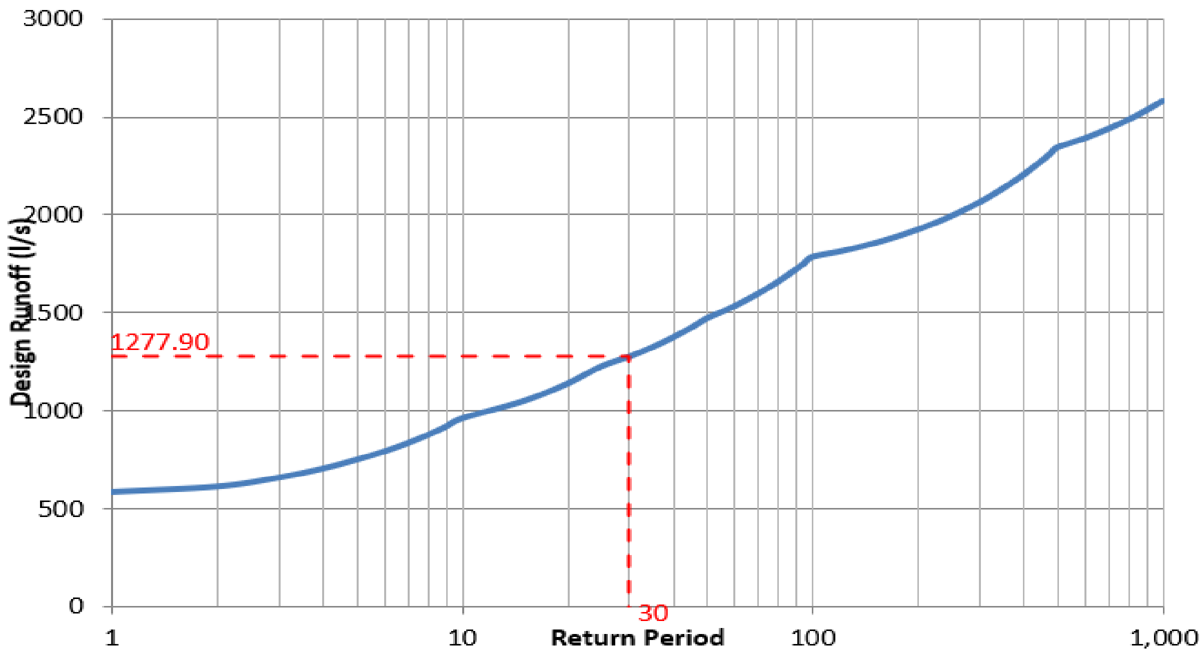

Figure 33: Design runoff Vs Return period graph IH124 method

Rainfall analysis was performed to find 1 in 30-year storm event using two different methods. Although Gumbel is a highly accepted method, it isn't very widely used in the UK (Rannard, 2022). It is extensively used in Canada &Asia (Svensson&Jones,2010). This method applies a reduction factor which considers different precipitation intervals for 24 h sub hourly rainfall and runoff records, and hence fails to explicitly consider the temporal variation of runoff (Perez et al, 2022) The UK does not have an empirical reduction formula for sub-hourly precipitation, therefore we used Indian Meteorological formula to find sub hourly precipitations (Rasel & Hossain, 2015).

Then, IH124 method was used to quantify 1 in 30 years rainfall in Dalmarnock. The results obtained were tabulated in

1 in 30 years	Intensity Gumbel distribution	Intensity IH124 method	Remarks
Peak Rainfall	816.69l/s	1227.90l/s	

Table 6: Peak rainfall for 1 in 30 years

Climate change allowance (40%)	1143.366l/s	1789.06l/s	40% allowance (Susdrains, 2020)

The highest rainfall was achieved through the IH124 method i.e 1143.36 l/s and 1789.06l/s, when climate change allowance of 1.4 was input; and this was chosen as design storm intensity. It also meant additional 31% drainage capacity due climate change. The current drainage system in Dalmarnock cannot cope with any further increment in rainfall. Thus, we explored the alternatives in drainage management to choose the site-specific and most efficient option for Dalmarnock.

There is two options to choose from. One is expanding the traditional grey system and the other is using retrofit SUDS system to tackle the drainage problem. Moreover, what kind of SUDS component can be used to gain multitude of benefits? This question was addressed through a site-specific SWOT analysis.

3.3 Swot analysis

Every site has unique characteristics, therefore, the extrapolation of SUDS from one area might not work in the other. They require thinking holistically with its setting and context in relation to neighbouring plots so that the downstream water is safe. For the most part the selection of SUDS depends on Land spatial characteristics, Site Natural characteristics, social characteristics and planning and governance. SWOT analysis was used in the decision-making process for what kind of SUDS components to choose for the area. We found the typology of SUDS by comparing 3 of the most used systems; Swales, permeable pavements and bioretention system. Table 7: Factors influencing SUDS selection Source: Author's own adopted from literature review, is used to choose appropriate SUDS.

Factors	Variables	Description	Source
Land Spatial Characteristics	LandUse/Land Cover Catchment size Area available for SUDS	Alteration of land cover resulting in considerable changes to the dynamics of the hydrology. The cost of constructing a SUDS scheme is inherently variable and will depend heavily on the size of the contributing catchment area Area determines the type of SUDS to be adopted.	(Rozos & Makropoulos, 2012) (UK, 2011)
Site Natural Characteristics	Soil Type	Groundwater presents limitations to the desired extent of infiltration-based SUDS & Flood magnitude and peaks in basins is influenced by antecedent soil moisture.	(Yang et al., 2011)
	Micro Environment	Trees and canopy reduce runoff in urban areas by reducing throughfall and increasing infiltration of rain.	(Armson et al., 2013)
	Topography	Confirms the important impact of the level of details of topography on both surface and sewer drainage systems and how it affects runoff amount.	(Salvan et al., 2016)
	Flood Impacts	Urban designers need information on rainfall statistics With return periods and past flooding events	(Ferrans et al., 2022)
	Runoff quality	Runoff characteristics of each event monitored provide information to support the implementation of compensatory techniques for urban drainage that reduces that specific pollution.	(Christian et al., 2020)

Social Characteristics	Income Heritage Citizen participation and Inclusivity	Micro approach of the SUDS is more favorable for communities or area with low average income. Any new subsurface structure can potentially damage archaeology, directly or indirectly through water balance changes causing accelerated decay of Heritages Quantitative risk analysis is often inadequate, and engagement of the different stakeholders is considered as an important factor in the implementation of the successful flood management measures.	(Kuller et al., 2017a) (de Beer & Boogaard, 2017) (Raymond et al., 2017)
Planning and Governance	Capital & Operation and maintenance costs Political stability Coordination with other stakeholders and investors.	Application of SUDS is highly dependent on its O&M costs, including return on investment and have "profit" margins. Ongoing and strong political commitment is imperative for SUDS implementation Involves multiple actors across sectors and levels of decision making.	(Ferreira et al., 2022) (Kuller et al., 2017b) (Cumiskey et al., 2019)

Table 7: Factors influencing SUDS selection Source: Author's own adopted from literature review

3.3.1 Swales

STRENGTH	WEAKNESS	OPPORTUNITIES	THREATS
More resilient to reduce peak flow for short durations rainfall compared to previous pavements and bioretention cells. (Dutta et al., 2021)	Suffer a significant performance decline in winters.(Zaqout & Andradóttir, 2021)	Most efficient for draining in Highways and linear structures(South Gloucestershire,2021)	Declined efficiency overtime, due to accumulation of pollutants by settling and filtering processes.(Leroy et al., 2016)
Can serve as thermal regulators, owing to their capacity to provide higher temperature in winter and vice versa in summer.(Sañudo-Fontaneda et al., 2020)	Incorrect construction results in different heavily contaminated loaded zones leading to massive failure.(Rommel et al., 2019)		
LCA revealed they had very low environmental impact(Fathollahi & Coupe, 2021)	Take up maximum space (CIRIA,2015)		

Table 8: SWOT analysis of Swales

3.3.2 Permeable Pavements

STRENGTH	WEAKNESS	OPPORTUNITIES	THREATS
Suitable for settlements with high building density such as parking spaces, sidewalks etc.(Rahman et al., 2015a)	LCA revealed high environment impact(Fathollahi & Coupe, 2021b)	Excellent choice of construction near trees as they allow air and water to enter the soil which is beneficial for their growth (CIRIA, 2015)	If hydraulically overloaded, can cause soil instability risks from over saturation (CIRIA, 2015)
Performs adequately in cold climate throughout the	No direct biodiversity benefits. (CIRIA,2015)	They represent an opportunity to employ recycled/reused materials in	Not ideal for high traffic/speed areas because

cycle of freezing and thawing. (CIRIA,2015)		urban retrofitting for reduction in carbon footprint(Rahman et al., 2015b)	of its low load bearing capacity. (Un, 2010).
	Does not take part in removing total nitrogen (TN) because of lack of anaerobic conditions(Brown & Borst, 2015)		

Table 9: SWOT analysis of permeable pavements

3.3.3 Bioretention system

STRENGTH	WEAKNESS	OPPORTUNITIES	THREAT
Is efficient in nutrient removal(Zhang et al., 2019), dissolved metals remova(Lange et al., 2020), biological transformation of pollution(Laurenson et al., 2013), heavy metal removal and hydraulic conductivity and water holding capacity to improve and optimize the technical performance(Fassman-Beck et al., 2015).	The bioretention area to catchment area ratio of systems needs consideration to avoid unnecessary environment impacts associated with over-dimensioned systems(Öhrn Sagrelius et al., 2022)	Offer amenity, CO2 sequestration, biodiversity benefits and groundwater recharge opportunities(Kapetas & Fenner, 2020)	The regions with soils of low permeability coefficient (e.g., compaction, clayey texture), special care should be taken in terms of structural pathologies, such as erosion, leading to water bypass in the system(de Macedo et al., 2017)
Better Life cycle performance as compared to permeable pavements.(Bhatt et al., 2019)		For public spaces, bioretention systems were the most suitable SUDS for all urban configuration types.(Fonseca Alves et al., 2022)	

Can be integrated into existing landscaped areas, within traffic islands or underused parking or road space.(CIRIA,2015)			

Table 10: SWOT analysis of Bioretention systems

Bioretention system was found to be the most suitable method for three major reasons:

1. High runoff pollutants in the site due to existing morphology (parking spaces, Wastewater treatment plant and pharmaceutical pollutants)
2. Highly dense area with limited space.
3. To enhance the biodiversity

3.4 Cost Analysis

3.4.1 Retrofit Bioretention System

There is greatest flexibility in the ponding depth, filter media depth and the depth of the internal water storage reservoir beneath the optional underdrain pipe.

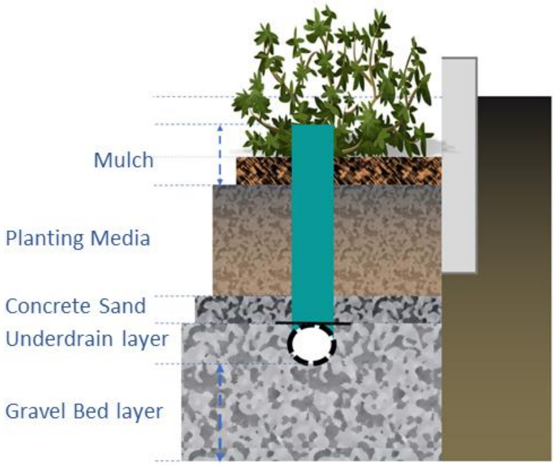

Figure 34: Components of Bioretention System

(CIRIA manuals suggest the maximum dimension of bioretention system should not be greater than 0.8ha). Typically, the surface area of the bioretention system should be 2–4% of the overall site area to be drained to prevent rapid clogging of the bioretention surface (Payne, et al., 2015).

Furthermore, impermeable liners may be required to prevent infiltration if the selected saturated filter medium hydraulic conductivity is less than 10 times that of the local soils. It may also be necessary to add an impermeable liner to the filter medium's sides to prevent horizontal exfiltration and subsequent short-circuiting of the bioretention system's treatment.

The surface area of our site =30000sqm

Assuming, Area of bioretention system=30m*15m

Top layer =400-600 mm or deeper (To provide sufficient depth to support vegetation Shallow systems are at risk of excessive drying)

Middle layer =>100mm (CIRIA,2015)

Drainage layer (base) = min 50mm cover over underdrainage pipe (to prevent pipe from clogging)

Assuming Total depth = 1000mm

Volume =30*15*1 = 800 cubic metre

Item	Depth	Quantity	Unit	Average unit price in $	Average total cost
Perf. PVC Underdrains (includes cap/elbows)-10" PVC	8	30	Metres (Running length)	70.53	2115.9
Bioretention Layer-Planting Media	500	30*15*0.5 225	Cubic metre	238.87	53745
Bioretention layer-Concrete sand	300	30*15*0.3 135	Cubic metre	101.43	13635
Drainage layer -Gravel	200	30*15*0.2 90	Cubic metre	88.35	7920
Excavation	1000	450	Cubic metres	26	11700
Sum					**$89115** **£77,423**

Table 11: Cost analysis of bioretention tank based on - (DOEE, 2018)

According to (CIRIA, 2015), quarterly maintenance is recommended for bioretention systems.

SuDS Feature	Lower bound (£)	Upper Bound(£)	Unit
Permeable Pavements	0.3	1.3	per m^3 stored volume
Swales	0.1	0.1	per m^2 swale area
Bioretention	0.1	0.4	per m^2 bioretention area
Source: (Stevens & Ogunyoye, 2012)			

Table: Annual maintenance unit costs

Maintenance cost for 30 years= quarterly maintenance for 30 years taking £0.3 as unit average cost,

= 0.3*450*4*30= £16,200

Total cost of bioretention system = Construction cost + maintenance cost = 77423+16,200=£93,623

3.4.2 Traditional Grey Retrofit

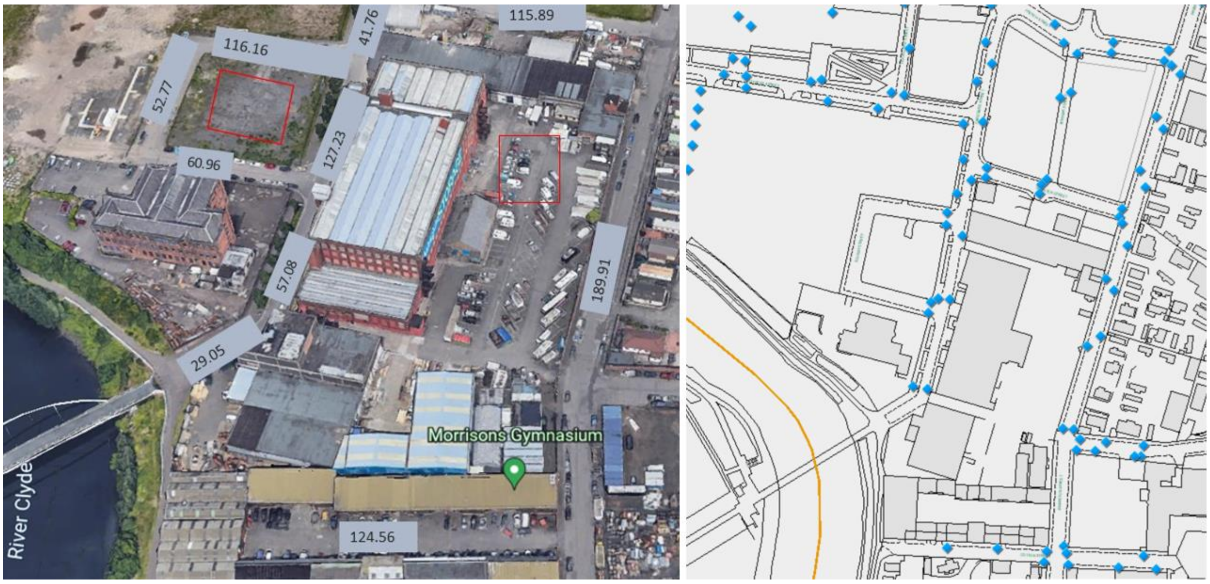

Figure 35: (a) Map showing perimeter of pipelines in the site area and (b) Map of Gullies in the site area (Source: Glasgow city council)

To retrofit grey infrastructures, Perimeter of new retrofit pipelines(figure 30 and 31) for the site area = sum of pipelines on both sides

= (124.56+189.91+115.89+41.76+127.23+57.08+29.05)*2= 685.48*2= 1371m

Pipe diameter = 150mm

Standard cost for sewer laying per m for 150mm pipes in Sub-urban highways = £209 (Keating, et al., 2015)

Total construction cost= Unit cost per m * perimeter

= 209*1371 = £286,530

3.5 Benefits Analysis

For the benefits, we used benefit transfer method from (Flood Authorities, 2013) and from the literature review and PESTEL analysis.

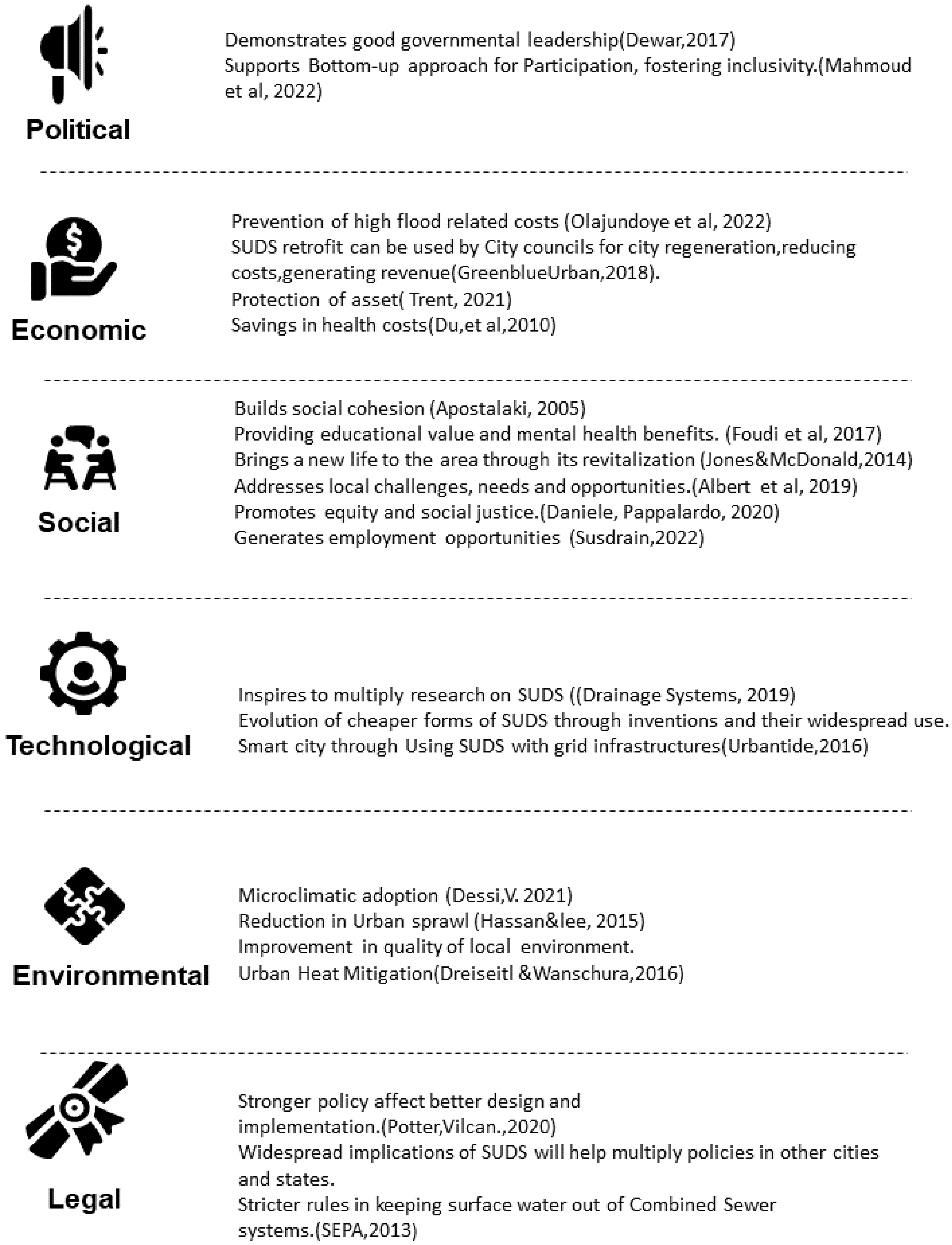

Figure 36: PESTLE Analysis for SUDS retrofit

● No benefits

●● Low

●●● High

●●●● Very High

Benefits	*Grey Retrofit*	*Bioretention system*	*Swales*	*Permeable pavements*
Attenuation	●	●●●●	●●●●	●●●
Water treatment (Removal of TSS, N,P, heavy metals)	●	●●●●	●●●	●
Infiltration	●	●●●	●●●	●●●
Water reuse	●	●●●	●●	●●
Biodiversity	●	●●●●	●●●	●
Education	●	●●●●	●●	●
Amenity	●	●●●●	●●●●	●
Microclimate	●	●●●●	●●●●	●
Open space	●	●●	●●	●

Figure 37: Comparison using benefit transfer and literature review

Source: (Flood Authorities, 2013)

From the literature, it was found that most SUDS components are cheaper than their traditional counterparts (Susdrain, 2022). A cost-benefit analysis was performed as a decision support tool, to evaluate the monetary feasibility and perceived benefits.

Because there has been a plethora of research done in the UK regarding SUDS, it was quite easy to find individual costs of its components. However, these rates need to be revised for accounting for inflation as they are almost more than a decade old. Moreover, we could not find unit cost of bioretention systems in the documents published in the UK. Therefore, we opted another document to find them which was USA based. The units were converted and thus the final price was found out. Unit costs of sewer pipes was readily available in UK. Unsurprisingly, retrofitting bioretention system was found to be much cheaper than retrofit grey infrastructures.

	Construction cost	Maintenance cost	Total cost
Grey Infrastructures	£268,530	-	**£268,530**
Green Infrastructures (bioretention system)	£77423	£16,200	**£93,623**

Table 12: Final cost of Bioretention systems and Grey Infrastructures

From the benefit transfer framework and PESTEL analysis, it was evident that green infrastructures can provide a more holistic development in Dalmarnock, which will benefit the society, biodiversity, and environment, which grey alone cannot.

$$\left(\frac{\text{Cost}}{\text{Benefit}}\right)_{\textit{Green}} > \left(\frac{\text{Cost}}{\text{Benefit}}\right)_{\textit{Grey}}$$

3.6 Interview analysis

3.6.1 Findings from interviews

An inductive analysis was performed to understand the main concepts and ideas of regeneration and SUDS in Glasgow and the themes were identified from the transcript. Some of the highlights from interviews were as follows.

INFRASTRUCTURE FIRST APPROACH

If blue-green infrastructure for water management is considered early as part of an "infrastructure first" approach, then Suds for flood risk control can easily be integrated inside urban regeneration

In the past, regeneration hasn't used an infrastructure-first strategy, thus any SUDS that were provided—if any were provided at all—were done so as an afterthought and weren't very good. The emphasis was frequently on keeping watercourses at the back of houses and burying them underground in pipelines or culverts. The water reaching the surface must follow gravity flow and to achieve that, the conveyance flow paths for water must be highly considered from the beginning of the design process. This will facilitate the integration of the SUDS with other regeneration components, such as public open space and access routes, to provide an integrated approach to blue green in the urban realm that can provide numerous benefits, including flood risk management, a habitat for biodiversity, urban cooling, battling pollution, noise reduction, and general health and wellbeing benefits.

and access routes, to provide an integrated approach to blue green in the urban realm that can provide numerous benefits, including flood risk management, a habitat for biodiversity, urban cooling, battling pollution, noise reduction, and general health and wellbeing benefits.

Recent examples from the public sector, including those at Sighthill (Haugh, 2021) and in the Clyde Gateway region, show that putting infrastructure first may be effective and enable the delivery of the advantages of retrofit blue-green infrastructure to reinforce regeneration. Water is more often being managed on the surface and being used as a feature, as part of delivery of Scotland's vision of water resilient places.

SCALING UP SUDS RETROFIT

The main issue facing Glasgow, like most cities throughout the world, is that most of the wastewater (sewer) network is a "combined" drainage system, in which surface water and foul flow are merged.

As a result, it is insufficient to handle climate change and growing urbanisation, which will bring more heavy rain and overburden the system, leading to CSO overflows and flooding. Keeping this in mind, investment in retrofit SUDS for urban areas is increased, to attenuate flow to the combined system.

Interviewee responded that SUDS delivery for new (re)developments is generally good, but SUDS retrofit for existing areas needs to increase in its scale and ambition. There is scope for better integration of blue-green approaches, rather than below ground storage areas and permeable paving, but often the choice of SuDS measure is dictated by the available space. Moreover, In Glasgow, and elsewhere in the UK, there is a lack of quantitative monitoring of SUDS, which means there is a lack of data on the long-term performance and benefits of SUDS.

SUDS IN THE CITY

In the case of regeneration in the city; for private investors to invest in SUDS, High quality delivery of SUDS remains a challenge as the density of development, for commercial reasons, is the main driver of regeneration. The public investors, nonetheless, do not have the commercial motive and hence can stay on the frontline and lead by example.

Glasgow City Council has delivered a number of surface water management plans, the Avenues Project will deliver significant retrofit in the city centre, the Liveable Neighbourhoods programme should deliver SUDS, and the Active Travel programme should also deliver SUDS alongside active travel routes

Another interviewee responded that *it is a very practical approach to use SUDS for regeneration and flood mitigation. Furthermore, when it comes to funding, when we showcase the pay benefits together, it attracts more money.*

North Glasgow SMART Canal project: A successful regeneration with SUDS

The current drainage system in North Glasgow is not fit for purpose because it has exceeded the combined sewer capacity, and therefore substantial amounts of land had been rendered unusable. The smart canal and SUDS approach will provide North Glasgow with a fully functioning drainage system which is able to dynamically respond to fluctuating precipitation, thus, freeing up previously unusable land to developers. It is estimated that almost 110 hectares land will be unlocked for regeneration, investment, and development. The Smart canal uses grid infrastructures such as sensors with Sustainable urban drainage systems. SUDS play a crucial role in slowing the water down so that the canal takes its time to get filled in the event of the rainfall.

The interviewee responded *that's deliberately regeneration. It's also connected to the Claypits local nature reserve, which is now very, very well used in terms of health. Furthermore, because of that, the NHS Scotland put in 100,000 so that there was a link between two of the health centres in the area. And they're deliberately using the local nature reserve as a therapy tool*. What's even more great is Scottish government are trying to make these regenerated sites, a 20 mins community, promoting more sustainable living for the residents including active travel and social cohesion. (Hayes & Ian, 2022). The Smart Canal is helping to manage flood risk, allowing areas of the city to be regenerated whilst also providing safe active travel routes for people to walk, wheel and cycle.

CHALLENGES

Some of the key challenges that were outlined was

- SUDS retrofitting is expensive and typically disruptive. Other than the Scottish Government Capital Grant and the Nature Scot Nature Restoration Fund, there aren't many financing sources available to implement retrofit SUDS.
- There is a lack of local government funding for maintenance of open spaces, including parks and SUDS.
- There is a scarcity of integration between Climate mitigation (net zero) activities and Climate adaptation activities. As climate mitigation actions are pushed forward to try to deliver 2030 and 2045 net zero goals, there is a lack of consideration of also delivering climate adaptation benefits. This lack of collaboration risks widening the 'Adaptation gap'.
- To find ways to introduce more private finance and urban green infrastructures.

4 DISCUSSIONS

This chapter discusses research findings in relation to the objectives of this dissertation, as derived from literature, interviews and analysis.

4.1 To review the history of practice of SUDS and regeneration in Glasgow.

Regeneration

As has been explained in chapter 1&2, regeneration in Glasgow has a far from successful history. Past regeneration did not focus on people and quality of areas. Gentrification was imposed on them with no regards to their ancestral homes. As the redevelopment areas evolved, the small business that existed were taken down, people were made to move elsewhere, and the existing social fabric of the place was torn apart without any considerations. Authors have explored the role of small businesses in strengthening the local economy (products and services sourced locally) and its positive effect on local businesses and social networks, with implications for community building and improved sense of place (Sacks, 2002; Ward & Lewis, 2002). Despite this, benefits of retaining some of the existing businesses as re-development areas evolve were often neglected. Overall, gentrification was the most prominent thing when it came to regeneration; any area that was beautified was done to sell it to affluent people, while the working class were made to leave their homes, promised falsely to get another better housing to live in.

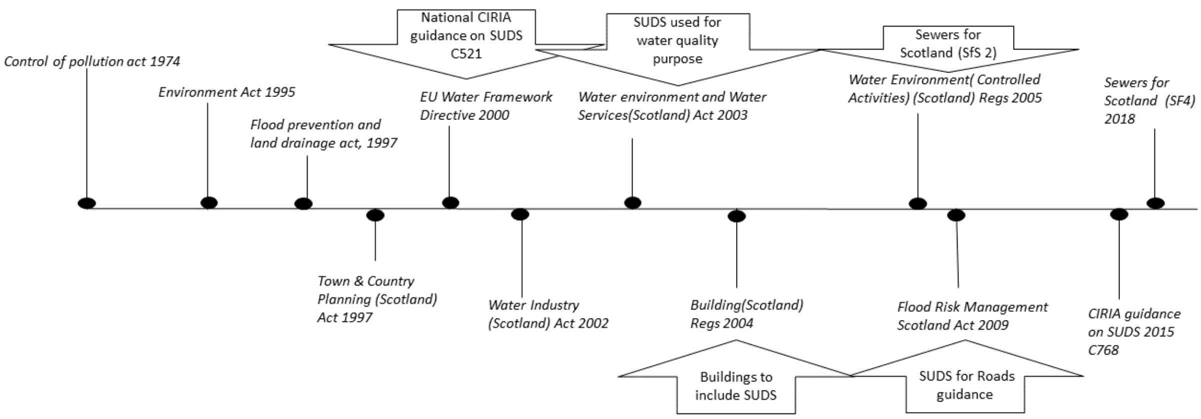

Figure 38: Evolution of SUDS in Scotland

Scotland was the first country in the UK to introduce SUDS. It has led many successful examples of SUDS, with Glasgow in particular. There has been a lot of progress over the last few years and Glasgow is progressing faster than most other Scottish cities, but despite an early start, Glasgow is still lacking in number of SUDS.

Figure shows the historic barriers for SUDS in Scotland. While some of them, such as technical barriers, costing mechanisms have been removed because of various guidance publications, the others remain to this day. People still do not know the benefits SUDS offers, there is still unambiguity in adoption/maintenance, and it lacks funding mechanisms.

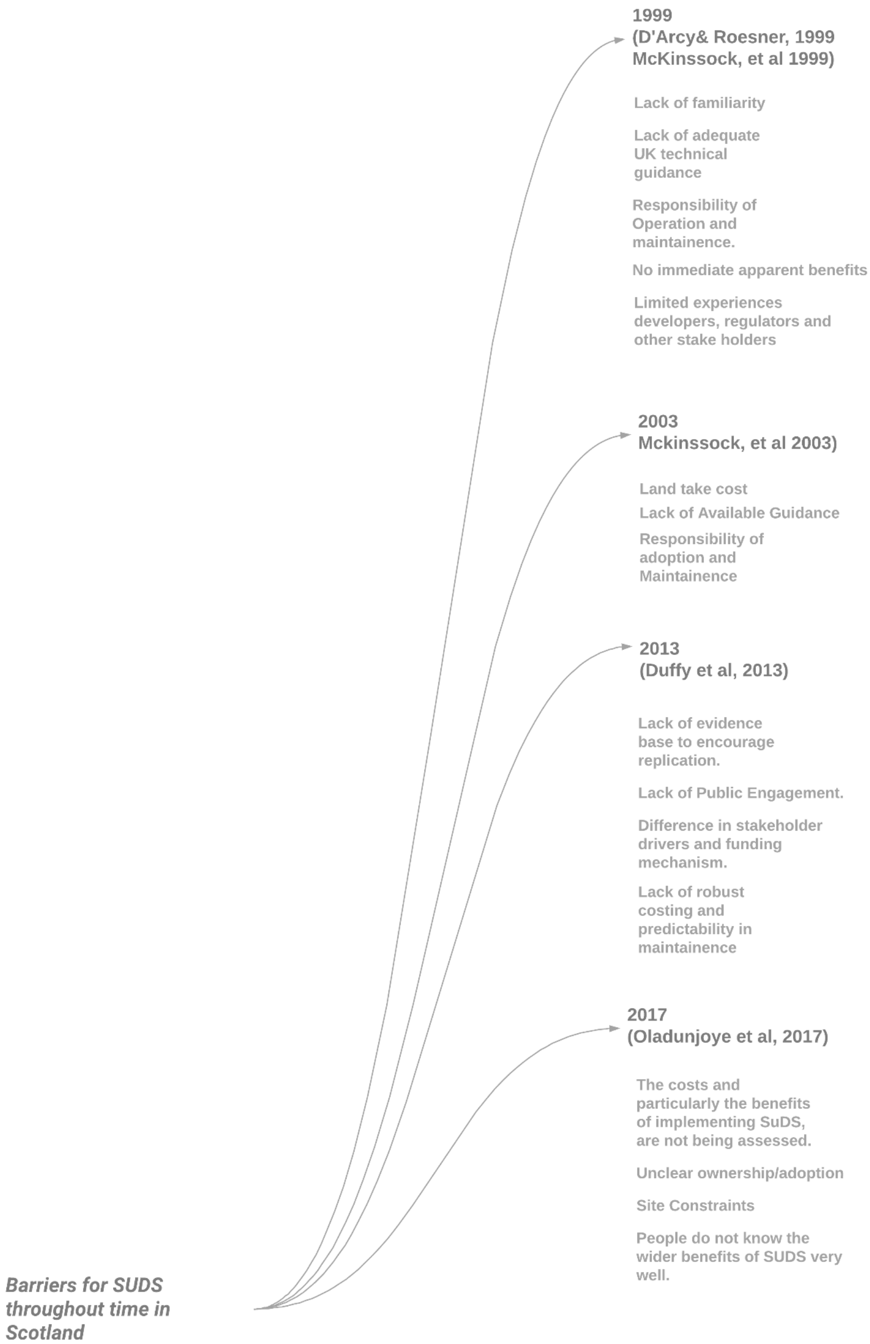

Figure 39: SUDS barriers in Scotland throughout time

4.2 Analyse cases of integrating suds with regeneration in Glasgow and develop insights

It is a ubiquitous concept that urban space is a product of complex, often contradictory, social interactions, which are simultaneously social and spatial(Ordor & Michell, 2022) .

Experiential learning

For most of the part, Glasgow has learned and accepted these past mistakes in regeneration, and the city council and other organizations are now investing in a more equitable regeneration. Glasgow City Council has a Strategic Drainage surface water management strategy that aims to reduce flooding while stimulating regeneration and promoting environmental improvements. The idea of emerging SUDS with regeneration is still in its rudimentary stage as there are no such policies yet. However, projects such as the SMART canal project have demonstrated from the Sighthill Transformational Regeneration Area (TRA), known as the "biggest regeneration" effort in the UK outside of London, that the area what once reflected the doom & gloom of the old dead industrial area that Sighthill one was ;is now unrecognisable, with canal walkways, neatly stacked houses, and thousands of trees (Haugh, 2021).This is a quintessential example of regenerating areas with the use of SUDS. This result can be used as a prototype for other regeneration projects in the future.

Participatory Planning

Among the many hurdles of SUDS integration, one lacks public participation in planning process. Jane Jacob, in Life & Death of great American cities, “Cities have the capability of providing something for everybody, only because, and only when, they are created by everybody”. Fostering transdisciplinary for co-identifying and co-designing the urban space among Engineers, Urban Planners, Government, and the public is imperative for any successful urban planning. Owing to its troublesome past in regeneration, there is a historic lack of community experience in socio-innovation. There is a need to find new ways to form and sustain partnerships with communities, especially in flood prone areas. Citizens here are still unaware of plethora of benefits SUDS can provide to them. Although efforts are being made by organizations such as Nature Scot through initiatives such as blogging and interviewing people, the scale is not big enough and more efforts are required.

Killing two birds with one stone

It is not only cost effective to use SUDS for regeneration and flood mitigation altogether but also it is a great way to attract investments in SUDS. One of the biggest impediments of SUDS is lack of funding. If we can portray SUDS as a lucrative business, which they are, there will be more investments coming from private sectors and public sectors. For example- One way to subsidize SUDS is through flood insurance companies, because it means the insurance pay-outs can go to them.

Next, the literature explains how current levels of monitoring and evaluation of existing SUDS were either 'reasonable' or not very effective' which corroborated with our findings from the interview that it is still not monitored. This is resulting in a great under appreciation of SUDS and consequently limiting its use. It is a vicious cycle that needs to be broken.

Effects of Brexit on GI funding

The UK government has established the Shared Prosperity Fund to compensate for the loss of EU funds as a result of Brexit. By 2024/25, the Fund will have provided £1.5 billion per year. According to the prospectus for the UKSPF, funding will be allocated to local areas across the UK using formulas rather than inviting competitive bids. This fund, however, has a much broader scope than GI because it invests in public services, living standards, housing, local businesses, and so on. The SPF's operation is not yet clear. The formulas largely replicate the amounts received by areas from EU structural funds, with some area-specific adjustments. Contracts made as part of the 2014-2020 programme are being honoured by the EU. In practice that funding is supposed to be spent by end June 2023. After that there is no EU funding for GI in the UK.

4.3 To explore the commonality between urban regeneration and flooding.

Urban planning must adopt a broader perspective on addressing several polycentric requirements and attempting to make and identify reasonable trade-offs between various outcomes and perspectives on land use. The trade-off in this case being land allocation for SUDS for its many benefits. The trade-off transferring this urban planning viewpoint to sectoral planning initiatives (like FRM) is crucial, especially in industries where the idea of resilience as a comprehensive and all-encompassing term is expanding.

In the face of influences that are destroying the physical environment, causing social isolation, disintegrating communities, and destroying our sense of place, urban policies must embrace sustainability, diversity, and community. These three keywords are inextricably linked to one another.

There seemed to be an inherent interdependent relationship between Urban flooding and Urban regeneration, an interplay, as one thing could not be achieved without another. SUDS used for regeneration provides flood mitigation benefits, and SUDS for flood mitigation provides amenity benefits, regenerating the area. Moreover, both uses for SUDS provide other similar and more comprehensive community benefits, neighbourhood resilience, environment revival, even economic benefits. Urban regeneration can be a more extensive umbrella of which flood mitigation is a part, and the sectoral policies should soon realize and incorporate it in cities.

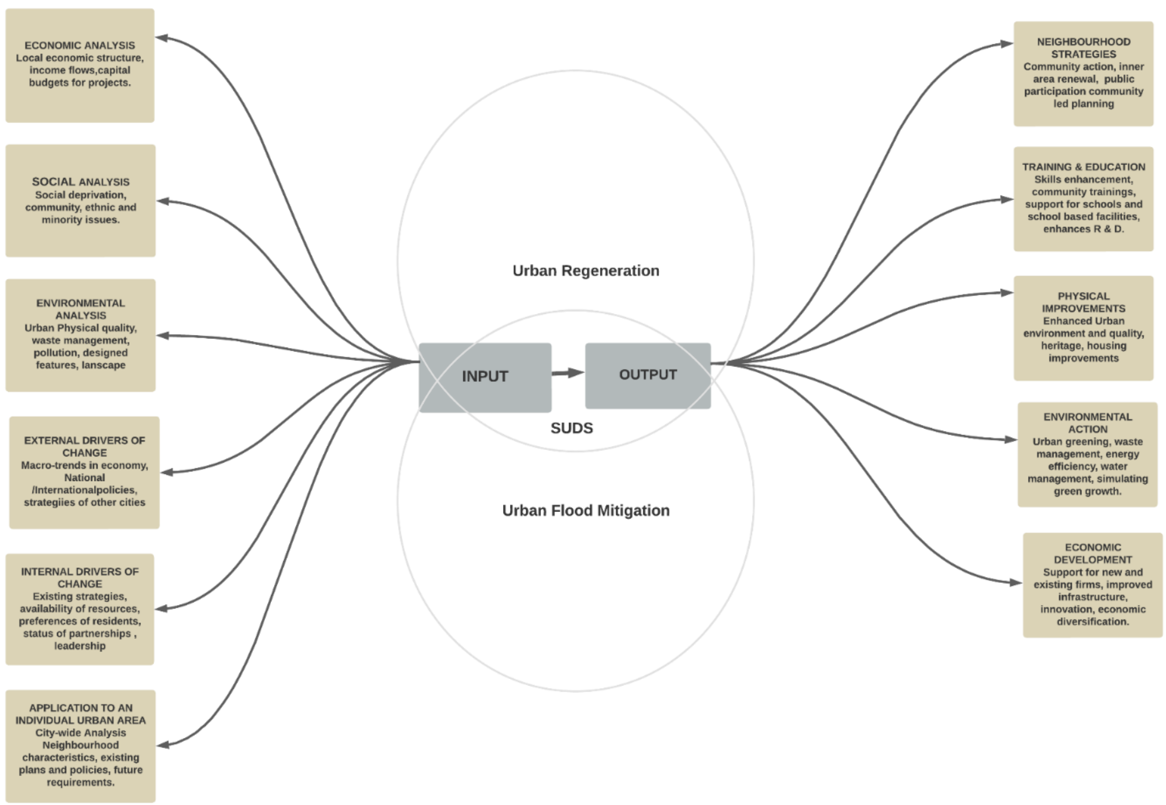

Figure 40: Adaptive system through SUDS for Urban regeneration and Urban flood mitigation (Source: Conceptualized from (Robert&Sykes, 2003))

4.4 To advocate for a more equitable urban environment through wider SUDS implementation.

From the late 1990s, there has been growing policies and emphasis on supporting people as an integral part of restoring places. No city is immune when the external forces begin to dictate the need to adapt, or the internal forces that are present within urban areas and which can precipitate growth or decline in that area (Roberts and Sykes ,2000). Moreover. the challenges faced by those in deprived neighbourhoods require collective interventions, which considers local, regional, and national point of views. Dalmarnock, the case study area is one of the deprived areas.

Dalmarnock: The context

Like many other areas in Glasgow, Dalmarnock's history has been very bleak. The place was in ruins due to deindustrialization in the 1960s. There was social and economic upheaval when the population was reduced from 50,000 to more than 2000. The Margaret Jaconelli case (BBC, 2011) comes to mind when one thinks of Dalmarnock, who, like many others, was forced to leave their home when Glasgow was chosen as the host for “Commonwealth games" and What is so wrong with this picture is that before Glasgow was chosen to host this prestigious game, Dalmarnock was entirely off the government's radar. The area had been derelict for decades, with no investment pouring in. However, when the area got some development prospects, it was devoid of public consultation, so there were never genuine possibilities for communities to better their quality of life in Dalmarnock. Communities were only passive receivers of plans which were devised by governments and private sectors. Unsurprisingly, past approaches to neighbourhood renewal have failed to revitalize this area, and even today it remains one of the most deprived areas in Glasgow.

(a) (b)

Figure 41: Pictures depicting deprivation and dereliction in Dalmarnock

Winds of change

Rainfall analysis showed an increment of at least 31% of rainfall in Dalmarnock in the next 30 years. The current drainage capacity cannot cope with this and therefore chronic damage and loss due to flooding is a big probability in the future. However, SUDS analysis put a cogent argument of how SUDS can be used for surface water management in the area and its revitalization with acknowledgement of minorities and vulnerable groups.

The South Dalmarnock Integrated Urban Infrastructure Framework ("the Framework"), which was approved by the URC Board in August 2011 and endorsed by the Council's Executive Committee in March 2012, outlined the 20-year redevelopment goals for a 99-hectare area shared by local communities, businesses, the Council, Clyde Gateway, stakeholders, and partners. This integrated surface water management system, which is critical to unlocking development activity, is now finished. This system is the final component of the Framework area's Regional Sustainable Urban Drainage system. However, there is also a possibility that the past might repeat itself, the regeneration schemes through SUDS might be just another way to boost the economy by displacing the vulnerable communities and beckoning big businesses and affluent people in the area. One way to make this possibility smaller is to engage in public participation. When public becomes aware of their rights, there is no force that can make them go back to being silent on unfair treatments.

Change of rhetoric

Glasgow is gradually coming to appreciate SUDS and its potential benefits. As part of the 100,000 raingardens project in Scotland, inspired from Melbourne, Philadelphia and Portland; NatureScot is delivering raingardens for surface water management, greenspace creation, and flood mitigation. (Naturescot, 2021) A Glasgow-based pilot is operating in the vicinity of Queensland Court and Gardens, a Southside Housing Association property in Glasgow's south. General awareness will be raised through public engagement and a media campaign, while a variety of events across Glasgow will provide an excellent forum for communities to influence the shape of developments. The project will contribute to Glasgow's policies and plans while reinforcing use of SUDS for wider regeneration.

Another project, delivered through the Metropolitan Glasgow Strategic Drainage Partnership (MGSDP), is Sustainably Drain Glasgow!. It also uses raingardens to reduce the impact of flooding in vulnerable communities, homes, businesses, and transportation links while also improving greenspace and preventing pollution. (Scotland, 2020)

Next, the Avenues Project will deliver significant retrofit in the city centre, the Liveable Neighbourhoods program (GCC, 2021) should deliver SUDS, and the Active Travel program should also deliver SUDS alongside active travel routes.

Moreover, Clyde Gateway Initiatives (NatureScot, 2021) will promote green infrastructure, community connections, and work and recreation areas in Malls Mire. It aims to strongly support proposals that improve the mental and physical health of people in need, such as Toryglen and its neighbors, to revitalise an area that had suffered from decades of declining prosperity, education, employment, and health issues, like Dalmarnock. 16 hectares of vacant and derelict land was transformed into a woodland retreat. It is another amazing example of flood mitigation through regeneration using SUDS.

Figure 42: Transformation of Malls Mire Area through regeneration (a) Before (b) After

5 CONCLUSIONS

The physical forms of cities should be underpinned by values and an aspiration to support social interaction, creating urban spaces where community and mutual support are strong. However, what happens when there are **w**idened income gaps, suburbs arranged based on class and race or ethnicity, when the bourgeois take up the better area of the city while the working class is left to live in deprived and unsafe living conditions? Additionally, what when climate change brings extreme weather events, causing massive damages to life and assets? As these areas might not be financially able to repair the damages caused by climate change or receive adequate assistance, (Majekodunmi et al, 2020) demonstrated that interventions, particularly those in deprived areas, would have the greatest climate-just and equitable impact.

SUDS as a safety net

"The range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time." –(IPCC,2007)

- Even though Scotland has not yet fully utilized its SUDS potential, it was found to be quite active in its strategies with it in recent years, especially Glasgow.
- As described throughout this thesis, SUDS can be an excellent adaptation strategy against climate proofing and adapting the cities against climate change. Additionally, SUDS benefits include the removal of pollution as well as possible co-benefits, such as carbon sequestration, support to biodiversity, social and economic use of spaces. Scotland has got the technical support to do this, but what it lacks is institutional and social pressures. Given the climate risk, identifying optimal opportunities to build, or retrofit SUDS must be a top priority for urban planners and governments.
- Regenerated urban areas improve flood resilience and allow society to better weather potential flooding while at the same time providing a better living space.
- The knowledge and needs related to the challenge or opportunity for SUDS for regeneration and flood mitigation was identified through literature, interviews, and analysis. The integration of SUDS into regeneration was found to be to be a rational solution, although necessary that the fragmented nature of knowledge across different departments should work together, and citizens' perception of SUDS is enhanced and ameliorated.
- A new approach to Urban Regeneration is advised, one in which "Infrastructure First" ideology is prioritized, one that makes urban spaces resilient to climate change and one engulfs ideas from planners and residents.

- Because the existing sewer network does not have the capacity to accommodate for more development works in Glasgow, through analysis and literature review, SUDS is clearly a better option for decentralizing the surface water flow and reduction in surface water flood risk.

SUDS: Certainty in an uncertain world

Urban planning is critical in establishing the framework for urban development, and if that development is sustainable or compromised depends on the quality of urban planning. The world's governments have come together and made policies that guide professionals toward sustainability. For example, sustainable Development Goal 11 implores "Make cities and human settlements inclusive, safe, resilient, and sustainable," COP26 advocates "supporting those most vulnerable to climate change while putting actions on adaptation." Moreover, the Paris Agreement has policies promoting and cooperating in preparing for adaptation to the impacts of climate change; to develop and elaborate appropriate and integrated plans for watercourse management. All these treaties have one thing in common: they have accepted that today's world is more vulnerable than ever.

There are uncertainties surrounding us. Natural disasters and health crises such as covid-19 are some of these uncertainties. However, human beings evolved from nature and are a part of it. Every biotic being innately finds solace in nature. It is a protector and a healer. When we incorporate SUDS into our environment, we attach pieces of nature around us. However, this is a capitalistic world where every action demands revenue and profit. Unsurprisingly, SUDS also gave an excellent benefit for money. We have explained how it can provide multiple benefits for various stakeholders if applied correctly. Because the old ways are not working, it seems logical to deconstruct contemporary urban policies and the goal of the sustainable urban development process is to achieve "Sustainability" status in urban communities. In other words, the goal is to create or strengthen sustainability characteristics in the city's economic, social, cultural, and environmental life. This dissertation demonstrated that SUDS, on the one hand, can be used in regeneration projects to construct an equitable, healthier, liveable environment and, on the other hand, prevent biotic and abiotic components from the deadly effects of flooding while boosting the economy and community values, in other words, life by enhancing essential life domains through the built environment.

5.1 Limitations of the study

This study aims to demonstrate how to build the integration between SUDS and urban regeneration and showcase its positive effects in the light of social equality and climate change. However, there are some limitations in the process.

1. Quantification of rainfall that SUDS can drain would have given a concrete picture of flood mitigation capacity od SUDS, adding more depth to the study.

2. GIS-based multi-criteria approach might have limitations such as being inappropriate or inadequate.

3. This dissertation lacks first a hand public perception of SUDS as only experts were asked about their point of view and not the public.

4. Benefits of SUDS was only qualified and not quantified because it was beyond the scope of this thesis.

5. Unit costs of bioretention systems were not found in standard UK manuals, therefore a manual from the USA must be used with converted units. It can give an inaccurate cost.

6. The cost of SUDS in our analysis was quite less when compared to the cost of traditional drainage system. However, the reasons can be because this was a small SUDS system and the area it was built on a suitable location, with a low permeable soil type with no groundwater vulnerability, as mentioned in Figure 3: Factors affecting cost of SUDS Source: (Albert et al, 2020). This does not mean every SUDS component are cheaper than its grey counterparts.

5.2 Recommendations

1. Glasgow needs to come up with creative ways to allocate funding for SUDS. The issuing of green bonds from organizations like the Glasgow City Council, allowing investors to get a more secure return on their investment could be a way to attract more money for SUDS. Another way was to make the funding streams available to a housing association providing affordable homes for social rent if they can put in SUDS and get paid for the flooding. This will be providing developers with a bit more money and they don't have to assign a proportion of their development to high value houses, reducing gentrification effects.

2. Because retrofitting SUDS is disruptive to the ground, the utility service providers and SUDS professionals are recommended to have a better coordination.
3 Due to the growing risk within FRM, regeneration initiatives call for collaboration among all parties involved in the risk chain to proactively reduce risk and improve the city's and citizen's health.
4 Rather than fragmented or governance strategies, there should be deeper integration between flood management and regeneration; and this thesis suggests we achieve it through SUDS.

BIBLIOGRAPHY

Albert, C., Brillinger, M., Guerrero, P., Gottwald, S., Henze, J., Schmidt, S., Ott, E., & Schröter, B. (2021). Planning nature-based solutions: Principles, steps, and insights. *Ambio*, *50*(8), 1446–1461. https://doi.org/10.1007/s13280-020-01365-1

Ali Ahmad, B., Shahabi, H., & bin Ahmad, B. (2015). Application of GIS Based Multi-criteria Analysis in Site Selection of Water Reservoirs (Case Study: Batu Pahat, Malaysia). *Research Journal of Applied Sciences, Engineering and Technology*, *9*(11), 995–1005. https://doi.org/10.19026/rjaset.9.2593

Allen, D., Olive, V., Arthur, S., & Haynes, H. (2015). Urban Sediment Transport through an Established Vegetated Swale: Long Term Treatment Efficiencies and Deposition. *Water*, *7*(12), 1046–1067. https://doi.org/10.3390/w7031046

Armson, D., Stringer, P., & Ennos, A. R. (2013). The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. *Urban Forestry & Urban Greening*, *12*(3), 282–286. https://doi.org/10.1016/j.ufug.2013.04.001

Ballard, W. et al., 2015. *The SuDS Manual,* Griffin Court, 15 Long Lane, London, EC1A 9PN, UK: CIRIA.

BBC, 2011. *Margaret Jaconelli loses 2014 Games eviction fight,* Glasgow: s.n.

Breton, N., Zorica, T. & Fiona, C., 2013. *Screening tool for water quality improvements, floodrisk management and urban regeneration through surface water flood reduction at a regional scale,* Blackpool: Atkins, Chadwick House.

Bhatt, A., Bradford, A., & Abbassi, B. E. (2019). Cradle-to-grave life cycle assessment (LCA) of low-impact-development (LID) technologies in southern Ontario. *Journal of Environmental Management*, *231*, 98–109. https://doi.org/10.1016/j.jenvman.2018.10.033

Brown, R. A., & Borst, M. (2015). Nutrient infiltrate concentrations from three permeable pavement types. *Journal of Environmental Management*, *164*, 74–85. https://doi.org/10.1016/j.jenvman.2015.08.038

Castro, C. V. (2022). Optimizing nature-based solutions by combining social equity, hydro-environmental performance, and economic costs through a novel Gini coefficient. *Journal of Hydrology X*, *16*, 100127. https://doi.org/10.1016/j.hydroa.2022.100127

Commision, S. L., 2022. *Scottish Land Commision.*[Online]

Availableat:https://www.landcommission.gov.scot/our-work/housing-development/early-engagement-in-planning/dalmarnock-a-masterplanning-approach

Commission, E., 2020. *INVESTING IN NATURE: FINANCING CONSERVATION AND NATURE-BASED SOLUTIONS.* [Online]
Available at: https://www.eib.org/attachments/pj/ncff-invest-nature-report-en.pdf

Committee, S. a. T. S., 2022. *Nature-based solutions: Rhetoric or Reality?,* London: House of Lords.
Craig, W., 2021. *Toxic Glasgow burn contaminated by cancer-causing chemical 'glowing luminous green',* s.l.: Glasgow Live.

Chandio, I. A., Matori, A. N. B., WanYusof, K. B., Talpur, M. A. H., Balogun, A.-L., & Lawal, D. U. (2013). GIS-based analytic hierarchy process as a multicriteria decision analysis instrument: a review. *Arabian Journal of Geosciences*, *6*(8), 3059–3066. https://doi.org/10.1007/s12517-012-0568-8

Checkland, S., 1976. The Upas Tree. Glasgow: University of Glasgow Press.

Christian, L., Epps, T., Diab, G., & Hathaway, J. (2020). Pollutant Concentration Patterns of In-Stream Urban Stormwater Runoff. *Water*, *12*(9), 2534. https://doi.org/10.3390/w12092534

COLLINS, M. G., STEINER, F. R., & RUSHMAN, M. J. (2001). Land-Use Suitability Analysis in the United States: Historical Development and Promising Technological Achievements. *Environmental Management*, *28*(5), 611–621. https://doi.org/10.1007/s002670010247

Cumiskey, L., Priest, S. J., Klijn, F., & Juntti, M. (2019). A framework to assess integration in flood risk management: implications for governance, policy, and practice. *Ecology and Society*, *24*(4), art17. https://doi.org/10.5751/ES-11298-240417

de Beer, J., & Boogaard, F. (2017). Good practices in cultural heritage management and the use of subsurface knowledge in urban areas. *Procedia Engineering*, *209*, 34–41. https://doi.org/10.1016/j.proeng.2017.11.127

DEFRA, 2010. *Surface Water Management Plan Technical Guidance,* London: Department for Environment, Food and Rural Affairs .

de Macedo, M. B., Rosa, A., do Lago, C. A. F., Mendiondo, E. M., & de Souza, V. C. B. (2017). Learning from the operation, pathology and maintenance of a bioretention system to optimize urban drainage practices. *Journal of Environmental Management*, *204*, 454–466. https://doi.org/10.1016/j.jenvman.2017.08.023

Dutta, A., Torres, A. S., & Vojinovic, Z. (2021). Evaluation of Pollutant Removal Efficiency by Small-Scale Nature-Based Solutions Focusing on Bio-Retention Cells, Vegetative Swale and Porous Pavement. *Water*, *13*(17), 2361. https://doi.org/10.3390/w13172361

Dewar, D., 2017. *Potential benefits of sustainable drainage schemes 'not being assessed'.* [Online] Available at: https://www.planningresource.co.uk/article/1422979/potential-benefits-sustainable-drainage-schemes-not-assessed

DOEE, 2018. *Department of Energy & Environment.* [Online] Available at: https://doee.dc.gov/sites/default/files/dc/sites/ddoe/service_content/attachments/Bioretention%20-%20SWM%20BMP%20Green%20Infrastructure%20Construction%20Price%20Calculator_1.xlsx

Drainage Systems, S., 2019. *New Ways of Thinking Make the Future Bright for SuDS.* [Online] Available at: https://www.externalworksindex.co.uk/entry/147430/SDS/New-Ways-of-Thinking-Make-the-Future-Bright-for-SuDS/

DREISEITL, H. & WANSCHURA, B., 2016. *STRENGTHENING BLUE GREEN INFRASTRUCTURES IN OUR CITIES,* s.l.: Ramboll.

EPA-USA, 2019. *WATER INFRASTRUCTURE IMPROVEMENT ACT,* s.l.: Government of United States.

Flood Authorities, L., 2013. *Water. People.Places. A guide for master planning sustainable drainage into developments ,* South-East England: Local Flood Authorities.

Fassman-Beck, E., Wang, S., Simcock, R., & Liu, R. (2015). Assessing the Effects of Bioretention's Engineered Media Composition and Compaction on Hydraulic Conductivity and Water Holding Capacity. *Journal of Sustainable Water in the Built Environment*, *1*(4). https://doi.org/10.1061/JSWBAY.0000799

Fathollahi, A., & Coupe, S. J. (2021a). Life cycle assessment (LCA) and life cycle costing (LCC) of road drainage systems for sustainability evaluation: Quantifying the contribution of different life cycle phases. *Science of The Total Environment*, *776*, 145937. https://doi.org/10.1016/j.scitotenv.2021.145937

Fathollahi, A., & Coupe, S. J. (2021b). Life cycle assessment (LCA) and life cycle costing (LCC) of road drainage systems for sustainability evaluation: Quantifying the contribution of different life cycle phases. *Science of The Total Environment*, *776*, 145937. https://doi.org/10.1016/j.scitotenv.2021.145937

Ferrans, P., Torres, M. N., Temprano, J., & Rodríguez Sánchez, J. P. (2022). Sustainable Urban Drainage System (SUDS) modeling supporting decision-making: A systematic quantitative review. *Science of The Total Environment*, *806*, 150447. https://doi.org/10.1016/j.scitotenv.2021.150447

Ferreira, C. S. S., Kalantari, Z., Hartmann, T., & Pereira, P. (Eds.). (2022). *Nature-Based Solutions for Flood Mitigation* (Vol. 107). Springer International Publishing. https://doi.org/10.1007/978-3-030-77505-6

Fonseca Alves, L. G., de Oliveira Galvão, C., de Farias Santos, B. L., Fernandes de Oliveira, E., & Andrade de Moraes, D. (2022). Modelling and assessment of sustainable urban drainage systems in dense precarious settlements subject to flash floods. *LHB*, *108*(1), 1–11. https://doi.org/10.1080/27678490.2021.2016024

Foudi, S., Osés-Eraso, N., & Galarraga, I. (2017). The effect of flooding on mental health: Lessons learned for building resilience. *Water Resources Research*, *53*(7), 5831–5844. https://doi.org/10.1002/2017WR020435

Fu, X., Goddard, H., Wang, X., & Hopton, M. E. (2019). Development of a scenario-based stormwater management planning support system for reducing combined sewer overflows (CSOs). *Journal of Environmental Management*, *236*, 571–580. https://doi.org/10.1016/j.jenvman.2018.12.089

Gaffield, S. J., Goo, R. L., Richards, L. A., & Jackson, R. J. (2003). Public Health Effects of Inadequately Managed Stormwater Runoff. *American Journal of Public Health*, *93*(9), 1527–1533. https://doi.org/10.2105/AJPH.93.9.1527

GCC, 2018. *Glasgow City Development Plan,* Glasgow: Glasgow City Council.

Gordon-Walker, S., Harle, T. & and Naismith, I., 2007. *Cost Benefits of retrofit in Urban Areas,* s.l.: s.n.

Government, S., 2020. *Scottish Index of Multiple deprivation.* [Online] Available at: https://simd.scot/#/simd2020_5pc/BTTTFTT/11/-4.2177/55.8406/ [Accessed 2020].

Government, T. S., 2017. *Maps of vacant and derelict land in Glasgow.* [Online] Available at: Maps of vacant and derelict land in Glasgow

Haugh, J., 2021. *Regeneration efforts transform Glasgow's former Sighthill tower blocks into green dream.* [Online]
Available at: https://www.forestryjournal.co.uk

Hayes, G. & Ian, H., 2022. *Are 20-minute communities the future of cities?.* [Online]
Available at: https://www.bbc.co.uk/news/uk-scotland-glasgow-west-62680001

Health, G. C. f. P., 2015. *Understanding Glasgow.* [Online] Available at:https://www.understandingglasgow.com/profiles/neighbourhood_profiles/1_ne_sector

Hiller, A. et al., 2019. *Using climate projections in economic appraisal for flood risk management measures,* s.l.: ClimateXChange.

Hudson, P., Raška, P., Macháč, J., & Slavíková, L. (2022). Balancing the interaction between urban regeneration and flood risk management – A cost benefit approach in Ústí nad Labem. *Land Use Policy*, *120*, 106276. https://doi.org/10.1016/j.landusepol.2022.106276

Jin, H.-Y., Kwon, Y., Yoo, S., Yim, D.-H., & Han, S. (2021). Can urban greening using abandoned places promote citizens' wellbeing? Case in Daegu City, South Korea. *Urban Forestry & Urban Greening*, *57*, 126956. https://doi.org/10.1016/j.ufug.2020.126956

Ingvertsen, S., 2011. *Sustainable urban stormwater management: the challenges of controlling water quality,* s.l.: s.n.

Jonathan, G., 2022. *Dailyrecord.* [Online] Available at: https://www.dailyrecord.co.uk/in-your-area/lanarkshire/lanarkshire-residents-left-sickened-after-26884231
[Accessed 2022].

Jones, P. & MacDonald, N., 2014. *Sustainable drainage and planning practice: an investigation of the Clyde Waterfront regeneration.* [Online]
Available at:
https://www.birmingham.ac.uk/documents/collegeles/gees/miscellaneous/jonespisudsapp.pdf

Kandilioti, G., & Makropoulos, C. (2012). Preliminary flood risk assessment: the case of Athens. *Natural Hazards*, *61*(2), 441–468. https://doi.org/10.1007/s11069-011-9930-5

Kapetas, L., & Fenner, R. (2020). Integrating blue-green and grey infrastructure through an adaptation pathways approach to surface water flooding. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *378*(2168), 20190204. https://doi.org/10.1098/rsta.2019.0204

Keating, K., Keeble, H., Pettit, A. & Stark, D., 2015. *Delievering Benefits through evidence,* Bristol: Environment Agency.

Khan, M. P., Hubacek, K., Brubaker, K. L., Sun, L., & Moglen, G. E. (2022). Stormwater Management Adaptation Pathways under Climate Change and Urbanization. *Journal of Sustainable Water in the Built Environment*, *8*(4). https://doi.org/10.1061/JSWBAY.0000992

Kintrea, K., & Madgin, R. (2019). Introduction: transforming post-industrial Glasgow – moving beyond the epic and the toxic. In *Transforming Glasgow* (pp. 1–18). Policy Press. https://doi.org/10.1332/policypress/9781447349778.003.0001

Kuller, M., Bach, P. M., Ramirez-Lovering, D., & Deletic, A. (2017a). Framing water sensitive urban design as part of the urban form: A critical review of tools for best planning practice. *Environmental Modelling & Software*, *96*, 265–282. https://doi.org/10.1016/j.envsoft.2017.07.003

Kuller, M., Bach, P. M., Ramirez-Lovering, D., & Deletic, A. (2017b). Framing water sensitive urban design as part of the urban form: A critical review of tools for best planning practice. *Environmental Modelling & Software*, *96*, 265–282. https://doi.org/10.1016/j.envsoft.2017.07.003

Krivtsov, V.; D'Arcy, B.J.; Sevilla, A.E.; Arthur, S.; Semple, C. Mitigating Polluted Runoff from Industrial Estates by SUDS Retrofits: Case Studies of Problems and Solutions Co-Designed with a Participatory Approach. *Sustainability* **2021**, *13*, 12357. https://doi.org/10.3390/su132212357

Lange, K., Österlund, H., Viklander, M., & Blecken, G.-T. (2020). Metal speciation in stormwater bioretention: Removal of particulate, colloidal and truly dissolved metals. *Science of The Total Environment*, *724*, 138121. https://doi.org/10.1016/j.scitotenv.2020.138121

Laurenson, G., Laurenson, S., Bolan, N., Beecham, S., & Clark, I. (2013). *The Role of Bioretention Systems in the Treatment of Stormwater* (pp. 223–274). https://doi.org/10.1016/B978-0-12-407686-0.00004-X

Leroy, M., Portet-Koltalo, F., Legras, M., Lederf, F., Moncond'huy, V., Polaert, I., & Marcotte, S. (2016). Performance of vegetated swales for improving road runoff quality in a moderate traffic urban area. *Science of The Total Environment*, *566–567*, 113–121. https://doi.org/10.1016/j.scitotenv.2016.05.027

Li, L., Collins, A. M., Cheshmehzangi, A., & Chan, F. K. S. (2020). Identifying enablers and barriers to the implementation of the Green Infrastructure for urban flood management: A comparative analysis of the UK and China. *Urban Forestry & Urban Greening*, *54*, 126770. https://doi.org/10.1016/j.ufug.2020.126770

Lin, B. B., Ossola, A., Alberti, M., Andersson, E., Bai, X., Dobbs, C., Elmqvist, T., Evans, K. L., Frantzeskaki, N., Fuller, R. A., Gaston, K. J., Haase, D., Jim, C. Y., Konijnendijk, C., Nagendra, H., Niemelä, J., McPhearson, T., Moomaw, W. R., Parnell, S., … Tan, P. Y. (2021). Integrating solutions to adapt cities for climate change. *The Lancet Planetary Health*, *5*(7), e479–e486. https://doi.org/10.1016/S2542-5196(21)00135-2

Marc, E., 2021. *Scotland,* s.l.: s.n.

Mayfield, J., 2016. *Automating the Classification of Thematic Rasters for Weighted Overlay Analysis in Geoplanner for ArcGIS,* s.l.: s.n.

Majekodunmi, M., Emmanuel, R., & Jafry, T. (2020). A spatial exploration of deprivation and green infrastructure ecosystem services within Glasgow city. *Urban Forestry & Urban Greening*, *52*, 126698. https://doi.org/10.1016/j.ufug.2020.126698

Mehdizadeh, R., & Fischer, M. (2012). SUSTAINABILITY RATING SYSTEMS. *Journal of Green Building*, *7*(2), 177–203. https://doi.org/10.3992/jgb.7.2.177

Miller, R., 1970. The New Face of Glasgow. Scottish Geographical Magazine, Volume 86, pp. 5-15.

Min, J. L. J., & Halim, S. A. (2020). Rainfall Modelling using Generalized Extreme Value Distribution with Cyclic Covariate. *Mathematics and Statistics*, *8*(6), 762–772. https://doi.org/10.13189/ms.2020.080617

Mooney, D., Richards, K. G., Danaher, M., Grant, J., Gill, L., Mellander, P.-E., & Coxon, C. E. (2020). An investigation of anticoccidial veterinary drugs as emerging organic contaminants in groundwater. *Science of The Total Environment*, *746*, 141116. https://doi.org/10.1016/j.scitotenv.2020.141116

Naturescot, 2021. *100000 raingardens for Scotland.* [Online] Availableat:https://www.nature.scot/doc/green-infrastructure-project-update-10000-raingardens-scotland

NatureScot, 2021. *Malls Mire.* [Online] Available at: https://www.nature.scot/funding-and-projects/green-infrastructure-strategic-intervention/projects/gi-fund-projects/malls-mire

Öhrn Sagrelius, P., Blecken, G., Hedström, A., Ashley, R., & Viklander, M. (2022). Environmental impacts of stormwater bioretention systems with various design and construction components. *Journal of Cleaner Production*, *359*, 132091. https://doi.org/10.1016/j.jclepro.2022.132091

Office, M., 2020. *Effects of climate change.* [Online] Available at: https://www.metoffice.gov.uk/weather/climate-change/effects-of-climate-change

Payne, E. et al., 2015. *Adoption Guidelines for Stormwater Bioinfiltration systems,* s.l.: s.n.

Ordor, U., & Michell, K. (2022). Exploring Interdisciplinary Cooperation in the Relationship Between Urban Management Strategies, Modes of Production and the Production of Urban Space in Cape Town, South Africa. *Urban Forum*, *33*(2), 153–171. https://doi.org/10.1007/s12132-021-09439-3

. Pacione, M., 1979. Housing Policies in Glasgow since 1880. Geographical Review, Volume 69, pp. 395-412.

Pacione, M., 1986. Quality of life in Glasgow: an applied geographical. Environment and Planning A, Volume 18, pp. 1499-1520.

Pacione, M., 1990. A tale of two cities: the migration of the Urban Crisis in glasgow. CITIES, 7(4).

Pacione, M., 1995. Glasgow: The Socio-Spatial Development of the City. s.l.:Wiley Chichester.

Paice, L., 2008. Overspill Policy and the Glasgow Slum Clearance Project in the Twentieth Century: From One Nightmare to Another? Reinvention: An International Journal of Undergraduate Research, 1(1).

Rahman, Md. A., Imteaz, M. A., Arulrajah, A., Piratheepan, J., & Disfani, M. M. (2015a). Recycled construction and demolition materials in permeable pavement systems: geotechnical and hydraulic characteristics. *Journal of Cleaner Production*, *90*, 183–194. https://doi.org/10.1016/j.jclepro.2014.11.042

Rahman, Md. A., Imteaz, M. A., Arulrajah, A., Piratheepan, J., & Disfani, M. M. (2015b). Recycled construction and demolition materials in permeable pavement systems: geotechnical and hydraulic characteristics. *Journal of Cleaner Production*, *90*, 183–194. https://doi.org/10.1016/j.jclepro.2014.11.042

Rannard, G., 2022. *How Pakistan floods are linked to climate change.* [Online] Available at: https://www.bbc.co.uk/news/science-environment-62758811

Rasel, M. M. & Hossain, S. M., 2015. Development of Rainfall Intensity Duration frequencies R-IDF equations and curves for seven divisions in Bangladesh. *International Journal of Scientific & Engineering Research.*

Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M. R., Geneletti, D., & Calfapietra, C. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science & Policy*, *77*, 15–24. https://doi.org/10.1016/j.envsci.2017.07.008

Rommel, S. H., Ebert, V., Huber, M., Drewes, J. E., & Helmreich, B. (2019). Spatial distribution of zinc in the topsoil of four vegetated infiltration swales treating zinc roof runoff. *Science of The Total Environment*, *672*, 806–814. https://doi.org/10.1016/j.scitotenv.2019.04.016

Rozos, E., & Makropoulos, C. (2012). Assessing the combined benefits of water recycling technologies by modelling the total urban water cycle. *Urban Water Journal*, *9*(1), 1–10. https://doi.org/10.1080/1573062X.2011.630096

Salvan, L., Abily, M., Gourbesville, P., & Schoorens, J. (2016). Drainage System and Detailed Urban Topography: Towards Operational 1D-2D Modelling for Stormwater Management. *Procedia Engineering*, *154*, 890–897. https://doi.org/10.1016/j.proeng.2016.07.469

Sañudo-Fontaneda, L. A., Roces-García, J., Coupe, S. J., Barrios-Crespo, E., Rey-Mahía, C., Álvarez-Rabanal, F. P., & Lashford, C. (2020). Descriptive Analysis of the Performance of a Vegetated Swale through Long-Term Hydrological Monitoring: A Case Study from Coventry, UK. *Water*, *12*(10), 2781. https://doi.org/10.3390/w12102781

Sarkar, S., Butcher, J. B., Johnson, T. E., & Clark, C. M. (2018). Simulated Sensitivity of Urban Green Infrastructure Practices to Climate Change. *Earth Interactions*, *22*(13), 1–37. https://doi.org/10.1175/EI-D-17-0015.1

Scotland, G., 2020. [Online] Available at: https://www.greenspacescotland.org.uk/News/glasgow-city-deal-projects-to-reduce-flooding-and-improve-greenspaces-starting-soon

Scotland, H. E., 1937. *Britain from above.* [Online] Availableat:https://britainfromabove.org.uk/image/spw056005 [Accessed 2022].

Scotsman, T., 2016. *Remembering Glasgow's floods of 2002,* Glasgow :The Scotsman.

Scottish, W., 2018. *Sewers for Scotland - A technical specification for the design and construction of sewerage infrastructure,* s.l.: Scottish water.

SEPA, 2017. *Delivering river basin planning in the Clyde Catchment.* [Online] Available at: https://www.sepa.org.uk/media/306627/delivering-river-basin-planning-in-the-clyde-catchment-may-2017.pdf

SEPA, S. W. T. S. G., 2013. *Surface Water Management Planning Guidance,* s.l.: s.n.

Sheppard, R., 2014. *Sheppard Robson.* [Online] Available at: https://www.sheppardrobson.com/projects/south-dalmarnock-integrated-urban-infrastructure [Accessed 2022].

Stevens, R. & Ogunyoye, F., 2012. *Cost and Benefits of Sustainable Drainage Systems,* s.l.: Royal Haskoning.

Susdrain, 2022. *Deliverence and Use of SUDS.* [Online] Available at: https://www.susdrain.org/delivering-suds/using-suds/the-costs-and-benefits-of-suds/comparison-of-costs-and-benefits.html

Susdrain, 2022. *Susdrain: Economic Growth.* [Online] Available at: https://www.susdrain.org/delivering-suds/using-suds/benefits-of-suds/Economic-growth

Shafique, M., & Kim, R. (2017). Green stormwater infrastructure with low impact development concept: a review of current research. *DESALINATION AND WATER TREATMENT*, *83*, 16–29. https://doi.org/10.5004/dwt.2017.20981

Syafrina, A. H., Norzaida, A., & Jannatul Ain, J. (2019). Stationary and Nonstationary Generalized Extreme Value Models for Monthly Maximum Rainfall in Sabah. *Journal of Physics: Conference Series*, *1366*(1), 012106. https://doi.org/10.1088/1742-6596/1366/1/012106

Trent, S., 2021. *Building sustainable, flood resilient communities.* [Online] Available at: https://www.stwater.co.uk/content/dam/stw/regulatory-library/09_Business%20case%2003_Building%20sustainable%20flood%20resilient%20communities_FINAL_R.pdf

Tavakol-Davani, H., Burian, S. J., Devkota, J., & Apul, D. (2016). Performance and Cost-Based Comparison of Green and Gray Infrastructure to Control Combined Sewer Overflows. *Journal of Sustainable Water in the Built Environment*, *2*(2). https://doi.org/10.1061/JSWBAY.0000805

Tudunwada, I. Y., & Abbas, A. (2022). Flood vulnerability mapping and prediction for early warning in Jigawa State, Northern Nigeria, using geospatial techniques. *International Journal of Disaster Risk Reduction*, *79*, 103156. https://doi.org/10.1016/j.ijdrr.2022.103156

UK, G., 2011. *Additional evidence for SUDS,* s.l.: s.n.

Un, K., 2010. *Permeable Pavements.* [Online] Available at: https://www.mapc.org/resource-library/fact-sheet-permeable-paving/

Urbantide, 2016. *Glasgow city centre regeneration - how smart can Glasgow be?.* [Online] Available at: https://urbantide.com/fullstory2/glasgow-city-centre-regeneration-master-planning-project

Wiseman, R., 2015. *The history of Parkhead, Glasgow, and the surrounding areas..* [Online] Available at: http://parkheadhistory.com/surrounding-areas/dalmarnock/

Vijayaraghavan, K., Biswal, B. K., Adam, M. G., Soh, S. H., Tsen-Tieng, D. L., Davis, A. P., Chew, S. H., Tan, P. Y., Babovic, V., & Balasubramanian, R. (2021). Bioretention systems for stormwater management: Recent advances and future prospects. *Journal of Environmental Management*, *292*, 112766. https://doi.org/10.1016/j.jenvman.2021.112766

Young, S., 2012. *Aerial view Dalmarnock Sewage Treatment Works in Glasgow.* [Online] Available at: https://www.alamy.com/stock-photo-aerial-view-dalmarnock-sewage-treatment-works-in-glasgow-49

Wang, Z., Qi, F., Liu, L., Chen, M., Sun, D., & Nan, J. (2021). How do urban rainfall-runoff pollution control technologies develop in China? A systematic review based on bibliometric analysis and literature summary. *Science of The Total Environment*, *789*, 148045. https://doi.org/10.1016/j.scitotenv.2021.148045

Xu, C., Liu, Z., Chen, Z., Zhu, Y., Yin, D., Leng, L., Jia, H., Zhang, X., Xia, J., & Fu, G. (2021). Environmental and economic benefit comparison between coupled grey-green infrastructure system and traditional grey one through a life cycle perspective. *Resources, Conservation and Recycling*, *174*, 105804. https://doi.org/10.1016/j.resconrec.2021.105804

Yang, G., Bowling, L. C., Cherkauer, K. A., & Pijanowski, B. C. (2011). The impact of urban development on hydrologic regime from catchment to basin scales. *Landscape and Urban Planning*, *103*(2), 237–247. https://doi.org/10.1016/j.landurbplan.2011.08.003

Zaqout, T., & Andradóttir, H. Ó. (2021). Hydrologic performance of grass swales in cold maritime climates: Impacts of frost, rain-on-snow and snow cover on flow and volume reduction. *Journal of Hydrology*, *597*, 126159. https://doi.org/10.1016/j.jhydrol.2021.126159

Zhang, W., Sang, M., Che, W., & Sun, H. (2019). Nutrient removal from urban stormwater runoff by an up-flow and mixed-flow bioretention system. *Environmental Science and Pollution Research*, *26*(17), 17731–17739. https://doi.org/10.1007/s11356-019-05091-4