Paving the way for Green

A study on the effect of residential gardens in The Hague on local climate

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Preface

Dear reader,

Before you lie the thesis *Paving the way for Green: a study on the effect of residential gardens in The Hague on local climate*. This study was carried out to fulfil the graduation requirements of the master's degree in Industrial Ecology, at the University of Leiden and Technical University of Delft. It was written between January and July 2023.

Ever since my bachelor's in Human Geography and Urban Planning at the University of Amsterdam, I have become interested in sustainability. During my studies, both this master's degree and my master's degree in Spatial Planning at the Radboud University Nijmegen, I have explored sustainability even more. For me, and many others, protecting our environment is the biggest challenge we as a society will ever face. I hope this thesis can help contribute to this pressing matter.

I became interested in residential gardens ever since I came across the social media account *Onderhoudsarmoe*. Here, the transformation in gardens is photographed. Most often, the gardens which were once lush and green are now transformed into grey and impervious surfaces. This motivated me to look further into this, and what effects this could have on topics such as heat stress.

I would like to thank my supervisors: Arjan van Timmeren, Maarten van 't Zelfde, and Janneke van Oorschot. Without their helpful feedback and guidance during these six months, this study could not have been achieved. I very much enjoyed working alongside them and discussing the research. In addition, I would like to thank my girlfriend, friends, and family for supporting me throughout this journey. Finally, I want to thank Cobra Groeninzicht for allowing me to use their data. This data has been very useful.

I hope you enjoy reading this thesis,

Huub Diepens

Summary

Climate change is one of the most pressing matters our society faces. As a result, temperatures are rising across the globe. This effect is especially prevalent in urban areas, where artificial surfaces such as pavements are abundant and vegetation scarce. This effect is called the Urban Heat Island Effect (UHI). Another issue that is caused by climate change are increased rainfall extremes, which lead to a higher risk of flooding. This risk of flooding is higher in urban areas, as vegetation that can hold and absorb water is scarce. Vegetation can thus help mitigate both issues. Residential gardens could be an interesting source of vegetation within urban areas. The city of The Hague, in the Netherlands, is assumed as having one of the highest UHI intensities in the country. Moreover, it is the densest city in the country and thus poses an interesting location to study these gardens.

This study's objective is to find out what it is that drives people to have vegetation within their gardens, and what effect this could have on both the UHI effect as well as runoff. The main research question entails: *"How, and where, can vegetation in residential gardens in The Hague improve climate on a neighbourhood level?".* To answer this question, ArcGIS and SPSS are used. Initially, drivers behind vegetation within gardens are explored. Then, the current effect of vegetation within gardens is analysed. Finally, the potential of vegetation within gardens is calculated. This leads to several neighbourhoods that could be of great interest to policymakers who want to increase the amount of vegetation.

First, four factors emerged that influence vegetation within residential gardens. Green in the public environment, the average value of the residence, and the average size of the garden have a positive impact on vegetation within gardens. The more green in the public environment, or the higher economic value the residence has, the more vegetation there is within gardens according to this study's findings. In contrast, the average household size instead sees a negative impact. The more people within a household, the more impervious surfaces within gardens.

Next, the effect of vegetation within the gardens on the UHI effect and runoff was calculated. This has shown that across all neighbourhoods, residential gardens reduce on average 2.7% of the local median UHI effect. The largest reduction is observed in Parkbuurt Oosteinde with 6.7%, and the smallest reduction in Westvliet-Oost, with 0.2%. As for runoff during a rainfall event of 100mm, the amount differs between 0.374mm in Vlietbuurt and 21.634 mm in Lage Veld, with an average of 7.3mm. Runoff stands for the amount of rain that cannot be absorbed by the soil.

Finally, the potential for residential gardens was calculated for a scenario in which all impervious surfaces were replaced with vegetation. As for the reduction of the UHI, increases up to 7.8% are noted. In addition, runoff can be reduced by up to 77% of the current amount. With these calculations, three neighbourhoods emerged as having high potential in both cases. These are van Hoytemastraat e.o., Parkbuurt Oosteinde, and Lage Veld. One thing that these neighbourhoods share is that they all consist of a large part of gardens of their total surface area. Policymakers could address these three to test their ideas, as the effects are likely to be easier to identify here than in other neighbourhoods.

Table of contents

List of figures

List of tables

List of abbreviations

Table 1: Abbreviations

Abbreviation	Term
UHI	Urban Heat Island
GIS	Geographical Information System
SPSS	Statistical Package for Social Sciences
GI	Green Index
CBS	Central Bureau of Statistics
RIVM	Dutch National Institute of Public Health and the Environment
ANOVA	Analysis Of VAriance
PCA	Principal Components Analysis

Chapter 1. Introduction

This chapter introduces the topic of this research. Here, the role that residential gardens can play in mitigating climate change is emphasized. Following is an explanation of issues associated with impervious and artificial surfaces, focussing on heat stress and water drainage. Next, the research objective is described, along with it the research question and sub-questions. The hypothesis follows after that. Finally, this chapter ends with an explanation as to why The Hague was selected for this study.

1.1 Potential role of residential gardens

With temperatures increasing across the globe due to climate change (Guerreiro et al., 2018), the risk of heat-related illness and mortality grows. See for example the heat wave in France in 2003, in which between 15000 and 19000 heat-related mortalities were recorded (Bamat, 2015). The rising temperatures are most noticeable in urban areas, where natural surfaces are replaced with pavements and buildings that absorb and retain heat. This is called the *Urban Heat Island Effect* (UHI) and is observed all around the globe in urban areas. Climate change affects this effect and is likely to increase its intensity many times in the near future (Ward et al., 2016).

Heat stress is not the only issue that is appearing due to climate change, it also brings increased rainfall extremes, which in turn increases the risk of flooding (Arnbjerg-Nielsen et al., 2011: KNMI, n.d.). An example of these rainfall extremes is the flooding in Limburg, the Netherlands, Belgium and Germany in 2021, where more than 200 persons lost their lives. (NOS, 2021). Urban flood risk is being worsened by climate change (O'Donnell & Thorne, 2020), and with more than 68% of the world population likely living in cities by 2050 (UN, 2018) the danger these floods hold is immense.

Much research has been done on the effects of vegetation in reducing the UHI effect and increasing resilience against extreme rainfall. There are many gains to be made in public spaces regarding the use of plants to become more climate resilient, yet also in our backyards. Up to 70% of all residences in the Netherlands have a garden (Kulberg, 2016, p.38). Residential, or domestic, gardens are most often small-scale, privately-owned outdoor spaces around homes. These can range from gardens at the front of a residence, to the entire area surrounding villas. Gardens offer an effortless transition between inside and outside (Cardinali et al., 2023).

Additionally, the types of vegetation differ from garden to garden. Where one garden has trees and grass, another has tiles and other impervious surfaces. These bring different effects. Trees can reduce temperatures, as they bring shade or through evapotranspiration (Cameron et al., 2012). Impervious surfaces, such as tiles, instead reduce the amount of water that can infiltrate into the soil. This causes the water to be directed into nearby soils or drains, thus putting more strain on the local drainage system. On the contrary, green surfaces such as grass can instead alleviate some of the burdens of the drainage systems, as these surfaces can take up water temporarily (Warhurst et al., 2014). How one designs his or her garden can thus affect not only their own surroundings but also that of their neighbour.

Moreover, research by Deloitte suggests that, for example, in the city of The Hague a reduction of 0,47 degrees Celsius can be achieved if the residential gardens are optimized in regards to the use of green (van Loon et al., 2019). Another example, Eindhoven could see its temperatures reduced by up to 0,68 degrees Celsius if its gardens are optimized. This shows that residential gardens can play an important role in reducing heat stress.

Vegetation is thus a key component in reducing temperatures and drainage problems. However, it can be difficult to have much vegetation within urban areas (Li et al., 2020). Urban land is often highly desired and is thus more and more transformed into residential and commercial areas instead of gardens or parks. Indeed, a rise in impervious surfaces is noted, not only in the public environment but as well in domestic gardens (Perry & Nawaz, 2007: Kulberg, 2016, p.36).

Perry and Nawaz (2008) investigated the increase of impervious surfaces in Leeds and revealed that around 75% of the 13% overall increase in impervious surfaces is due to the paving of residential gardens. A similar trend is occurring in the Netherlands, where a decrease of around 18% in green in residential gardens is noted between 2002 and 2011 (Kulberg, 2016, p.36). The rise of such gardens is problematic, with the issues being mentioned in the coming section.

The potential role that residential gardens in the Netherlands can play is high, as in the Netherlands alone, a surface of around 1.4 billion m^2 of residential gardens is currently impervious, and could instead be green (van Loon et al., 2019). Even more, The Hague is host to around 90.000 residential buildings. With most of these having gardens, it means that residential gardens could play an important role in increasing local climate resilience. Furthermore, this means that among others, the effects of future rainfall problems and heat waves could potentially be partly diminished by optimizing domestic gardens.

1.2 Issues related to residential gardens

As mentioned, gardens can have both positive and negative effects on temperatures and the handling of rainfall. However, there are many other effects that gardens can have. Gardens can increase biodiversity, by housing certain types of plants and animals, or can be used for recreational purposes, thus increasing human wellbeing. Although these factors are quite important, this study focusses on temperatures and rainfall as these are the two most pressing matters, moreover including the other effects would not be feasible within the limited time-frame of the study. Following are some of the issues related to the Urban Heat Island Effect, and urban flooding. A more elaborate explanation follows in chapter 2.

Heat stress

The UHI effect brings with it several negative effects. Among them is the risk to human health. Naturally, the human body produces heat and can handle certain levels of heat. However, prolonged exposure to extreme temperatures can lead to health risks, such as during heat waves. There are several health effects associated with the UHI effect, as the temperatures can rise to unhealthy levels (Kleerekoper, van Esch & Salcedo, 2012: Tan et al., 2021). Extreme temperatures can put pressure on the human thermoregulatory system, which can lead to heat strokes. Furthermore, heat strokes can lead to cardiovascular stress and failure to supply oxygen to the brain (Kleerekoper, van Esch & Salcedo, 2012). Heat stress is thus one of the largest threats of the Urban Heat Island Effect to human health. Another health effect is the increased formation of ground-level ozone in urban areas, which can lead to respiratory diseases. The higher temperatures can increase the potential for ozone formation, thus leading to higher levels of ozone in urban areas (Stone & Rodgers, 2001).

Urban flooding

Urban floods can occur for multiple reasons. One of the key reasons is when precipitation exceeds the capacity of local drainage systems to handle the water. Most drainage systems can handle average rainfall volumes, yet peak rainfall is increasing (KNMI, n.d.). This means that when it is needed the most, the system is overrun. Examples are many, even in the Netherlands. As mentioned before, in 2021 a rainfall flood affected the Netherlands, Belgium, and Germany (NOS, 2021). The damage of this flood event is estimated at around 38 billion euros across the three countries. These areas were relatively green, indicating the potential damage it could cause in urban areas. Such rain events are becoming common due to climate change, and such floods will become more common if little action is taken in increasing our drainage system's capability in handling such volumes of precipitation. Gardens can play a role, albeit only a part, in decreasing the risk.

1.3 Research Objective

This study focuses on the role residential gardens in The Hague can play in improving local climate. For this case, climate is simplified into two main elements: the ability to reduce heat stress, and the ability to handle potential rainwater extremes. This is done since these two elements can be studied by the selected methods and on this particular scale of this study. Green surfaces are understood as surfaces with high amounts of vegetation and are in contrast to grey and often impermeable surfaces.

The main research question is as follows:

How, and where, can vegetation in residential gardens in The Hague improve climate on a neighbourhood level?

To help answer this research question, the following sub-questions are used:

- What factors influence the amount of vegetation in residential gardens in The Hague?
- To what extent does vegetation in residential gardens in The Hague improve climate on a neighbourhood level?
- In which neighbourhoods lie most potential for improving local climate through residential gardens?

To answer the research question ArcGIS and SPSS are used. ArcGIS allows to analyse the entirety of The Hague spatially and quantitatively, and easily compare different neighbourhoods of the city to each other. SPSS is one of the many statistical tools available and can analyse the relationship between the indicators studied.

For this case, the scale level of a neighbourhood is used. Another term for this is *microclimate* (Pijpers-van Esch, 2015). This refers to the distinctive climate in small-scale urban areas, which can be that of a neighbourhood. The urban design influences the microclimate, with residential gardens being part of this design.

This study will finally result in the formation of a model, which allows others to perform a similar study on different cases. This model will be built within ArcGIS's ModelBuilder, which is a visual programming language for building geoprocessing workflows (ESRI, n.d.-a). This allows to automate spatial analysis, thus allowing others to easily replicate this study. However, not all data that is used during this study is available for other cities in the Netherlands. Therefore, other cases might require some tweaking in the model to gather similar results.

To summarize, first, factors that influence residential gardens' amount of green surface are analysed. The following categories are established, based on literature analysis: built environment factors, socio-economic factors, and the amount of green in public spaces. Next, the extent to which residential gardens in The Hague contribute to the local climate is studied. This is compared to the amount of green in the neighbourhood. Finally, it is then possible to analyse where the most potential lies in achieving more green surfaces.

These questions are combined into one study to show firstly, what influences vegetation in gardens, and then what effect this vegetation can have on local climate. In addition, it provides a deeper analysis of several neighbourhoods to show how gardens could be improved in support of local climate. It thus provides an understanding of the drive behind vegetation in gardens, the process of how it improves local climate, and which neighbourhoods could benefit most from vegetation in gardens.

1.4 Hypotheses

Following are the hypotheses per sub-question of this study.

What factors influence the amount of green surface of residential gardens in The Hague?

It is estimated that several factors will influence the amount of vegetation in residential gardens. Firstly, the type of housing is estimated to have a great effect on vegetation within gardens, as it dictates even the possibility of having a garden.

Furthermore, the location and the value of the building likely accompany each other. Homes in the city centre are likely smaller and more expensive, whilst also having a smaller garden as a result. In addition, as mentioned before by Kulberg (2016), the age of the building often prescribes the size of the garden. The size of the garden is dependent on these factors. Moreover, it is predicted that smaller gardens will have little green surfaces, whilst larger gardens most often have at least some green surfaces.

As for socioeconomic factors, education and income are likely to be important factors regarding vegetation in gardens. However, education and income, and other data such as property value, are not available at the individual plot level. By using averages it is unsure whether a valid and accurate outcome can be had. Therefore, it is not likely that this study can discuss whether these factors influence residential gardens. A smaller level of scale would be required for that.

The relationship between public green and private green could go both ways. A mirroring effect, such as Kulberg (2016) describes, could be noted. Yet, it could also occur that people already have sufficient green and therefore chose not to have greener gardens.

To what extent does vegetation in residential gardens in The Hague improve climate on a neighbourhood level?

Greener gardens are predicted to influence local climate. Whilst being a sizable fraction of the total green in The Hague, residential gardens are likely to be important in reducing some of the heat and rainwater problems. Moreover, vegetation is a broad term consisting of many types of plants and soils. Trees and shrubs likely act have more effect in improving local climate, especially in reducing heat.

In which neighbourhoods lie most potential for improving local climate through residential gardens?

It is predicted that the relatively newer residential neighbourhoods, such as the Bras and Waterbuurt, are better suited for the optimization of residential gardens. These residences most often have front and backyards, thus having more space for green. Moreover, literature, such as Lin et al. (2017), suggests that newer houses have less vegetation. On the other hand, since these neighbourhoods are relatively far away from where the UHI effect is most problematic it can be debated whether it is necessary to focus on such neighbourhoods. The city centre, whilst consisting of mostly impermeable surfaces, has likely little garden surface area. Therefore, it is predicted that this question will bring up a debate on whether to focus on where it is most necessary, or where green surfaces can have the biggest increase.

1.5 Case

Figure 1.1: Satellite imagery of The Hague

To zoom in on a specific city, The Hague was selected as the case study of this thesis. This city is the political capital of the Netherlands and is host to the residence of the Royal family. Furthermore, it hosts several international organizations such as the IPCC and many embassies for the Netherlands. In Dutch, the city is called *Den Haag*. The location of The Hague is illustrated in figure 1.1. The city is closely located to other municipalities such as Rijswijk, Delft and Leidschendam-Voorburg.

It was once argued that The Hague would experience the most fierce Urban Heat Island Effect of all cities in the Netherlands (Klok et al., 2012), however, more recent research showed that this was not the case (Van der Hoeven & Wandl, 2018). According to van Loon et al. (2019, p.7) 0,47 degree Celsius could be decreased in this city if the amount of green in residential gardens is optimized.

The city is home to 562.446 residents (CBS, 2020), and is, therefore, the third largest city in the country. Amsterdam, with 922.679 residents, and Rotterdam with 664.311, rank above The Hague (CBS, 2023). However, The Hague is the densest city in the Netherlands with 6.712 residents per square kilometre (CBS, 2023). Table 1.1 lists the density of several of the larger Dutch cities. The Hague is much denser compared to the capital, Amsterdam. Moreover, Rotterdam, known for its modern look and skyscrapers has less than half the density of The Hague.

Table 1.1 Density in Dutch cities (CBS, 2023)

City	**Density (residents per square kilometre)**
The Hague	6.712
Amsterdam	5.336
Delft	4.614
Utrecht	3.857
Rotterdam	3.001
Eindhoven	2.708

The neighbourhoods within The Hague range from busy streets in the centre to luxurious housing near the beach, to dense *vinex* neighbourhoods in the east near Nootdorp. In total, 262.492 buildings are located in The Hague, 82% of them being built before 2000. Moreover, of all residences in The Hague, 57% are rental homes, and 42% are owner-occupied.

With its relatively unique location near the sea, as other large cities in the country are further away from the sea, The Hague is an interesting example to study. The sea affects UHI effects, as the adjacency leads to more moderate UHI effects in the spring and summer, and no UHI effect in autumn (Wu, Zhang & Zang, 2019). Even with the sea as a moderating factor, temperatures are still high in The Hague in the summer. This further indicates the need to study the effects in this particular city.

As for rainfall, The Hague is regarded as being prone to flooding if there are high amounts of precipitation, as much of The Hague's surface consists of grey surfaces (Krijger, 2018). Furthermore, rainwater issues are affected by the proximity to the sea, as coastal areas get more rain than inland areas (Zhang et al., 2022: KNMI, 2021). Most precipitation in the Netherlands is observed along the coast and near the Veluwe. Urbanization is also affecting precipitation, as an increase of 7% in precipitation is noted in urban areas (KNMI, 2021). Figure 1.2 highlights this. The area ranging from Rotterdam to Amsterdam, also called the *Randstad*, is observed to have among the highest amount of rainfall in the Netherlands.

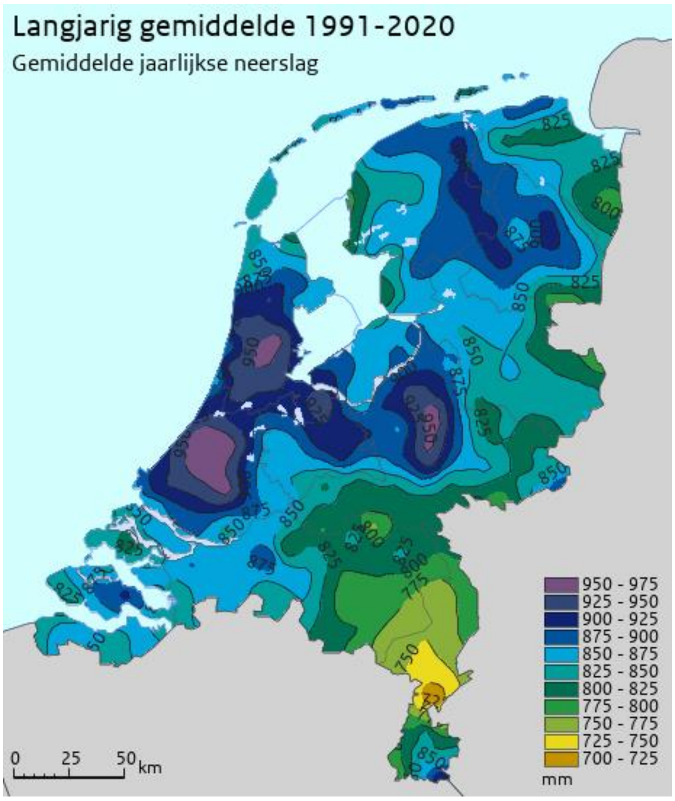

Figure 1.2: Average annual precipitation 1991-2020 (KNMI, 2021)

In addition, The Hague has much of its geographical data open for use through the Geo Portal of The Hague, which makes it easier to conduct this research. For instance, a map with all the green that is supervised by the municipality is available (Municipality of The Hague, n.d.). This could help analyse the factor of green in the public environment.

Finally, the study would benefit from analysing multiple cities, however, this would not fit the allocated time for this thesis. The computing time for various calculations would likely be too long. Similarly, specific data is needed for the study which could be lacking for other cases or hard to find. Instead, focusing on one city now allows to set up the required model correctly, which could be used for other studies on different cities.

Chapter 2. Theoretical framework

This chapter dives into several sources of literature on residential gardens and climate resilience and develops a theoretical basis on which to form factors that could influence the amount of green in residential gardens. The literature is retrieved by using Google Scholar. Terms used for searches were “residential gardens” or “ domestic gardens” and “Urban Heat Island Effect” or “runoff” or “rainwater”. In addition, sources used by found articles were used for further reading. This is also called *snowballing* (Wohlin, 2014).

First, three potential categories of factors are explained: built environment, socio-economic factors, and green in the public environment. In total 12 predictors are analysed, which are summarized in table 2.1. Then, an explanation of what impact vegetation in residential gardens can have. Finally, the conceptual framework is shown.

Table 2.1: types of factors

Type of factor	**Factor**
Built environment	- Type of housing - Location of the building - Value of the building - Age of the building - Size of the garden - Height of the building
Socioeconomic	- Age of residents - Amount of children in household composition - Income - Education - Type of ownership
Green in the public environment	- Amount of green in public environment nearby

2.1 Urban Heat Island Effect

The UHI effect is already a very pressing matter, but the intensity of the effect will only increase, as climate change causes the earth's temperatures to rise (Guerreiro et al., 2018). Similarly, with heat waves increasing in frequency and intensity due to climate change, urban regions are expected to be hit even harder than rural areas due to the UHI effect (Tan et al., 2010).

The Urban Heat Island Effect has several causes, which stem from anthropogenic causes such as the construction of buildings, yet residential gardens also have a role in this effect (Kleerekoper, van Esch & Salcedo, 2012: Nuruzzaman, 2015). Figure 2.1 illustrates several of the causes of the UHI effect. Following is an explanation of these, and how they relate to gardens. However, it is first important to understand solar radiation.

Naturally, solar radiation passes through the atmosphere, and on its way is reflected partly by clouds and the atmospheric contents (Pijpers-Van Esch, 2015, p.131). This is absorbed or re-emitted. Moreover, the earth also absorbs and reflects this radiation. The absorbed radiation is emitted back as long-wave radiation, which we feel as heat, and is mostly absorbed and re-emitted to earth's surfaces via the atmosphere. The other part is emitted into space. Similarly, the short-wave radiation that is absorbed by clouds and the atmosphere is also redirected at the earth as long-wave radiation (Pijpers-van Esch, 2015). Generally, there is more incoming radiation than outgoing.

In addition, there are also three types of heat fluxes: sensible heat fluxes, ground heat fluxes, and latent heat fluxes (Kluck et al., 2020, p.39). Atmospheric sensible heat fluxes are, as the name reveals, felt in the air and water around us. Ground heat is the heat that is saved up during the day in materials and surfaces. Latent heat is hidden, as it is not sensible nor is it saved in materials.

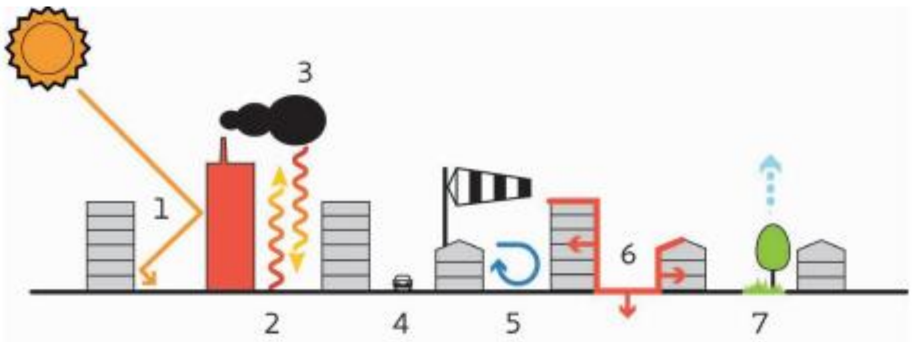

Figure 2.1: Causes of UHI (Pijpers-Van Esch, 2015, p.130).

Absorption of radiation

Starting with point 1 in figure 2.1, the absorption of radiation from the sun in low albedo materials and trapping by reflections between street surfaces and buildings. Albedo is the percentage of solar energy that is reflected at the surface (Hulley, 2012), is reliant on the arrangement of surfaces, materials, coatings, pavements and so on (Nuruzzaman, 2015, p.68), and has a direct impact on the microclimate. If the albedo is low, more solar energy will be stored and the temperature will increase. Urban surfaces, most often consisting of asphalt, concrete and bricks, have a low albedo or high thermal inertia, thus storing heat during the day (Ramamurthy & Bou-Zeid, 2016). This stored heat is then released at night as sensible heat. Natural surfaces often have a higher albedo than urban surfaces, thus storing less solar energy (Oleson, Bonan & Feddema, 2010). Residential gardens that have more grey surfaces than green will see higher temperatures compared to those with mainly green surfaces in a similar place.

The reflectivity of materials determines the amount of solar radiation that is reflected, with reflective surfaces most often being white of colour (Yang, Wang & Kaloush, 2015). Reflective surfaces are likely to have lower daytime temperatures and less radiation absorbed.

Heat-trapping in street canyons

Point 2 in figure 2.1 illustrates the decreased long-wave radiation heat loss from street canyons, which also influences the UHI effect (Pijpers-van Esch, 2015). Street canyons are streets where both sides of the street have tall buildings, which create a canyon feel. Taller buildings intercept the heat and absorb this heat. Figure 2.2 conveniently illustrates this process. Solar radiation is emitted and is partly absorbed and reflected by every passing surface. Multiple reflections of short-wave and long-wave radiation cause heat to be trapped in these street canyons. The dimensions of the street play an important factor here, as narrower streets trap more radiation, but also have fewer surfaces to irradiate (Shashua-Bar, Pearlmutter & Erell, 2011).

As for residential gardens in the Netherlands, it is highly unlikely to encounter high buildings within gardens as there is relatively strict legislation as to what is allowed to be built within gardens. This means that it is likely that little heat can be trapped within one's residential gardens in a similar process. However, if entire housing blocks were to have gardens consisting of mostly grey surfaces and were placed near each other, although not as severe, a similar process could occur. It is largely dependant on the height and width of the street canyon (Pijpers-van Esch, 2015, p.144).

Figure 2.2: Heat trapping in street canyons (Pijpers-van Esch, 2015)

Anthropogenic heat and air pollution

Urban areas also release anthropogenic heat, which adds up to the energy balance of radiation fluxes (Pijpers-van Esch, 2015). This heat is caused by traffic, space heating and cooling, and industrial activities. See for example the rise in usage of air conditioners: these cause the hot air from inside to be displaced outside, causing the outside environment to heat up (Nuruzzaman, 2015). This further empowers the UHI effect (Ramamurthy & Bou-Zeid, 2016). This relates to points 3 and 4 in figure 2.1: the absorption and re-emission of long-wave radiation by air pollution, and the release of anthropogenic heat by combustion processes (Pijpers-van Esch, 2015, p.129).

Gardens can both reduce and increase pollutant concentration, as well as reduce anthropogenic heat in general. For example, there is a significant positive correlation between the UHI effect and ozone concentration (Wang, Guo & Han, 2021). Gardens can increase this effect, as some activities such as barbequing or other polluting activities could increase ozone and other air pollutants concentrations. However, most of the air pollution that causes this effect stems from industrial areas (Pijpers-van Esch, 2015, p.176).

As for air conditioner usage, having a green garden could lead to reduced usage of air-conditioning, as, for example, the shade of trees could decrease local temperatures and thus reduce the demand for air conditioning (Kleerekoper, van Esch & Salcedo, 2012, p.31).

Reduced wind speeds

Point five in figure 2.1 refers to the reduced wind speeds in streets (Pijpers-van Esch, 2015). This decreases the amount of turbulent heat transported and thus reduces the cooling effect of wind. Instead, warm air is kept between the buildings. Wind has been reported to reduce the intensity of the UHI effect, and mitigate the effects for humans (Rajagopalan, Lim & Jamei, 2014). Moreover, the form of streets influences the flow of wind patterns. These patterns can cause the heat to either be kept inside the canyon or transport it out of it.

However, vegetation can also reduce wind speeds, as trees can reduce the velocity (Szkordiliszs & Zöld, 2016). Therefore, not all types of vegetation are helpful. It depends on the context and the type of vegetation. Trees, for example, could potentially alter the wind flow to keep the heat trapped inside the garden.

Surface area

Urban areas have more surface areas compared to rural areas, as illustrated in point 6 in figure 2.1 (Pijpers-van Esch, 2015). Similarly to the first point, these surface areas often have a low albedo, and thus allow for more heat to be stored compared to their rural counterparts, where there are green surfaces. Rural areas instead are less dense and consist of green surfaces.

Residential gardens are often larger in size in rural areas than in urban areas, as space is limited and expensive in urban areas (Kulberg, 2016) This means that there is relatively less potential in reducing this factor of UHI in gardens in cities, as it is likely that gardens are only a fraction of the surface areas. Instead, green roofs or other forms of surfaces might be more influential regarding this component of the UHI effect, as there are more surfaces like these.

Decreased evaporation

Finally, point 7 of figure 2.1: the decreased evaporation due to waterproof and impervious surfaces, as more energy is put into sensible heat than latent heat. With more waterproof surfaces, less vegetation than in rural areas, and less permeable materials being used the urban heat becomes more intense and more trapped (Kleerekoper, van Esch & Salcedo, 2012).

In addition, as the name suggests, these impermeable surfaces cannot store moisture (Ramamurthy & Bou-Zeid, 2016). As a result, the evaporative ability to cool diminishes. The water content of the soil is of great importance for its thermal admittance (Pijpers-van Esch, 2015, p.195). The wetter the soil, the higher this admittance is. This helps in reducing surface temperature, but causes the surface to be relatively warmer during the night as this heat is kept.

2.2 Urban floods

Water issues arise when there is more rainfall than the drainage system can handle (KNMI, 2019), which is most prevalent in urban areas where surfaces consist of asphalt and stone. Water can infiltrate into the soil. However, impervious surfaces such as asphalt obstruct this process. The water that cannot be absorbed into the ground is called water runoff (Water Education Foundation, n.d.), and impermeable surfaces increase this amount of runoff since the water cannot enter the ground (Mohajerani, Bakaric & Jeffrey-Bailey, 2017). As seen in many cases and studies, this greatly increases the risk and intensity of floods, as increased runoff often cannot be handled by drainage systems (Parsasyrat & Jamali, 2015: Li et al., 2020). This emphasizes that the presence of vegetation reduces floods as it impacts the hydrological cycle.

Higher levels of precipitation are expected, as warmer temperatures lead to warmer air, which can hold more water vapour (KNMI, n.d.). For every degree that is increased, an increase of 7% more water vapour can be expected. This means that their peak rainfall moments are even extremer than before. In that sense, the problem is increasing on two fronts. Our own ability to handle the peak rainfalls is at risk, due to the increasing amount of impervious surface, whilst the temperatures rise, due to climate change, leading to an increased amount of extreme rainfall. Moreover, the amount of people at risk of urban floods is also rising, as more and more people reside in urban areas (UN, 2018). Especially in the Netherlands, where 74% of its population resides in urban areas (PBL, 2015).

The usage of green infrastructure, such as parks, is one of the emerging strategies for decreasing runoff and flood peaks (Li et al., 2020). These pervious surfaces allow water to infiltrate into the soil, instead of going into the drains. Another contributor to urban green surfaces are residential gardens (Perry & Nawaz, 2008). These vary in shape and size per city but are most often an important asset. Gardens, if used well, can decrease urban flood in very important spots. Since these gardens are located near houses, they can potentially save the residents from floods or decrease the intensity of the flood. Residential gardens that consist of mainly grey surfaces will have more issues handling larger volumes of precipitation, and increase the risk of urban floods (Kelly, 2018). Vegetated gardens, instead, provide many urban green space ecosystem services, including flood regulation (Warhust et al., 2014, p.337). Section 2.5 elaborates further on how different types of vegetation can help in this regard.

2.3 Factors affecting green in residential gardens

Based on an analysis of existing literature on residential gardens, the following 3 categories of factors that influence the extent of vegetation in residential gardens are established. The ratio of surfaces occupied by vegetation has various names throughout literature, from green coverage ratio to vegetation fraction, or green index (Maiullari, 2023, p.76). As for this study, green index is used.

2.3.1 Built environment

Several architectural factors affect residential gardens. The type of housing is an obvious one, for example, high-rise apartments likely do not have gardens. The type of neighbourhood one lives in affects the size of gardens as well: Kulberg (2016) argues that in sub-urban neighbourhoods more interest is shown in gardening, with the green environment being appreciated yet not something that everyone wishes to contribute to. Those living here appreciate the peace and privacy it provides, and not as much the environmental values (Coolen & Meesters, 2012).

Moreover, in city centres, it is noticeable that gardening is not seen as an obligation, but only for those wishing to do so since few houses within city centres have gardens. Similarly, in rural areas gardening is seen as something to do, but not as a mandatory activity (Kulberg, 2016). This is further reinforced by developers and urban planners, as they plan and construct large houses on smaller surface areas thus reducing the garden sizes. Where it is assumed that people prefer little work on gardens, less surface area is allocated for residential gardens.

High median house value can indicate higher lawn-care expenditures, and overall more green surfaces according to Zhou et al., (2009). However, it can also be said that more expensive residences are larger, and thus are likely to have at least some green surfaces in their gardens. In the Netherlands, property values are often called WOZ-values. These are not the most accurate, as they are used by the Dutch Government to determine the value of a property for tax purposes. More accurate values are calculated by private concerns, yet are as the name implies not open to the public.

Furthermore, the age of the building contributes to the size of the garden: pre-war residences have large gardens, yet those built after the second world war have much smaller gardens (Kulberg, 2016). In the ’90s gardens decrease further, with land prices rising high. These factors are not able to be altered, but give an insight into what is one of the driving forces behind the extent of green surfaces in gardens. In addition, a study by Lin et al., (2017) revealed a negative relationship between house age and vegetation cover. This means that older houses will likely have more surfaces covered by vegetation.

The size of the gardens influences the garden composition and amount of vegetation (Loram, Warren & Gaston, 2008, p.371: Lin et al., 2017, p.242): as the area of a garden increases, the number of trees and tall shrubs increases. A dense city such as The Hague will likely have several little gardens, especially in the city centre. However, neighbourhoods on the brink of The Hague might instead have larger gardens, as more space is available.

The height of buildings was among the parameters used by Gupta et al. (2012, p.327) in their research on urban green spaces in India. This influences the openness of the neighbourhood and directly impacts the number of persons that can live there. Building height is one of the many morphological characteristics of cities (Maiullari, 2023). Morphologies, or urban form, come in various forms and shapes and directly affect local climate phenomena. The study by Maiullari observed a lower UHI effect in high-rise urban areas, as these create more shade and thus reduce solar radiation absorption. However, they do increase temperatures at night as solar radiation is trapped between the buildings (Maiullari, 2023, p.197). Thus, the owners of homes could be pushed towards a specific type of garden. Residents of high buildings might not see it as necessary to have green gardens, as their gardens are shaded by the building. On the contrary, low-rise buildings might see green gardens as they have little shade.

2.3.2 Socio-economic factors

First, Goddard, Dougill & Benton (2010, p.94) suggest that socioeconomic factors drive the complexity in the vegetation of residential gardens, with more complex gardens underpinning a larger diversity in species found. On the other hand, these gardens also influence the socioeconomic status of the owners. For example, it can lead to an increase in property value and thus change the socio-economic status of its owners.

Moreover, the common so-called *starterswoning*, Dutch for starter home, is no longer a long-term home for many in the Netherlands (Kulberg, 2016, p.38). Instead, these houses are seen as interchangeable, and just a stepping stone towards bigger, more expensive, houses. As a result, these starter houses often have a high amount of impermeable surfaces within their gardens as managing it is simpler than a green garden. Consequently, it is thus likely that in the observed data of the study many *starterswoningen* will have a high amount of grey surface areas. This is further reinforced by the observed relationship between green gardens and the age of residents (Kulberg, 2016, p.51), with older residents likely to have greener gardens than of those younger residents. In addition, the duration of exposure to vegetation is important (Dadvand et al., 2012). It is observed that unemployed people benefit more from green spaces than others, as they have a longer exposure.

Following up on that, most of the residential gardens in the Netherlands are owned by people ranging from age 35 to 65 (Kulberg, 2016, p.40: Zhou et al., 2009). This is largely contributed to families with children preferring to have a garden. Once the children move out, the parents remain in these residences. Furthermore, of the elderly population, a large segment still owns and manages their gardens. Age could thus influence residential gardens.

In addition, income and education level can also be used as factors to predict the amount of greenness in gardens, especially for lawn-care expenditures (Zhou et al., 2009). Lawn-care expenditures can indicate fertilizer application, which is associated with lawn greenness. In another study, education is also shown to be a suiting predictor for vegetation (Luck, Smallbone & O'Brien, 2009, p.617). Education could reflect a complex interaction between social status and a prefer for and capacity to live in areas with vegetation. Even though income and education are often largely cohesive, it is important to keep them separate, similar to the study of Luck, Smallbone & O'Brien. Higher education does not guarantee higher income, nor is it true that people with high income have higher levels of education.

The type of ownership is also important. Rental houses are not more likely to have tiled gardens than owner-occupied houses (Coolen & Meesters, 2012). Instead, resale properties are observed to have more tiled gardens as they are seen as investments. In another study, owner-occupied houses appear to have higher investments in lawn care (Zhou et al., 2009), yet also less lawn greenness. This indicates that owner-occupied houses get investments, yet these are not always investments into having more green surfaces.

2.3.3 Green in the public environment

Urban green spaces are closely linked to residential gardens and play a similar role: both as a support for the ecological integrity of urban areas, as well as protecting the health of residents by removing pollution and cooling temperatures (Wolch et al., 2014). It is possible that due to either a lack of green spaces or an abundance of green surfaces in neighbouring areas, the effects of residential gardens are diminished. Moreover, it could also reduce the need for residents to construct and maintain vegetation within their gardens.

The WHO recommends at least 0.5 hectares of green, no more than a 5-minute walk or 300 metres away from homes (Nieuwenhuijsen, 2021: Konijnendijk, 2022, p.). Therefore, it is necessary to analyse the number of green spaces near residential gardens. This 300 metres requirement is part of the 3-30-300 rule. This set of guidelines builds on the importance of the ability to see vegetation from work or home, living amongst trees, and being able to visit green public spaces with relative ease (Konijnendijk, 2022). The three relate to the ability to see at least three trees from their home, work, or school. These trees act as proxies for green spaces, thus other forms of vegetation can be swapped for this rule. The 30 points to the 30% canopy cover that should be a minimum for cities.

2.4 Effects of green residential gardens

Green residential gardens have several, often positive, effects, on local temperatures as well as rainwater runoff and even human health. Following are four categories of effects associated with green residential gardens.

2.4.1 Health and well-being

A garden influences an individual's well-being, as gardening can be seen as a form of pastime or retreat (Cameron et al., 2012, p.133). However, this effect is dependent on the individual's attitude to gardening. If little effort is taken and a garden consisting of mainly grey surfaces is had, then a smaller increase in well-being could be had. On the other hand, gardening can also increase the bond between an individual and nature (Goddard, Dougill & Benton, 2010).

Furthermore, gardens reflect a major source of joy, engagement and opportunity for self-reflection according to a study done by Chalmin-Pui et al., (2021). Greener gardens are merged with the concept of gardening, as taking care of vegetation is not observed in impervious gardens. More frequent gardening showed reduced perceived stress, increased well-being, and increased physical activity levels (Chalmin-Pui et al., 2020). Likewise, interacting with green has several health benefits, such as pain relief, a decrease in blood pressure, and even improved cognitive function (Cameron et al., 2012). In addition, this interaction is often outside, thus increasing the interactor's vitamin D levels if the sun is shining (Thompson, 2018).

More and more children grow up in urban areas. As a result, the interaction with nature is more and more limited (Hand et al., 2016). A lack of connection to nature can be linked to lower levels of motivation to protect nature. Residential gardens represent the main source of nature that these urban children interact with. If these are green then a connection to nature can be maintained, yet with an increase in impervious surfaces this connection is at risk.

Gardens are often used by hospitals, this idea dating back thousands of years ago (Thompson, 2018). Different studies show that exposure to plants can reduce length of stay in hospitals, and pain levels (Park & Mattson, 2009). Gardens are even closer and are more frequently attended by individuals than this, thus likely to have a great positive impact on human well-being. This impact is, again, related to the degree and amount of green in these gardens.

Vegetation has many different eco-system services. Two of them are most noticeable for humans, heat mitigation and the emission of oxygen (Thompson, 2018: Givoni, 1991). Thus, it increases well-being as the heat could be reduced through vegetation, and it can reduce air pollution.

2.4.2 Local temperatures

One of the things most mentioned when discussing climate change is the increase in temperatures. It is considered a very important factor affecting human health and comfort (Wang, Liu & Xu, 2021). In this study by Wang, Liu & Xu four factors influencing human perception of temperatures are listed: temperature, humidity, solar radiation, and wind speed. These can all be affected by vegetation. Briefly summarized, temperatures can be reduced through the process of evaporation (Kluck et al., 2020). Humidity, as vegetation stores water temporarily and permanently (Warhurst et al., 2014: Zhang, Ye & Shibata, 2020). Solar radiation, by shading surfaces from short wave radiation (Rahman et al., 2020). Finally, wind speed can be increased or redirected, and velocity reduced by vegetation (Szkordiliszs & Zöld, 2016).

As mentioned before, green surfaces can have a cooling effect in urban regions (Cameron et al., 2012). Vegetation and water capture the sun's energy by evaporation, and thus less energy remains that can heat the area (Kluck et al., 2020). This evaporation focuses on one of the three components of heat fluxes, namely that of latent heat. Evaporation allows for more latent heat, compared to the other types of heat. As a result, it decreases the temperature of the air and surfaces. This effect of cooling is most noticeable during the day, but at night it works as well as the saved-up heat is decreased during the day. Kluck et al., (2020) recommend evaporation as one of the key methods for decreasing sensible atmospheric temperatures. Furthermore, trees have a bigger impact compared to grass for evaporation, as they contribute more during droughts and warm periods. Trees can reduce the UHI effect by approximately 35% in The Hague (Oorschot et al., 2021). Therefore, it is often not about simply making something green but also about what type of green is used.

In addition, the benefits of vegetation vary from place to place. Different climates have different effects, and even specific locations have different effects (Solcerová, 2018). Trees planted near roads can reduce the cooling during the night-time due to reduced ventilation. Colder regions might prefer a reduction in wind speed, in contrary to tropical regions where higher wind speeds are preferred for cooling.

2.4.3 Energy conservation

With cooler temperatures due to greener surfaces, energy can be conserved (Cameron et al., 2012). Since with more shading and more evaporative cooling, the need to use air conditioning units is reduced. Trees can have seasonal energy savings of around 30%, as shown in an older study by Akbari et al. (1997). Newer studies show annual savings of around 107kWh per property, and 80kWh per tree (Ko et al., 2015). The savings are dependent being influenced by the size of the tree.

Even though the presence of air conditioning units in residential houses in the Netherlands is still low, the number of units sold each year is rapidly growing (Brunt, 2022). With around 75.000 units being sold in 2016, around one-fifth of the Dutch population owns one at home currently. If residential gardens become greener and thus have more shade and evaporative cooling then the usage and intensity of usage can be reduced.

If little effort is taken into green residential gardens, the little number of plants in gardens cannot mitigate the increase in temperature because of global warming. This would increase the amount of air conditioning units which use up more energy and thus increase the number of emissions, resulting in a negative feedback loop. On the other hand, if gardens are optimized in the number of green surfaces a positive feedback loop could occur. With lower temperatures, there is less need for the usage of air conditioning in houses in the Netherlands. This would result in fewer emissions and thus eventually a decrease in emissions and global warming.

2.4.4 Rainwater runoff

Urban floods have become more and more common due to climate change (O'Donnell & Thorne, 2020; Kelly, 2014), and impermeable garden surfaces can increase the risk and intensity of such events taking place (Perry & Nawaz, 2008). Figure 2.3 gives a simple overview of the difference between impervious, on the left, and pervious surfaces, on the right.

One of the many solutions suggested to reduce rainwater stress are rain gardens. Even though residential gardens are unlikely to be similar to these rain gardens, it is important to understand how these work. Rain gardens consist of areas with vegetation and an engineered soil mixture (Zhang, Ye & Shibata, 2020). Runoff travelling through these gardens is intercepted, settling down some particles in the vegetation. In addition, the runoff can be stored in these layers. Zhang's study suggests a reduction of around 13% in runoff volume. It could be that such constructions of gardens are to be recommended for domestic purposes by governments, to reduce local rainwater stress.

Furthermore, green surfaces can decrease flood vulnerability through infiltration, evapotranspiration or by storing the water temporarily or permanently (Warhurst et al., 2014: Zhang, Ye & Shibata, 2020). This decreases the burden on the sewage system, as the quantity of water and flow rate are reduced (Warhurst et al., 2014). Furthermore, vegetation distributes the runoff over a longer period, as water is slowly released. This allows drainage systems to catch up.

On the contrary, gardens with many tiles offer little room for water to enter the soil, and this water is thus redirected towards drains. Figure 2.3 reflects this, as the left halve shows this process. With residential gardens being an important part of green in urban areas, having green surfaces within these gardens can be of great usefulness in reducing runoff. Gardens with impervious surfaces instead alleviate the problem, increasing the stress put onto drainage systems at peak rainfall moments.

Surfaces come in various types and materials, which affect the amount of retention and runoff. A more elaborate explanation is in the following section.

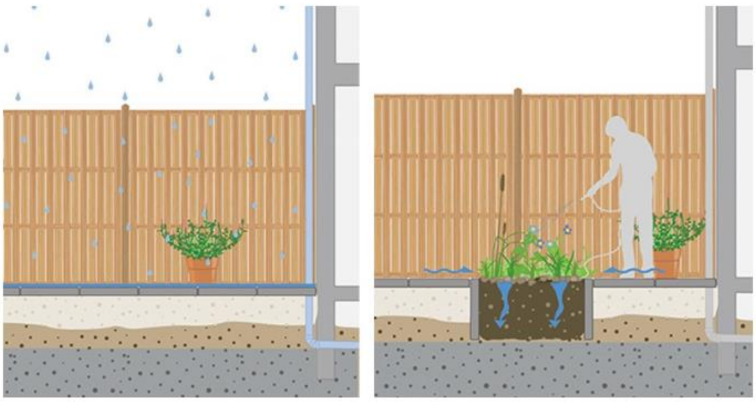

Figure 2.3: Impervious and pervious surfaces
(Amsterdam Rainproof, n.d)

2.5 Types of green

Residential gardens are diverse in vegetation and other surfaces. Most often they consist of a mix of trees, grass, and shrubs. Various plants offer various ecological functions. Trees offer different benefits compared to grass. In general, trees are better at reducing temperatures, whilst grass is better for reducing runoff. Cao et al., (2010) argue that grass has a different function compared to trees and shrubs, with the cooling effect being lower. In addition, Remme (2017) suggests different heat-reduction rates. In Remme's map on the cooling effect of vegetation, trees were given a reduction rate percentage of 50%, shrubs and bushes 30%, and grass and low vegetation a value of 20%. This further highlights the differences between the types of vegetation. Therefore, it was decided to divide these types of vegetation. Following is an explanation of the two categories established in this study, and what effects they can have.

2.5.1 Trees and shrubs

Shrubs come in various sizes and can be used to complement trees (Zhang, 2020). Trees, instead, are larger and less flexible. Even though they are different, they are categorized together in this study as their functions align. Furthermore, these two are often seen together, with trees having their roots covered by shrubs. Cao et al., (2010) also suggest that these two are of equal importance in reducing temperatures.

Trees and shrubs can help reduce heat stress. Firstly, by reducing the amount of short-wave radiation directed at the surface by providing shade using the canopies of the trees or shrubs (Rahman et al., 2020: Edmondson et al., 2016). This reduction can be as high as 60 to 90%. The amount of cooling largely depends on the local climate, and the surface underneath. Trees standing over asphalt can even lead to a temperature reduction of around 6 degrees Celsius (Rahman et al., 2020). Other studies show that a tree cover ratio between 25% and 40% can reduce temperatures by one degree Celsius (Giridharan et al., 2008). Important for the effect of trees is that there is little space between the tree crowns of different trees, to make sure that as much solar energy is absorbed by the tree crowns (Wang & Akbari, 2016).

Secondly, trees and shrubs reduce the amount of heat available to warm the air due to evapotranspiration (Rahman et al., 2020: Armson, Stringer & Ennos, 2012). This leads to decreased air temperatures around trees, as the shade cools them. This decrease can vary between 1 and 8 degrees Celsius below the tree canopy.

As for rainfall, trees and shrubs can reduce the amount of water runoff (Armson, Stringer & Ennos, 2013). Forests have little runoff, even under heavy rainfall. This is due to the tree or shrub roots absorbing the water, thus reducing the amount of runoff. In addition, trees and shrubs reduce overland flows of water, as they intercept rainfall. Tree canopies can store water on their leaves and stems during rainfall, and evaporate this subsequently.

2.5.2 Grass

Not just trees can reduce local temperatures, grass can also have a cooling effect (Wang, Liu & Xu, 2021). Similar to trees, grass lawns can cool the air through evaporation. In addition, grass lawns can absorb radiation quite well. However, the grass is affected by heat as well and can die due to longer periods of hot weather (Qin, 2015). Compared to impervious surfaces such as tiles which are common in residential gardens, grass will have a lower surface temperature (Takebayashi & Moriyama, 2009, p.1217). In addition, the study of Takebayashi & Moriyama showed that grass-covered parking spaces did not produce a sensible heat flux, confirming that grass can mitigate the Urban Heat Island Effect.

Grass surfaces work well in reducing the amount of runoff since grass allows water to infiltrate into the local soil (Armson, Stringer & Ennos, 2013: Shafique, Kim & Kyung-Ho, 2018). This greatly reduces the amount of water that is left to go into the drains. Furthermore, grass can be of great use in reducing water during peak rainfall, as it can delay the amount of water that is headed towards the drains.

In addition to reducing the amount of runoff, grass can also reduce the number of pollutants in the water (Stagge et al., 2012). It can take up nutrients such as nitrogen and phosphorus, which can increase the growth of eutrophication in water bodies. Thus, it can also help reduce the pollution of local water bodies or ground water.

2.6 Conceptual framework

Illustrated in figure 2.4 is the conceptual framework for this study, based on the literature review and arranged for every sub-question.

At the left of figure 2.4, the three main categories of factors and the indicators that are analysed and predicted to influence the amount of vegetation within residential gardens. This is part of the first sub-question of this study. Next, this study analyses to what extent the amount of vegetation in gardens influences the ability to reduce heat stress and handle rainfall extremes as per the second sub-question. In addition, the types of vegetation that are studied are mentioned. Finally, this leads to the revelation of which neighbourhoods have the most potential to improve the local climate through residential gardens.

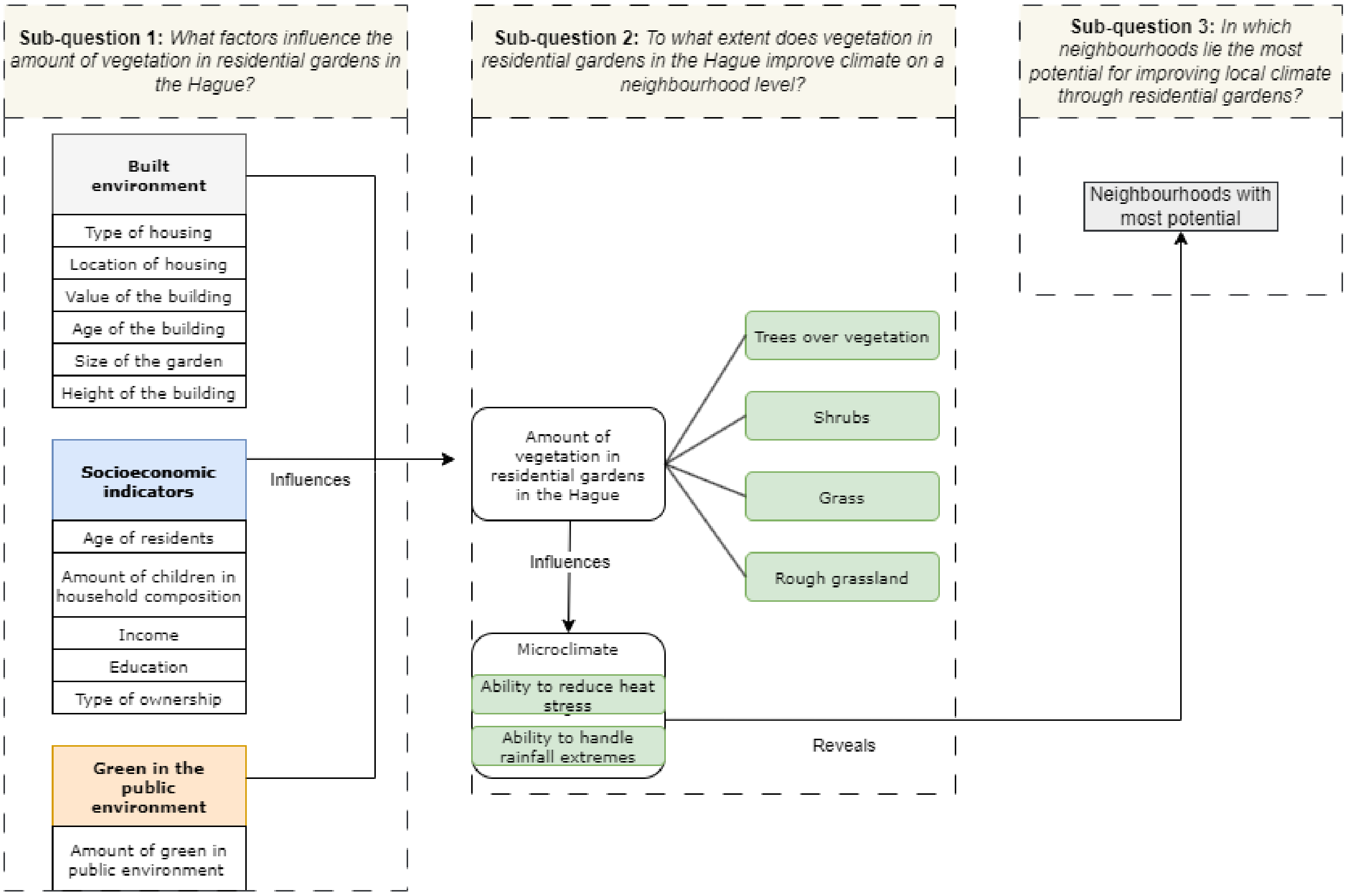

Figure 2.4: Conceptual framework

Chapter 3. Methodology

This chapter discusses the methods and scope of this study. Initially, it explains key terms in ArcGIS and a brief introduction to the statistical analysis of this study. Then, the scope of the research is elaborated upon. In this section, it is explained as to why some neighbourhoods are removed from the study. After that, the chapter applies the framework of the Geographical Approach (Aertz & Baumann, 2009) to this study. Here, the data used is explained, and what tools were used within ArcGIS to work with this data. Finally, a hypothesis for this research is given.

3.1 Research methods

ArcGIS

This study uses the literature review to set up categories that could influence the greenness of residential gardens. These categories are then combined and analysed using ArcGIS. GIS, which stands for Geographical Information System, is used to examine spatial information. It uses location as the connective thread to reveal patterns (ESRI, n.d.-b).

GIS has several terms that are predominately used. Vector files contain features with associated data and are used for storing the location, shape, and attributes of geographical features (ESRI, n.d.-d). Vector data is further divided into three types: points, lines, and polygons. Raster data is a matrix of pixels or cells, organized into rows (ESRI, n.d. -e). Each cell contains a value, representing information such as UHI temperatures.

ArcGIS is used predominantly for this research, to map residential gardens and analyse the factors influencing the amount of green in these gardens. Without GIS, this study would be very time-extensive or impossible, as GIS allows us to easily map and analyse spatial data. Likewise, GIS makes it possible to determine what and where the residential gardens are. It would not be possible to determine the size of gardens through other software, as this has not been calculated before. GIS can calculate this easily, as it uses coordinate systems to measure sizes. In addition, it enables conveniently aggregating the green index of individual residential gardens to the neighbourhood it is in, facilitating simple calculations and illustrations of it.

GIS allows for different maps to be stored and used alongside each other (Raju, 2006). In the case of this study, several different maps are used. For instance, the cadastral map is used alongside the shapefiles of the residences in The Hague to find out where and how many residential gardens there are.

Statistical analysis

To assess whether the factors influencing vegetation in residential gardens are valid, a statistical analysis is required to be performed. As for statistics, variables are divided into four levels of measurement (te Grotenhuis & van der Weegen, 2013, p.13): Nominal, ordinal, interval, and ratio.

Nominal variables are used to categorize data into different groups or categories. The order in which the categories are picked is not important, as these do not indicate any value. Instead, the categories are purely there to be able to differentiate between each other. For instance, the types of housing analysed in this study are a nominal variable, since one type of house is not objectively better than another. Next, ordinal variables, instead, can be put in a specific pick order. For example, education levels can be put in a specific order, ranging from the lowest level of education to the highest. Thirdly, the interval variables are used to measure variables with equal intervals, such as years between each other. There are no natural zero points for this type of variable. The year buildings were built is a good example of an interval variable, as these years are clear intervals. Finally, there are ratio variables which are similar to interval variables, yet also have a clear natural zero point (te Grotenhuis & van der Weegen, 2013, p.14).

Table 2.1 (chapter 2) summarizes the factors that are analysed. To apply the just-mentioned type of variables to these factors, table 3.1 is created.

Table 3.1: Type of variables for factors studied

Type of variable	Factors
Nominal	- Type of housing - Type of ownership
Ordinal	- Location of building - Education
Interval	- Value of the building - Age of the building - Size of the garden - Height of the building - Age of residents
Ratio	- Income - Number of children in household composition - Amount of green in public environment nearby

With so many variables in mind, a multivariate regression analysis is to be performed. This type of analysis allows all types of variables to be considered, even nominal and ordinal by changing them into dichotomous variables (te Grotenhuis & van der Weegen, 2013, p.109). In a multivariate regression analysis, one dependent variable's relationship with independent variables is measured. This can be done in different applications, for this study, this analysis was performed in SPSS 26 (Statistical Package for Social Sciences), as this software is often used in education and research. Moreover, SPSS allows for elaborate multivariate regression analysis.

3.2 Research scope

This study purely focuses on residential gardens, thus only gardens that are next to residences are analysed. Other types of public green surfaces are accounted for in the factor of green in the open environment.

Only gardens within the municipal borders of The Hague are studied. The Hague has 114 different neighbourhoods, illustrated in figure 3.1**.** As seen in the numbers attached to these neighbourhoods, several appear to be missing. However, these numbers are the codes attached to these neighbourhoods by the municipality. It is likely that these neighbourhoods used to exist but have been merged with others by now. The neighbourhoods are part of larger districts, of which there are 44. Seven neighbourhoods illustrated in figure 3.1 are crossed through, these neighbourhoods are disregarded for the study. Following is an explanation as to why.

Initially, three neighbourhoods within The Hague appear to have no residences with residential functions. These are neighbourhoods 70, Oostduinen, 107, Vliegeniersbuurt, and 109, Tedingerbroek. As such, these are not accounted for in the study, as there are no domestic gardens located within the borders of these neighbourhoods.

However, upon further research, it was shown that three more neighbourhoods have either a little number of residences or that the data was wrong. It was decided that an N of 10 was needed to make sure that there was a sufficient amount of residences within the districts. N here indicates the number of residential buildings. This number was chosen based on the available data, which showed that a higher N did not directly lead to different results.

Neighbourhood 60, Binckhorst, was removed from the study as most of the residences here were commercial buildings. Even though new constructions are going on in this mostly commercial neighbourhood, little data on these new plots is currently available, making this study difficult to be performed in the Binckhorst. Neighbourhood 85, Kerketuinen en Zichtenburg, is a similar case. This neighbourhood is mainly used for commercial purposes and has several buildings with a residential function. In addition, neighbourhood 117, De Rivieren, is also mostly functioning for commercial purposes. In this neighbourhood, only 7 residences were noted, thus being lower than the desired N. Upon further research using Google Streetview, it was decided that these areas do not fulfil a purely residential function. Thus, this neighbourhood does not reach the required N.

Finally, neighbourhood 36, Zuiderpark is also removed from this study. This neighbourhood mainly consists of, as the name regards, a park. A single apartment building is found in this neighbourhood. Even though there are more than 10 different residential addresses, it concerns a single residential building. Thus, the required N is not met.

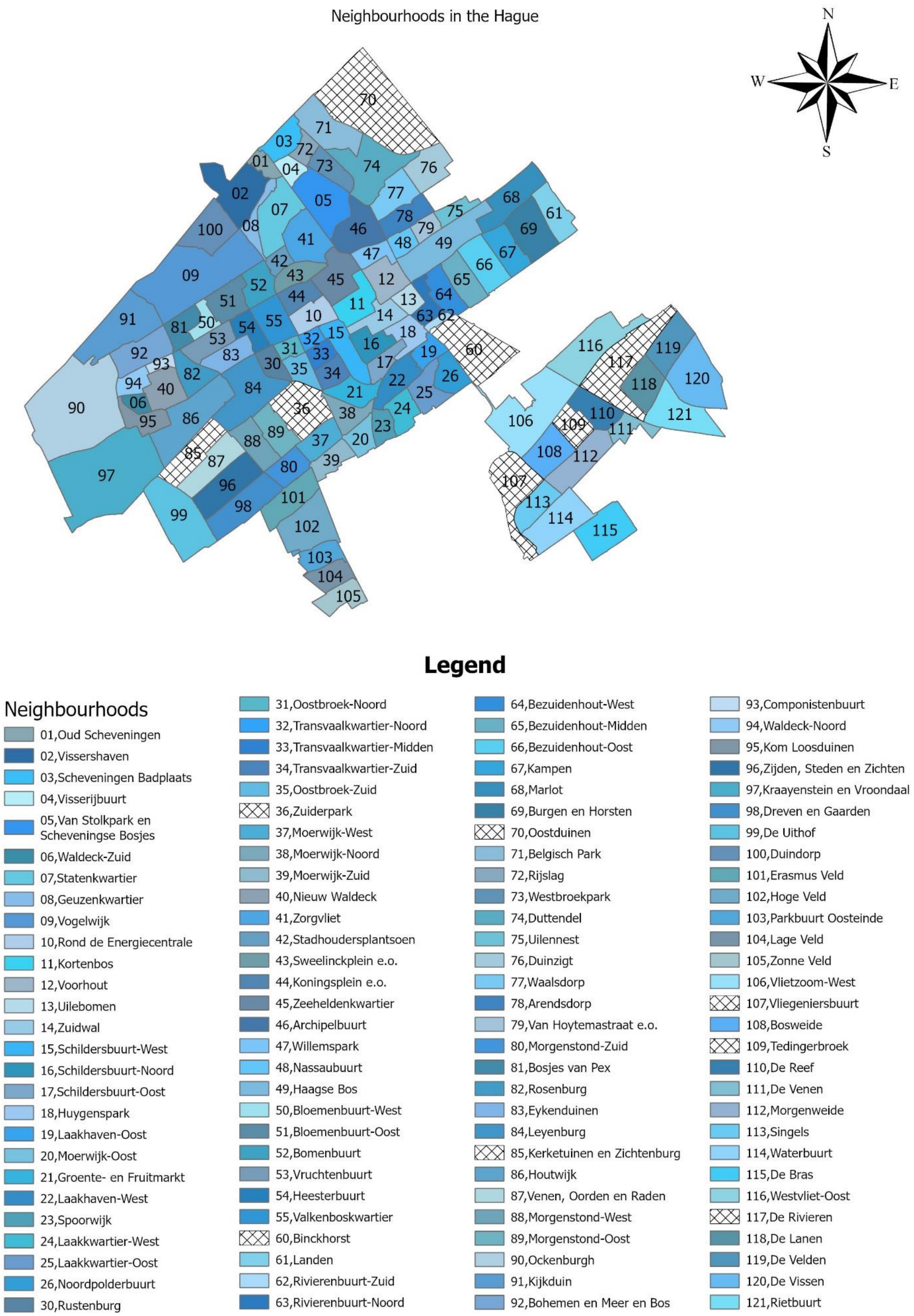

Figure 3.1: Neighbourhoods in The Hague

3.3 Geographic approach

This study follows the framework of the Geographical approach, which consists of 5 steps and is illustrated in figure 3.2 (Aertz & Baumann, 2009). The approach is often used for location-based analysis, and its focus enables the usage and exploration of diverse datasets. GIS is crucial to this approach, as it provides a clearer understanding of the complexity of the study at hand.

As shown in Figure 3.2, the first step, Step 1 is to *ask*: What is the problem, and where is it located (Aertz & Baumann, 2009)? The next step, Step 2, is to *acquire*: to complete the analysis, data is needed. Data can be acquired through existing sources, or it might have to be created anew. Step 3 is to *examine*: without a proper examination, it is not possible to know whether the acquired data is appropriate. Following is Step 4, *analyse*: this step involves the processing and analysis of the examined data. Finally, Step 5 *act*: presenting the results of the geographical study is crucial. These can be shared by maps, tables or reports. Following is a further explanation of these steps, and it is linked to this research.

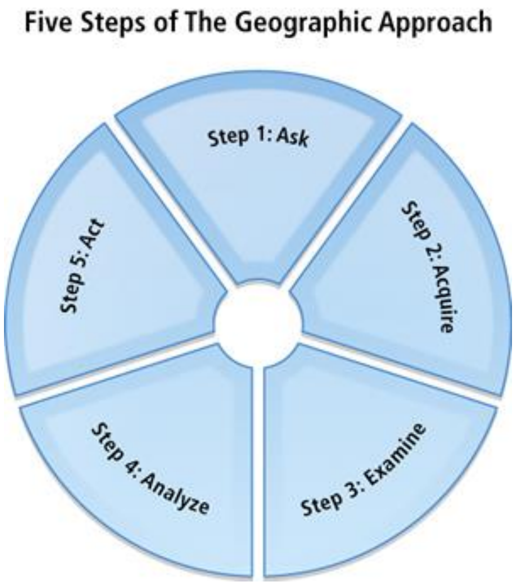

Figure 3.2: Five steps of the Geographic Approach (Aertz & Baumann, 2009)

3.3.1 Ask

As mentioned before, residential gardens can play a role in reducing local heat stress, as well as reducing (the risk of) urban floods. The question asked is what affects the greenness of residential gardens and to what extent they influence such problems. The location investigated is that of The Hague, the Netherlands. Moreover, only residential gardens within the municipal borders of the city of The Hague are analysed.

Residential gardens are seen as gardens that are allocated within a residential plot. Thus, gardens associated with commercial buildings are not considered. Green in the public environment, i.e. parks and lawns near roads, is measured for analysis as mentioned in the theoretical framework.

3.3.2 Acquire

Different types of data are required for this research. Maps are used, for instance, for analysing the UHI effect and precipitation. Data on neighbourhoods is often given in tables, such as by the CBS. Most of the data is publicly available, such as the BAG and cadastral data. However, the data supplied by Cobra Groeninzicht is not and the specific data required for this study was requested. An overview of the data used is shown in table 3.2.

Table 3.2: list of data sources used

Name	**Source**	**Type of data**	**Year**
BAG3D	TuDelft3d	Vector	2021
Cadastral plots	Municipality of The Hague	Vector	2023
Key figures neighbourhoods and districts	CBS	Table	2020 & 2022
Education level per municipality	CBS	Table	2018
Spatial key figures	Municipality of The Hague	Table	2021
Grey surfaces in gardens	Cobra Groeninzicht	Vector	2023
Vegetation layers The Hague	Cobra Groeninzicht	Raster	2022
Vegetation map of the Netherlands	RIVM	Raster	2017
Urban Heat Island Effect	RIVM	Raster	2020
Hydrological Soil groups	NASA (Ross et al., 2018)	Raster	2018

Data on The Hague

The Basisregistratie Adressen en Gebouwen (BAG) data set is one that is used. This contains much data, such as the address, function of the building and the year it was built. Moreover, a more elaborate BAG map in 3D exists which considers the height of the buildings (TuDelft3d, n.d.). This is relevant for this study, as it could influence the amount of green in residential gardens, as mentioned by Gupta et al. (2012).

The cadastral map of The Hague (Municipality of The Hague, 2023b) shows all plots in the city, whether they belong to the municipality or not, and whether there is a leasehold. This allows differentiating between what green is in the public environment, and what stems from residential gardens. Plots that do not belong to the municipality and plots that are owned by the municipality but have a leasehold are seen as residential. Municipal-owned areas without leasehold are areas such as roads. Both front yard and backyard residential gardens are considered, as these are accounted for in the plots. To measure the gardens, another shapefile is available, that of the buildings (Municipality of The Hague, 2023c). By taking the plot and removing the building it is possible to find the gardens. In addition to this, a map with the percentage of grey and green surfaces of residential gardens in The Hague is made available by Cobra Groeninzicht. This holds useful information for every garden.

Furthermore, data on socio-economic factors is available on the scale level of the neighbourhood, supplied by both the Central Statistical Office (CBS) and the municipality of The Hague. Here, data on factors such as income, age and whether these are rental homes or owner-occupied homes is available (CBS, 2022). Upon closer investigation, this data seemed incomplete for some crucial indicators such as income. Therefore, the data from 2020 was used, as this key figures table was the most recent one that is complete (CBS, 2020). Information on education per neighbourhood is also available through CBS (2018) but is given in a separate table. In addition to this data, key figures of The Hague were used (Municipality of The Hague, 2021). This dataset held similar information as that of the CBS but also included types of residential buildings. This allows for easily differentiating between houses and apartments.

Unfortunately, most of this socioeconomic data is not readily available on a lower level of scale, thus making it not possible to allocate socioeconomic data to each plot. As a result, the socio-economic factors used are average values and thus might not be as accurate for every neighbourhood.

Finally, crucial to speeding up the process are the municipal borders (PDOK, 2021). By selecting The Hague, it allows to only clip the data relevant to this study which is located within the borders of The Hague. For instance, the data on green surfaces is available for the entirety of the Netherlands yet this would slow down the computing speed of ArcGIS as it must run the data outside of The Hague as well.

Data on vegetation and Urban Heat Island Effect

The RIVM (2022), the Dutch National Institute of Public Health and the Environment, has created a map showing the number of green surfaces for every 10 by 10 meters in the Netherlands. At first, this data was used. However, it seemed that these 10 meters tiles are too broad due to their size. Parts of the residences that fit within these tiles would be included, thus rendering the green index of gardens inaccurate. Further research revealed that a consultancy firm, Cobra Groeninzicht, has very detailed data on vegetation. This data is on a 0.25 by 0.25 metres size and illustrates the vegetation during the summer of 2022. Here, differences in types of vegetation are available in 11 classes.

To measure the UHI effect, a map detailing this created by the RIVM (2020) was used. This map illustrated the urban heat island in the Netherlands. The heat is calculated by measuring the difference between urban areas and rural areas. Moreover, the RIVM also calculated the cooling effect of vegetation (Remme, 2017). The methods of this calculation are given by Remme, and a similar method will be used.

3.3.3 Examine

The entirety of how this data was handled can be seen in the model, illustrated in figure 3.3. ArcGIS has several tools among them being ModelBuilder, which is a visual programming language for building geoprocessing workflows (ESRI, n.d.-a). This figure will be explained in the coming paragraphs. The model will be divided into sections. Starting with the residential plots and gardens.

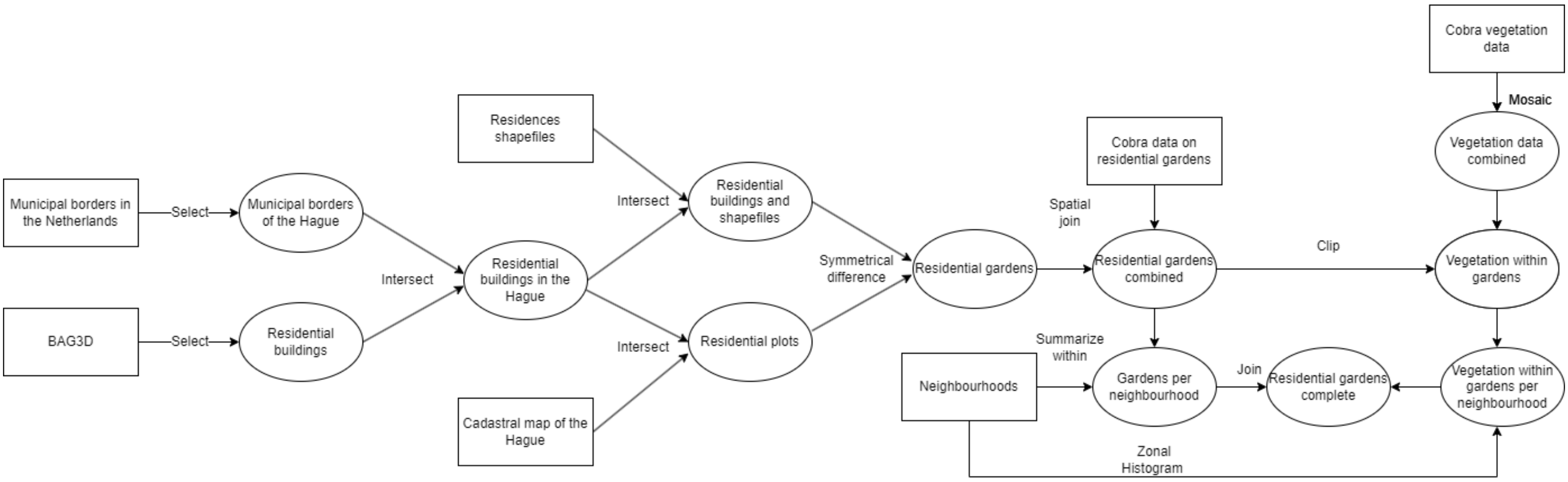

Figure 3.3: Method for finding residential gardens

Residential plots and gardens

Initially, the municipal borders of The Hague were selected, by using the *select* tool in the municipal borders file (PDOK, 2021). Next, the addresses with residence functions were selected in the BAG dataset, thus removing buildings with commercial and other types of functions. These are not considered in this study. This is done by the *select by attributes* tool in ArcGIS. Then, the BAG data for The Hague is selected, by intersecting with the municipal borders of The Hague. By using the *intersect* tool the plots with residential functions were revealed. The intersect tool creates an output of the overlap of all input layers. A visualisation of this geoprocessing tool is shown in figure 3.4. The BAG data used was already clipped to a smaller version, thus not requiring this step to be done first.

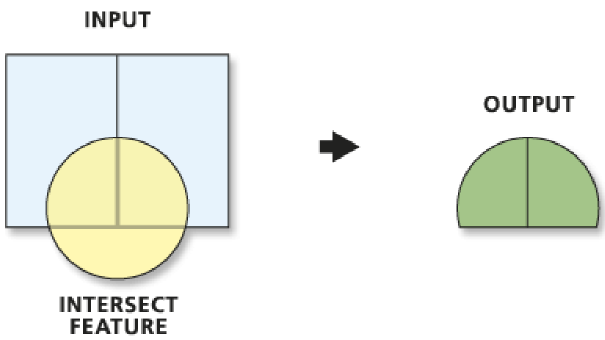

Figure 3.4: Intersect tool visualisation (ESRI, n.d.-c).

Then, the cadastral map was to be combined with these residences to reveal what areas were residential. This was done by using the *intersect* tool as well. Next, the cadastral map of the Netherlands (Municipality of The Hague, 2023b) is used alongside the data on the residences (Municipality of The Hague, 2023c) to determine the size of the gardens, by using the *symmetrical difference* tool in ArcGIS. This tool shows the difference between the input, the cadastral map, and the update features, the residences shapefiles. In return, the residential gardens are shown. By adding a field to the attribute table, and using the calculate geometry tool the size of the gardens was calculated.

The data of Cobra had quite a similar outcome regarding the residential gardens, yet also had some slight differences. Moreover, some inaccuracies regarding gardens and residential plots were observed. However, this dataset of Cobra held the data for the percentage of green in gardens. To account for accuracy, these two datasets were spatially joined in ArcGIS and matched through an intersect. As a result, this showed the gardens that were in the original dataset plus the data from Cobra on those garden plots. However, this means that it is likely that some gardens were part of the data of Cobra but were now removed. Moreover, some gardens were not calculated for in the Cobra data. However, the observed data showed that most gardens were still considered.

Yet, some mistakes remained. The cadastral map is mostly accurate, yet some buildings are still seen as gardens. Some of the larger, directly visible, errors were taken care of. For instance, the Haagse Hogeschool was seen as a garden of a nearby building. Table 3.3 lists the removed gardens and the reason why.

Table 3.3: List of plots removed

Location	**Reason**
Abraham Orteluspad	Agrarian grounds
Roeleveense weg 1	Agrarian grounds
Roompot Kijkduin	Inaccurate data
Catshuis	Ministerial residence
Haags Openbaar Vervoermuseum, Ter Borchstraat	Museum
Louwman Museum	Museum
Vredespaleis	No residential function
Haagse Hogeschool, Johanna Westerdijkplein	No residential function
Industrial area, Lau Mazirellaan	No residential function
Cemetery Sint Barbara	No residential function
Tennispark Hanenburg	No residential function
Prison Haaglanden, Pompstationsweg	No residential function
Crematory Ockenburg, Ockenburghstraat 21	No residential function
Dalton Den Haag, secondary school	No residential function
HTM Public transport depot, Lijsterbesstraat	No residential function
Zonweg & Melkwegstraat	No residential function
Maris College Nieuwe Duinweg, secondary school	No residential function
Large forest surrounding Parnassia Groep, Monsterse weg	Public park
Zorgvliet, public park	Public park
Oud Rosenburg, Dadelplein	Public park
Residence le Haye, Wassenaarseweg	Public park
Koekamp, public park	Public park
Paleis Huis ten Bosch	Royal residence
Waldorpstraat	Under construction
Ter Leedepad near Abdis Elizabethstraat,	Under construction
Uranusstraat 350	Under construction

These gardens were removed due to a wrong function of the type of residence, i.e. the museum being seen as a residential garden and the holiday retreat being seen as residences. It is possible that people reside within this retreat all year long, yet the cadastral map illustrates that the entire park is their residential garden, thus giving an inaccurate image of the situation. In addition, several large gardens are more akin to public parks. Moreover, residences such as Paleis Huis ten Bosch and Catshuis are residences, yet these hold a more monumental function than that of a residence. It is possible that there are more mistakes within this map, yet these were not immediately visible. These were removed by using the *edit* tool and deleting the gardens.

With the removal done, the gardens and their green index were finished. The only step left was to aggregate these results to a higher level of scale, that of the neighbourhood. This was done by using the *Summarize Within* tool, which calculates the average green index of the gardens per neighbourhood. However, the different vegetation types are not taken into account in this green index.

The different vegetation types were given in numerous raster tiles. First of all, these are combined, by using the *Mosaic* tool. This creates one single tile of the raster files. To speed up the computing process, these were clipped to the borders of The Hague. Next, the amount of vegetation that is within residential gardens can be calculated by using the *Zonal Histogram* tool. This creates a table showing how much the different vegetation is within gardens per neighbourhood. In addition, a similar method is used to retrieve the amount of green in the neighbourhood. This allows to calculate the percentage of green in a neighbourhood that stems from gardens. This data and the gardens with the green index are then combined by joining them together, as seen in figure 3.3.

Upon closer examination, the labelling given by Cobra turned out to be inaccurate. What was labelled as water were trees, and vice versa. Through trial and error, these labels could be corrected. Unfortunately, this meant a loss of complexity. As the original Cobra data had four different types of trees. With mislabelling of vegetation types, it proved impossible to differentiate between these types of trees. By using satellite imagery, the labels were corrected, and this did not allow to differentiate between trees as it was not visible whether a tree had grass or vegetation below it. The impervious surfaces consist of roofs and open and closed pavement. These also had to be corrected. The correction of the labels is given in table 3.4.

Table 3.4: Correction of labels

Vegetation type	**Original value**	**Converted value**
Grass	4	6
Rough grassland	7	10
Shrubs	6	3
Trees	8, 9, 10, 11	0, 1, 2, 7
Impervious surfaces	0, 1, 3, 5	4, 5, 8, 9
Water	2	11

Figure C.1 gives an illustration of how these land cover types are shown in ArcGIS.

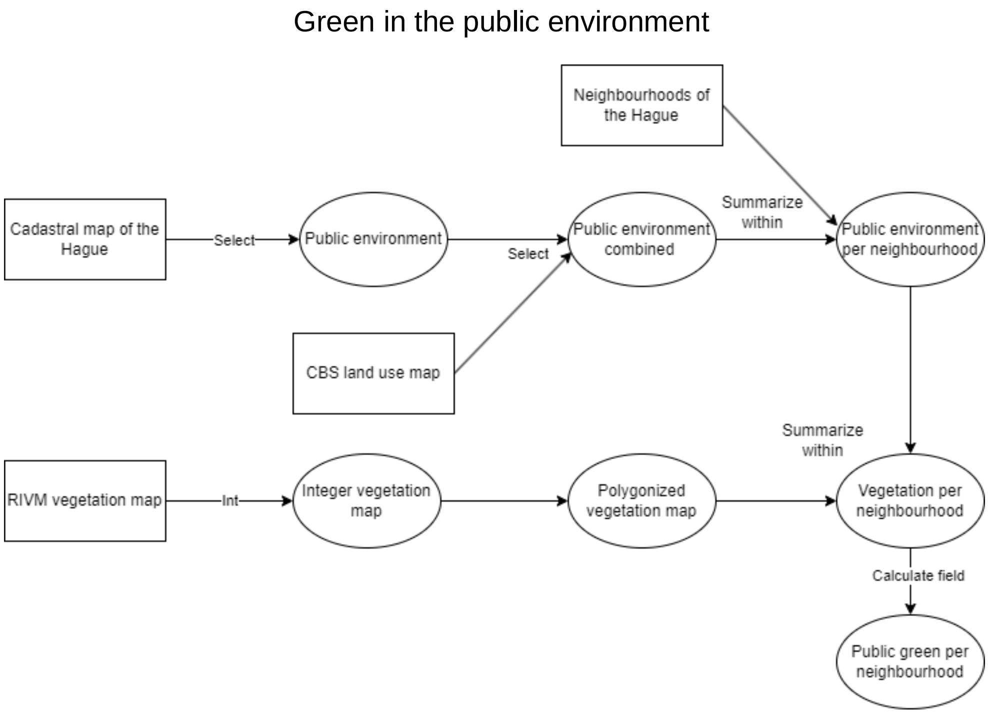

Figure 3.5: Method for calculating green in the public environment

The classification of what public green spaces are is divided throughout literature (Cardinali et al., 2023, p.11). Some include only parks, whereas others add forests and agricultural land. However, since some paths and interactions are informal, and thus not part of any database (Ferilli et al., 2019, p.194), it is hard to capture all forms of public green spaces. It could be that even though they act as a public green space, they are not classified as such. Some parks in The Hague are privately owned, whilst still being open to the public.

To measure the amount of public green two sources of data are used to determine public areas. First, to differentiate between public and private grounds, the cadastral plot map is used (Municipality of The Hague, 2023b). Here, as mentioned before, the plots are separated in whether they belong to the municipality and whether there is a leasehold. This study establishes the public environment as municipal grounds, without leasehold. The public environment mainly consists of roads, plazas, playing grounds and other open spaces. Vegetation between and next to such places is measured. These were then selected, by using *select by attributes.*

In addition, CBS's land use data (2021) is used alongside the cadastral map. The land use data of CBS holds all land uses ranging from recreational usage to industry and airports, thus a selection is needed to be made. The select tool was used to select these 8 types of land usage in The Hague, and its surrounding area.

For this case, 8 types of land usage were selected:

- Parks and gardens
- Sports fields
- Allotments
- Daytime recreational areas
- Residential recreational areas
- Forests
- Public dry natural areas

- Public wet natural areas

Even though some of the listed areas might not be open to the public, such as allotments or residential recreational areas, the green in these areas can still do good for all. For example, a tree does not stop reducing temperatures if it is on private property. Therefore, it was decided to include these areas within the realm of green in the public environment, since they still have a similar function. As mentioned before, residents in the surrounding area can likely use these areas and their greenery for recreational purposes. This is different from green in residential gardens which could be enjoyed similarly. For example, residents using other resident's greenery to recreate. This behaviour is largely unknown and immeasurable, and thus cannot be considered.

This, however, means that certain areas of green that cannot be used or reached are also considered (Cardinali et al., 2023, p.12). For instance, green near railroad tracks is not open to the public. Grass areas between roads are often non-accessible and thus do not invite physical activity. It would not be possible to search for and remove such areas on this scale level. Therefore, it is decided that such areas are considered. Likely, such areas are not many, as highways and near railroad tracks where green could be non-usable are not within the selected public environment. For example, the railroad tracks near the central station of The Hague are not part of the selection used in this analysis.

To determine the amount of green within these public spaces, the RIVM's vegetation map is used for the statistical analysis. This includes all green in the Netherlands, as mentioned before in the paragraphs on gardens. For gardens, this map is not very accurate due to the tile size of 10 metres by 10. However, this is less of an issue regarding green in public spaces, as it is less fixated on analysing the amount of green or types of vegetation. Therefore, it was decided to use this data to assess green in the public environment.

First, to analyse the amount of green the data needed to be made ready for usage. This was done by converting the file to an integer, by using the *Int* tool in ArcGIS. Next, this raster file is converted into a polygon. To be able to do this step, the raster file needs to be an integer grid type, therefore, the earlier step of converting the raster was needed.

Once the green was established, the calculation of green within 300 metres per plot was started. However, this seemed too ambitious as more than 150 million polygons were to be calculated. This could not be computed within a reasonable timeframe. Moreover, for the model, this meant that others could not replicate the study easily. This analysis would better fit research with a smaller scope. Therefore, it was decided to aggravate the amount of green in the public environment to each neighbourhood. This was calculated by dividing the total amount of green by the total surface area, as seen in the calculation below.

$$\frac{Total\ amount\ of\ green}{Total\ surface\ area} \times 100\%$$

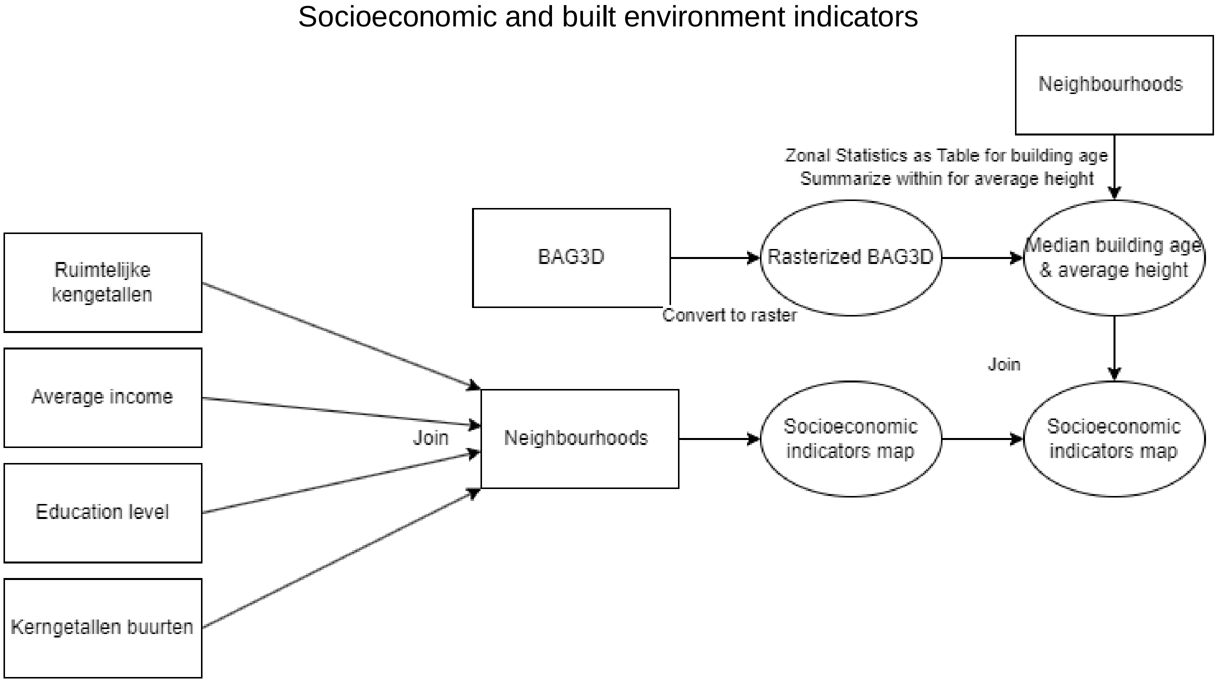

Figure 3.6: Method for combining socioeconomic indicators

To analyse the socio-economic and built environment indicators, several different sources are to be combined. Figure 3.6 illustrates the process. First of all, the spatial key figures for neighbourhoods in The Hague (Municipality of The Hague, 2021) are combined with another dataset, that of the CBS (2022). This dataset holds information on average income levels per household in the neighbourhood, which is not given in the key figures. As mentioned before, the data from 2020 was used, as 2021 was incomplete for several neighbourhoods and that of 2022 still missing. By using the *Join* tool in ArcGIS this combination can be achieved, by joining them based on their neighbourhood name.

Next, the education levels are added similarly by using the *Join* tool. This data stemmed from CBS (2020) as well and shows the education level in percentages, divided into lower, middle, and higher levels of education.

Finally, the spatial key figures provided by The Hague are combined with the key figures from CBS (2022). These key figures included several different factors, such as more elaborate data on residents' ages. This joining is done in a similar method.

It is often that these data sets had little differences between them, such as in the names of the neighbourhoods. For instance, CBS wrote Eykenduinen compared to the municipality writing it as Eykenduynen. This case and others were subsequently changed, as the joining requires them to be completely similar. Moreover, the incorporation into ArcGIS would reveal that some of the data were classified as a text value, instead of a numeric value. This meant that tweaking some of the data sets to be converted into numeric values was needed. Yet, this was easily done by replacing the missing values with zeroes, or by creating new values in the attribute table in ArcGIS and calculating the values there.

Since this data has no geographical coordinates attached to it, a spatial join is required to be performed. The neighbourhoods shapefile, retrieved from the municipality of The Hague (2023a), is used as a connection. Afterwards, these indicators are combined with the BAG3D data set (TuDelft3d, n.d.). To achieve this, the median values per neighbourhood of the age of the building were to be calculated. This was done by converting the BAG file to a raster file, through *Convert to Raster*. Then, the tool *Zonal Statistics as Table* was used to calculate this median value for every neighbourhood. This data was then joined with the indicators. In addition, the average height of the building was calculated by using the *Summarize Within* tool and joined similarly afterwards. Finally, this file was to be joined with the file on gardens, described in the earlier section.

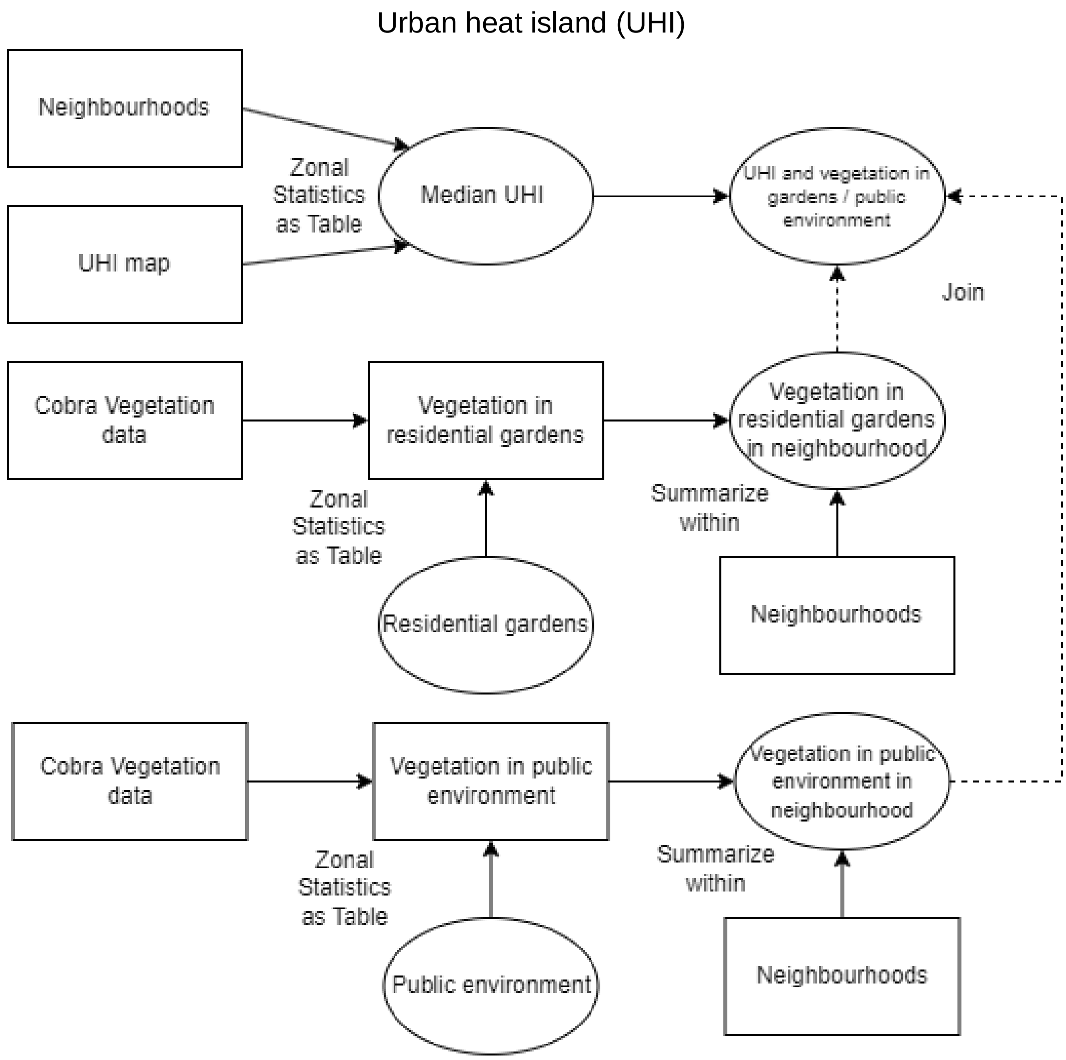

Figure 3.7: Method for gathering data on the effect of residential gardens on UHI

First, the Urban Heat Island Effect data is to be calculated per neighbourhood. This is done by using the *Zonal Statistics as Table* tool. Now, the median UHI value per neighbourhood is determined, and thus it becomes possible to measure the cooling effect of residential gardens on the UHI effect by combining it with the vegetation types. This is done by using the *Join* tool in ArcGIS, with the Cobra vegetation data which is done both for residential gardens as well as the public environment. The dotted line indicates that there will be two separate files as an outcome, one for residential gardens and one for the public environment.

Both the runoff reduction and the UHI calculations are made using the vegetation data supplied by Cobra. This is done for both public green as well as residential gardens. Thus, there is a difference in how public green is calculated for this step, from the data that was used for the statistical analysis. This has to do with the given time schedule, and when data was made available. The public environment listed in figure 3.7 corresponds to the public environment combined as seen in figure 3.5.

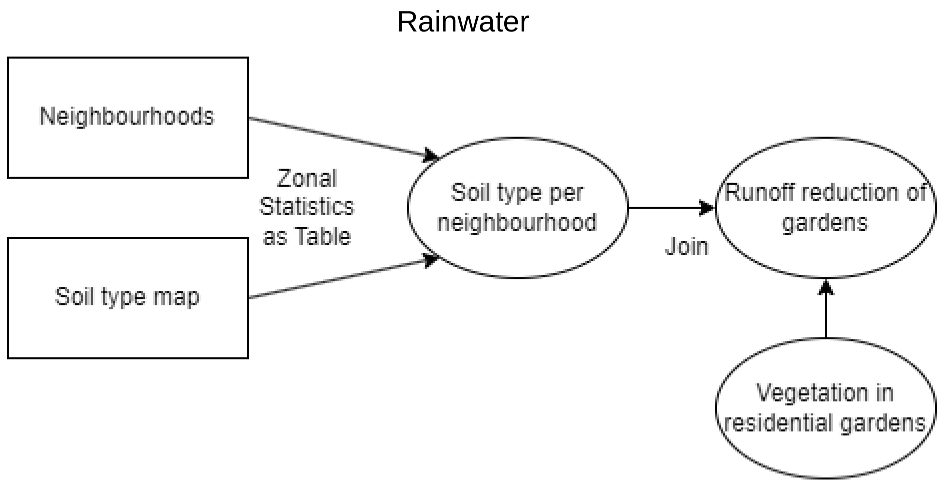

Figure 3.8: Method for gathering data on runoff

For this part, the vegetation types of Cobra are used as well. Moreover, to calculate runoff the soil type is needed. This data is publicly available (Ross et al., 2018). By using the *Zonal Statistics as Table* tool, and by selecting the majority, it is possible to determine the main type of soil within each neighbourhood. Next, the neighbourhoods are split for every soil type to be later merged. This is dependent on the soil types, thus it is not indicated in figure 3.8. This is done by selecting the neighbourhoods with a particular soil type and creating a new layer out of the selection. Then, the data on vegetation within residential gardens as seen in figure 3.7 is used and joined with this data on soil types. This then makes it possible to calculate the amount of runoff.

3.3.4 Analyse

This section is divided into three separate ones, reflecting the three different sub-questions used in this research. First of all, the analysis regarding the factors influencing vegetation in gardens is explained. Next, the method used to measure the degree to which the gardens influence local climate resilience is elaborated upon. Finally, the final sub-question regarding where the most potential lie is clarified.

Factors influencing vegetation

There are many different types of statistical analyses one can do to assess relationships between variables. As for this study, a multivariate regression analysis was chosen as most fitting. This analysis measures the degree to which several independent variables and a dependent variable are linearly related to each other (Alexopoulos, 2010). Thus, the regression describes how much one variable depends on another. In this case, the percentage of garden surfaces that are impervious is the dependent variable. The factors listed before in table 3.1are the predicted independent variables. Yet, the regression analysis cannot be done immediately. With so many variables multicollinearity between variables may arise.

PCA

First, a Principal Components Analysis (PCA) is performed to calculate whether some of the variables share similarities, and if possible, group them into components (Bro & Smilde, 2014). This analysis can be used to reveal relationships between variables and to find patterns. Moreover, it can detect collinearity or multicollinearity. An independent variable that is highly correlated with another will lead to an unstable regression, as the values will vary greatly per sample (Allen, 1997, p.176). This results in a large standard error, reducing the chance the variables are significant.

Multivariate Regression Analysis

With the PCA done, the regression analysis can be performed. Such an analysis produces an output, which consists of tables with different values. Three types of tables are created in SPSS when completing a regression analysis: A model summary, an ANOVA table, and a coefficients table. A model summary table reports the correlation between the independent variables and the dependent variable. The following values are given in a model summary: R, R square, adjusted R square and standard error of the estimate.

Firstly, **R** is the correlation between the observed and the predicted values of a dependent variable (UCLA, n.d.). **R square** is then the proportion of variance in the dependent variable that can be predicted from the independent variables used. This value thus illustrates the degree to which changes in the dependent variable can be attributed to the independent variables in the analysis. In addition to the R square, there is the **adjusted R square** (UCLA, n.d.). This is a more modest value of R square. When there are many independent variables and little observations then the variance in the dependent variable could also be due to chance. The adjusted R-value accounts for this using the formula:

$$1 - \frac{(1 - Rsq)(N - 1)}{N - k - 1}$$

N stands for the amounts of cases or observations, in this study neighbourhoods, and k is the number of independent variables in the analysis. Adjusted R square thus gives a more honest and accurate overview of the correlation between the independent variables and the dependent variable. Next, the standard error of the estimate is the standard deviation of the error.

ANOVA stands for ANalysis Of VAriance (te Grotenhuis & van der Weegen, 2013, p.74). Such tables are used to summarize the results of statistical analyses that compare multiple groups. Moreover, ANOVA tables report the sources of variation that can be attributed to each source. ANOVA tables give 5 values: sum of squares, degrees of freedom, mean square, F, and significance levels. However, it also comes in two rows: **regression** and **residual**. The regression row stands for the variance that can be explained by the independent variables used in the regression analysis (UCLA, n.d.). The residual is the amount of variance not explained by these variables.

The **sum of squares** provides a measure of the variation within the data analysed, and can help in determining whether the differences observed are significant (UCLA, n.d.). Next, the **degrees of freedom**, or df, corresponds to the number of predictors minus 1. Higher degrees of freedom allows for a more precise estimation of results. The **mean square** reports the sum of squares divided by the degrees of freedom, and it indicates the variability in the data. Higher values indicate greater variability. It is used to calculate **F**, which is the mean square regression divided by the mean square residual. The F-statistic is a probability distribution and is used to compare variability between the variables (UCLA, n.d.).

Moreover, it is crucial in calculating **significance levels**, or sig**.** These levels refer to the statistical significance values and are often mentioned as probability values or **p-values** (UCLA, n.d.). Most often, p-values are to be smaller than 0.05 to be able to argue that the independent variables reliably predict the dependent variable. Values higher than 0.05 do not show a statistically significant relationship between the variables. The 0.05 value stands for the 5% chance that the null hypothesis is rejected whilst it is true, which is also called a Type 1 error. The null hypothesis is the hypothesis that it is the mirrored research hypothesis (te Grotenhuis & van der Weegen, 2013). Where it is presumed that one independent variable leads to an increase in the dependent variable, the null hypothesis suggests that the increase was 0.

Finally, a coefficients table reports the relationship between the independent variables and the dependent variable (UCLA, n.d.). It shows the estimated regression coefficients and is used to determine which variables are statistically significant predictors. Values that are given in such tables are B, standard error, t, significance levels, and Beta.

B is given per independent variable and reveals the amount of which the dependent variable changes if the independent variable increases (UCLA, n.d.). For example, it could be that a rise in the percentage of higher education levels in a neighbourhood greener gardens could be expected. As such, these values cannot be compared to each other. The independent variables mostly measure different things, such as value or education and cannot be directly compared. The **standard error** relates to the errors associated with the coefficients (UCLA, n.d.). It is used to test whether the variables are significantly different from 0, and leads to the **t** value. This value measures the size of the coefficient relative to its standard error. If the t-value is large, and the associated p-value small (<0.05) then it is often considered statistically significant. The **significance levels** are similar to that of the ANOVA table, only that it now is calculated per variable. Again, values lower than 0.05 are preferred. Finally, **Beta** refers to the standardized coefficients (UCLA, n.d.). If the variables were to be standardized, then these coefficients would be given. Therefore, this value gives a better comparison among the different independent variables, as they are put all on the same scale.

Table 3.5 lists some of the most important values in a regression analysis explained.

Table 3.5: Key terms in regression analysis

Term	Usage
R	Correlation between observed and predicted values of dependent variable
R square	Proportion of variance in the dependent variable
Adjusted R square	Most accurate value of R, as it takes into account the amount of variables
Significance levels / p-value	Statistical significance levels
B	Amount to which the dependent variable changes for changes in the independent variable
t	Size of the coefficient relative to its standard error

UHI effect and residential gardens

The calculation for the UHI reduction is based on the method of Remme (2017). Remme classifies different vegetation types and gives them different values of heat reduction. Based on his approach, the following assumptions were made regarding the heat reduction of different vegetation as given in table 3.6.

Table 3.6: UHI reduction of different vegetation types

Type of vegetation	Reduction in Remme (2017)
Grass	20%
Shrubs	30%
Rough grassland	20%
Trees	50%

Remme (2017) uses three types of vegetation in his study. For this study, similar values are used to analyse the cooling effect of gardens.

Thus, the following calculation is done to calculate the cooling effect:

$$UHI * (1 - (\sum V\% * Reduction\ value) * G)$$

The UHI used in these calculations is the median value of the neighbourhood. V stands for the vegetation type in gardens, and G for the percentage that a neighbourhood's surface area consists of gardens.

To give an example of how this would look like for a neighbourhood where 10% of its surface area consists of gardens, and where gardens consist of 10% of its surface of grass, 15% shrubs, 20% rough grassland and 25% trees:

$$UHI * (1 - (0.1 * 0.2 + 0.15 * 0.3 + 0.2 * 0.2 + 0.25 * 0.5) * 0.1)$$

This calculation gives per neighbourhood the number of degrees in Celsius that could be cooled from current vegetation in gardens.

Moreover, to calculate the potential UHI reduction of residential gardens for every neighbourhood the following calculation is needed:

$$UHI * (1 - (\sum V\% * Reduction\ value) * \frac{100}{vegetation\ \ in\ gardens\ of\ \ total\ surface\ area\ of\ \ gardens} * G)$$

This calculation is a simplistic way of generating the potential UHI reduction. It assumes that a similar vegetation composition as is right now stays present, and that all gardens will only have green surfaces. This is not realistic, but it allows for the calculation to be done. The values gained from this calculation can be changed to better reflect realistic values by multiplying them with the assumed realistic percentage. These calculations are done in ArcGIS, by using the *Calculate Field* tool.

These calculations are also used to calculate the UHI reduction of green in the public environment, to allow to compare the role of gardens in the total amount of green. Similarly to the calculations, however, now the vegetation in gardens of the total surface area is changed into the amount of vegetation in the neighbourhood of total surface area. This calculation is shown below. The potential is calculated in a similar way as that of gardens.

$$UHI * (1 - (\sum Vegetation\ type\ in\ neighbourhood\ \% * Reduction\ value) * \%\ neighbourhood\ of\ total\ surface\ area)$$

Runoff and residential gardens

As for runoff reduction, a method similar to van Oorschot et al. (2022) is used: the SCS runoff curve method (Cronshey & et al., 1986). This method is as follows:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

In this calculation, *Q* stands for runoff in inches, and *P* for the amount of rainfall in inches. Both have been converted into mm for this study. For this study, a rainfall event of 100mm is used for P. Once converted into inches, this leads to an amount of around 3.937 inches.

S entails the potential maximum retention after runoff begins. To calculate *S* another calculation is used:

$$S = \frac{1000}{CN} - 10$$

CN stands for curve number and is the maximum storage capacity of the soil. This differs per soil type and is based on the hydrological soil group, land use, treatment, and condition (Cronshey et al., 1986). The curve numbers are based on the work of Cronshey et al. (1986). The different soil types are based on data from NASA (Ross et al., 2018). In general, the lower the curve number, the higher the infiltration rate. Following is a table of the curve numbers per landcover type.

Table 3.7: Curve numbers for landcover types

Landcover type	Curve number for soil type B	Curve number for soil type C
Grass	58	71
Shrubs	48	65
Rough grassland	58	71
Trees	60	73
Impervious surfaces	98	98

Since impervious surfaces still can reduce runoff, even if slightly, they are to be considered. Cronshey et al. (1986) suggest a curve number of 98 for paved streets, which most likely corresponds with the tiles in gardens. Therefore, the impervious surfaces are listed with the vegetation types in table 3.7.

These calculations are performed in ArcGIS, using the *Calculate Field* tool. This eventually results in the following process as depicted in figure 3.8.

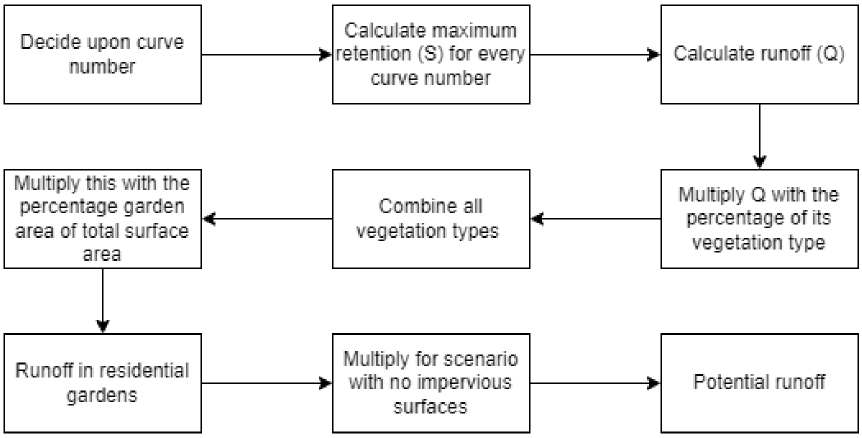

Figure 3.8 Process of calculating runoff

3.3.5 Act

With the analysis and maps done, it becomes possible to assess if, where, and which neighbourhoods have the most potential for improving local climate through vegetation in residential gardens. The objective is thus to create a map indicating which neighbourhoods in The Hague could be focused on, and where they are located. This map will reflect the outcome of the study. As for potential, both the potential in reducing UHI temperatures as well as runoff will be illustrated in two different maps for the different elements.

With these maps, policymakers could identify potentially interesting neighbourhoods. For example, one neighbourhood has the potential for reducing runoff as well as reducing UHI temperatures. These policymakers can then use the statistical analysis to see which factors drive impervious surfaces, and thus implement policy to motivate vegetation within residential gardens. Policy could be one way to tackle this.

Chapter 4. Results

This chapter reports the results for every sub-question of the study. First, the question regarding the socioeconomic factors influencing gardens is answered. Here, four factors are shown to be statistically significant:

- Average amount of green in the public environment;
- Average value of building;
- Average size of garden;
- Average household size.

Secondly, the impact of vegetation within gardens on the UHI effect and runoff is examined. In addition, the potential of more vegetation is also analysed. These results are then compared to vegetation in the public environment to give a more nuanced view of the extent of vegetation within gardens.

Finally, the third sub-question is answered. Here, the neighbourhoods with the most potential for improving local climate are discussed.

4.1 What factors influence the amount of vegetation in residential gardens in The Hague?

This section will answer which factors influence the amount of vegetation within residential gardens in The Hague. Firstly, the PCA results are explained

4.1.1 PCA

The PCA was performed in SPSS, by using the factor analysis tool. When performed for the first time, it appeared that the variable *onvrije woning* (non-independent homes) is not observed in The Hague, as all neighbourhoods have a value of zero for this variable. Therefore, this variable was not taken into account for analysis. Upon further observation, the initial PCA analysis leveraged a correlation matrix with all variables and had a determinant of 0. The accepted level is 0.00001 (Samuels, 2017). This meant that there could be the risk of multi-collinearity.

The next step was to remove some of the variables to see where the problem could lie. Seeing as the type of housing was one of the largest variables in the analysis, it was decided to replicate the PCA without these 12 variables. This could give different results, and it did. With the other variables in the PCA, a determinant lower than 0.00001 was observed, thus still too low. Using only three age groups, 25-45, 45-65 and 65+, a determinant much lower than 0.00001 was given. If the type of housing is added, a determinant of 0 is again observed. These two groups of variables are thus likely very correlated with each other. Moreover, when analysing only the variables concerning housing types, the determinant remains 0 as seen in table A.4 in Appendix A. Yet, the age groups do reveal a determinant of 0.003 when analysed separately as seen in table A.2 in Appendix A. Summarized, the variables concerning the type of housing, ownership, age of residents, and whether there are children in the household composition are too correlated to be used for further analysis.

Thus, the following variables are removed from the analysis:

- Average age of residents
- Type of housing
- Type of ownership
- Number of children in household composition

When analysing the value of building, average household size, degree of urbanity, income, education, age of building, height of building, size of the garden, and the amount of green in public space, a satisfactory value of 0.012 is noted. Moreover, the data used for this PCA also reached the required KMO score of 0.5 (Samuels, 2017), with 0.642. Table A.3 and A.4 in Appendix A shows the corresponding table to these values.

Thus, the following factors are considered for the regression analysis:

- Average amount of green in the public environment
- Average value of building
- Average household size
- Degree of urbanity
- Average income
- Education (low/middle/high)
- Median age of building
- Average building height
- Average size of garden

Tables on the performed PCA can be found in Appendix A.

4.1.2 Results of regression analysis

The dependent variable, the average degree of grey surfaces per neighbourhood, was regressed on the 9 variables mentioned before.

The following hypotheses were proposed:

H_1: There is a significant impact of the average amount of green in the public environment on the average degree of grey surfaces in residential gardens.

H_2: There is a significant impact of the average value of the building on the average degree of grey surfaces in residential gardens.

H_3: There is a significant impact of average household size on the average degree of grey surfaces in residential gardens.

H_4: There is a significant impact of the degree of urbanity on the average degree of grey surfaces in residential gardens.

H_5: There is a significant impact of average income on the average degree of grey surfaces in residential gardens.

H_6: There is a significant impact of education level on the average degree of grey surfaces in residential gardens.

H_7: There is a significant impact of the median age of the building on the average degree of grey surfaces in residential gardens.

H_8: There is a significant impact of the average height of the building on the average degree of grey surfaces in residential gardens.

H_9: There is a significant impact of the average size of the garden on the average degree of grey surfaces in residential gardens.

The accepted p-value of the hypotheses is 0.05. Thus, if a value lower than 0.05 is noted then the hypothesis is accepted, and a statistically significant relationship between the independent and the dependent variable can be noted.

Following are the three tables produced by the regression analysis, and how these results can be interpreted. This was done by using the linear regression tool in SPSS.

Model summary

Table 4.1: Model summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
,772[a]	,595	,548	12,214

Observed in table 4.1 is an R-value of .772. The R-value indicates a moderately strong positive correlation. If one of the independent variables changes, so does the average degree of grey surfaces. In addition, R square gives a value of .595. This means that up to 59.5% of the variances in the number of grey surfaces in gardens in The Hague can be predicted according to the chosen independent variables. This, however, means that 40.5% of the variance cannot be explained with these variables. It could be due to wrong data, sample size, or even the complexity of gardens that 40% cannot be explained with these factors. Seeing as the PCA test removed several variables, it is likely that this can be attributed to the nature of the data. Ozili (2023) suggests that an R square between 0.50 and 0.99 is acceptable in social sciences, and even more when most of the independent variables are statistically significant.

The adjusted R square value of this analysis is .548. Similarly to the R square, this gives a percentage indicating the amount of variation in the dependent variable that can be explained by the independent variables, however now it is adjusted for the number of independent variables in the analysis. Thus, after adjusting, up to 54.8% of variation can be explained with the analysed independent variables.

ANOVA

Table 4.2 illustrates the ANOVA table of the analysis. Most importantly, an F-value of 12.704 and a p-value of 0 is noted. The P-value is lower than 0.05, this indicates that the model is statistically significant and that at least one of the independent variables analysed is significantly related to the dependent variable. However, this table does not yet show which variables are significant. The following section will discuss this.

Table 4.2: ANOVA

ANOVA						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	20845,560	11	1895,051	12,704	,000[b]
	Residual	14171,298	95	149,172		
	Total	35016,858	106			

Coefficients

The regression analysis produced a coefficients table, as seen in table 4.3.

Table 4.3: Coefficients

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	47,853	101,861		,394	,694
	Average amount of green in the public environment	-,434	,076	-,404	-5,697	,000
	Average value of building	-,047	,014	-,437	-3,350	,001
	Average size of garden	,000	,000	-,198	-2,823	,006
	Average household size	12,513	5,534	,254	2,261	,026
	Degree of urbanity	-4,066	2,561	-,149	-,1588	,116
	Average income	,169	,136	,116	1,244	,217
	Lower education	,286	,159	,225	1,801	,075
	Middle education	,053	,138	,028	,381	,704
	Higher education	,073	,107	,075	,683	,496
	Median age of building	,006	,054	,011	,107	,915
	Average building height	-,377	,259	-,108	-1,458	,148

A p-value of lower than 0.05 is required to be statistically significant. This means that the following variables are significant: the average amount of green in the public environment, the average value of building, the average household size, and the average size of garden. This means that $\mathbf{H_1}$, $\mathbf{H_2}$, $\mathbf{H_3}$, and $\mathbf{H_9}$ are accepted.

For every increase in the average amount of green in the public environment, a relatively high decrease in the average degree of grey surfaces can be noted. This suggests a strong negative relationship between the two variables. With a Beta value of -.404, this variable is the second most impactful variable analysed.

As the value of the building increases, the average degree of grey surfaces decreases. A Beta value of -.437 suggests a similar relationship to that of the average amount of green in the public environment, which is the highest value noted.

The average size of the garden is the third significant variable and notes a Beta value of -.198. This indicates a weaker negative relationship, compared to the other two significant variables.

Finally, the variable concerning average household size is statistically significant and has a Beta value of ,254. This means that there is a positive relationship between the two variables. For every extra person in the household, the number of grey surfaces within a garden increases.

4.1.3 Interpretation

This section elaborates upon the relationships established in the regression analysis. Initially, the map detailing the average percentage of grey surfaces for every neighbourhood is shown. Then, four maps are shown illustrating the four statistically significant variables.

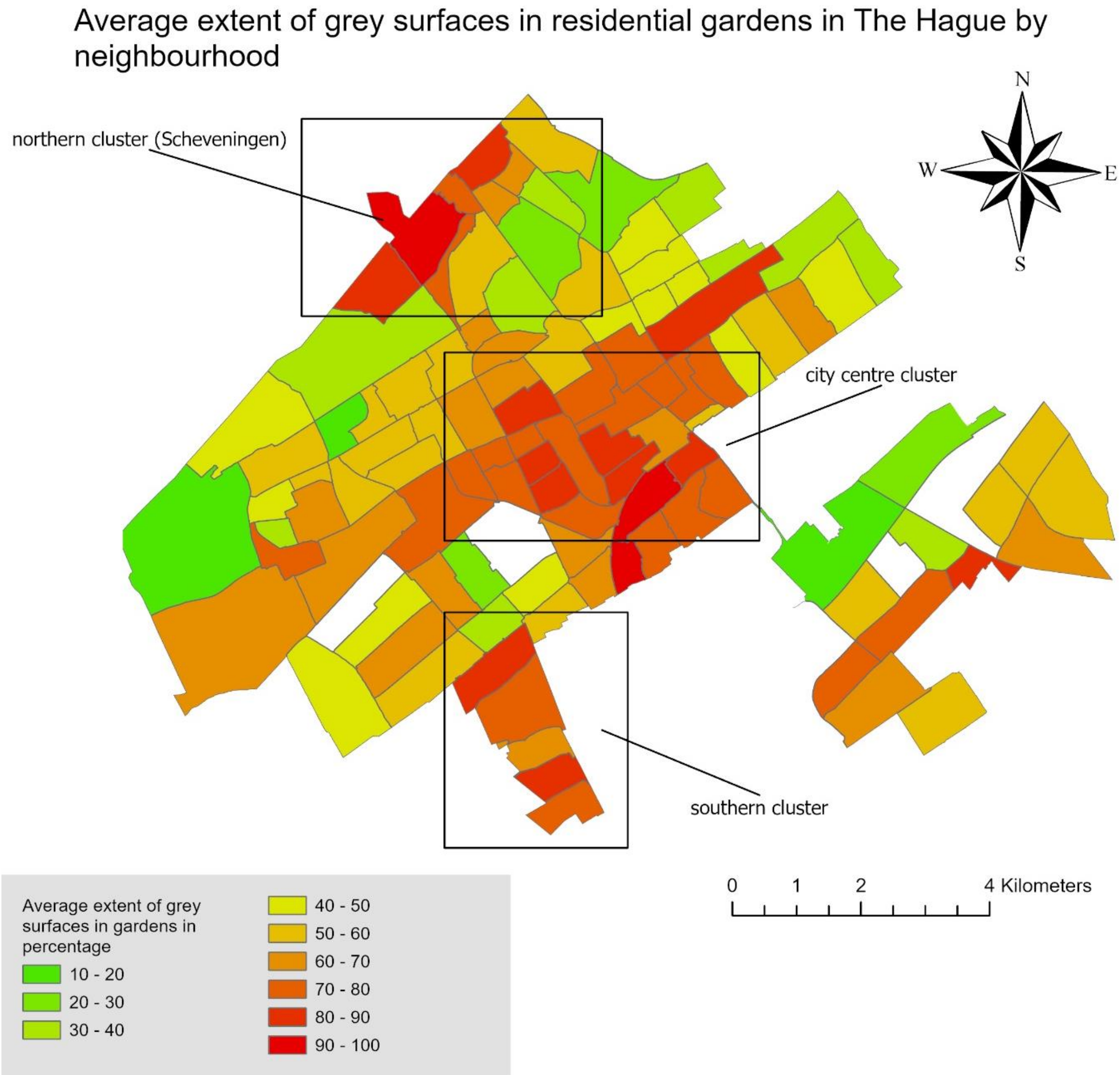

Figure 4.1: Average extent of grey surfaces in residential gardens in The Hague by neighbourhood

Figure 4.1 illustrates the average percentage of grey surfaces per garden for every neighbourhood analysed in The Hague. The greener the neighbourhood on the map, the more green surfaces in the gardens that there are. The lowest value observed is 18%, in Bosjes van Pex, and the highest value in Laakhaven-West with 93%.

These values are largely reliant on multiple factors. For instance, apartment blocks are often attributed to larger gardens as they share the area with many households. This is mostly seen in apartment buildings outside of the city centre. Moreover, these gardens often consist of grass lawns and several trees.

Three red clusters are observed. Firstly, the neighbourhoods to the north, near the sea. This cluster of several neighbourhoods is noted as having a high degree of grey surfaces in their gardens. Next, the city centre is another cluster with many ‘red’ neighbourhoods.

Finally, the cluster to the south of The Hague. Five neighbourhoods are part of this cluster and are observed with relatively high percentages of grey surfaces.

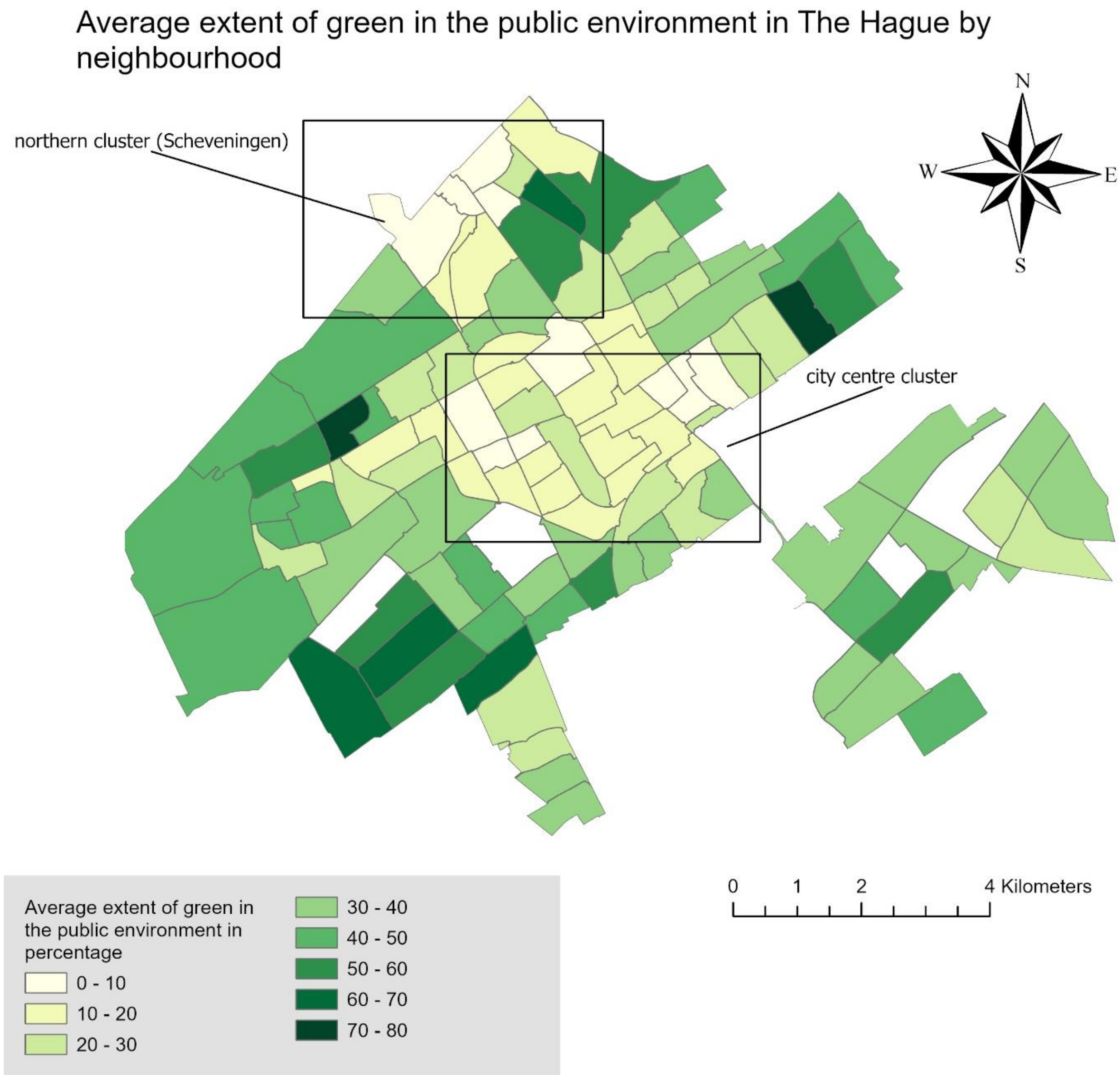

Figure 4.2: Average extent of green in the public environment in the Hague by neighbourhood

Figure 4.2 illustrates the average amount of green in the public environment for every neighbourhood. The city centre offers relatively little green in the public environment. Space is valuable, and green is often given less priority. However, there are still several parks near the city centre, such as Koekamp and Haagse Bos. For this last park, a decent section of it is a private area as it belongs to the royal family’s residence. Moreover, areas outside of the city centre are observed to have more green in the public environment. Whereas space is limited in the centre, the outside areas are less dense and thus have more space available for green.

Again, two clusters are observed similar to figure 4.1 The cluster near the sea to the west show little green in the public environment. Moreover, the cluster appears to be bigger than in figure 4.1. Similarly, the city centre is observed with low values of green in the public environment. In addition, this cluster is larger as well. In contrast, the cluster to the south is instead diverse, with some neighbourhoods still having low values whereas others are greener.

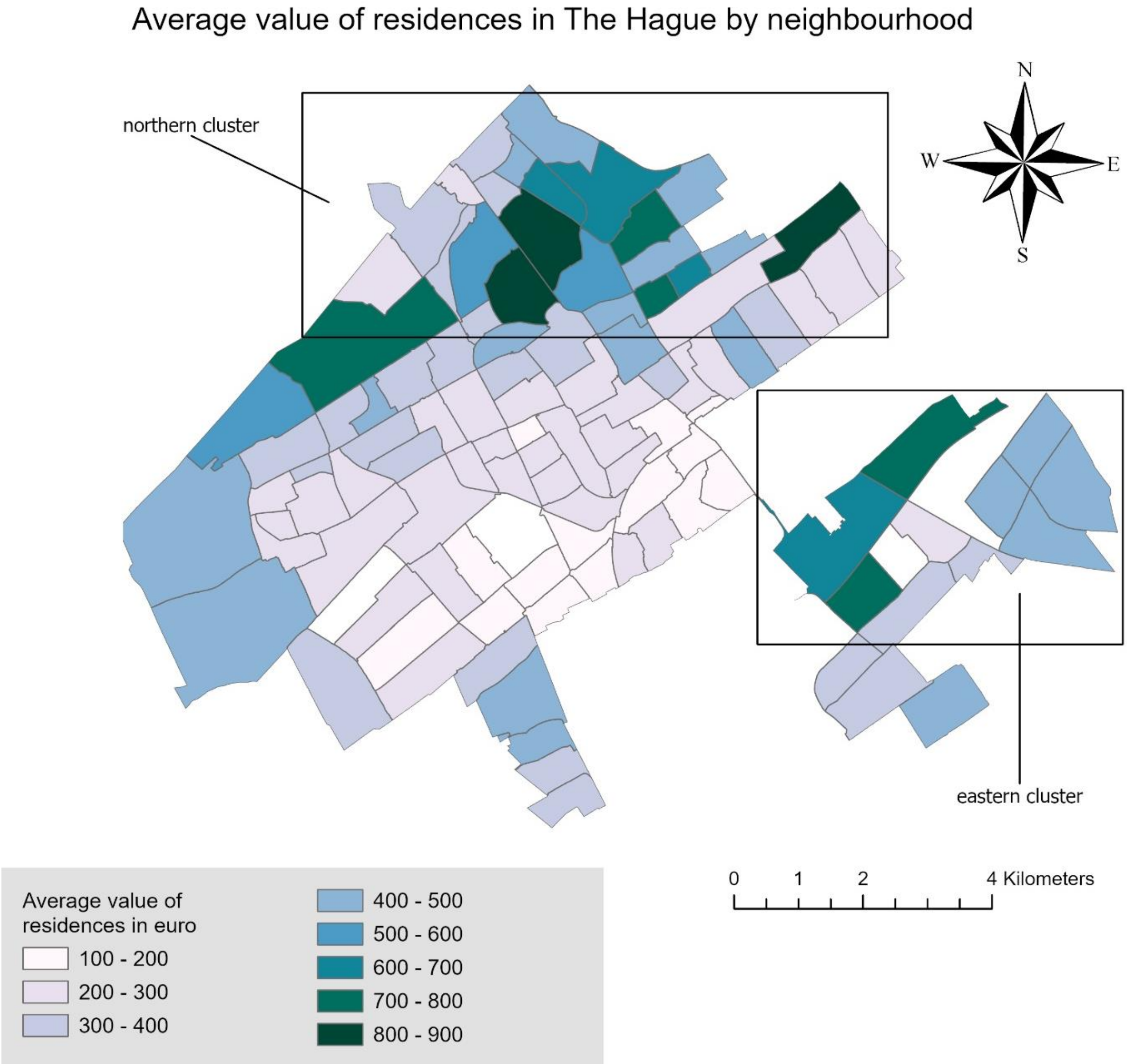

Figure 4.3: Average value of residences by neighbourhood in the Hague

Figure 4.3 reports the average value of the residential buildings for every neighbourhood in The Hague. The highest values are observed in neighbourhoods to the north in The Hague. This cluster extends from the west side of The Hague to the northern neighbourhoods. In addition, the eastern cluster appears to be relatively more expensive as well compared to the city centre. The centre of The Hague has relatively low values. It thus appears that there is quite a geographical divide in residential building value within the city.

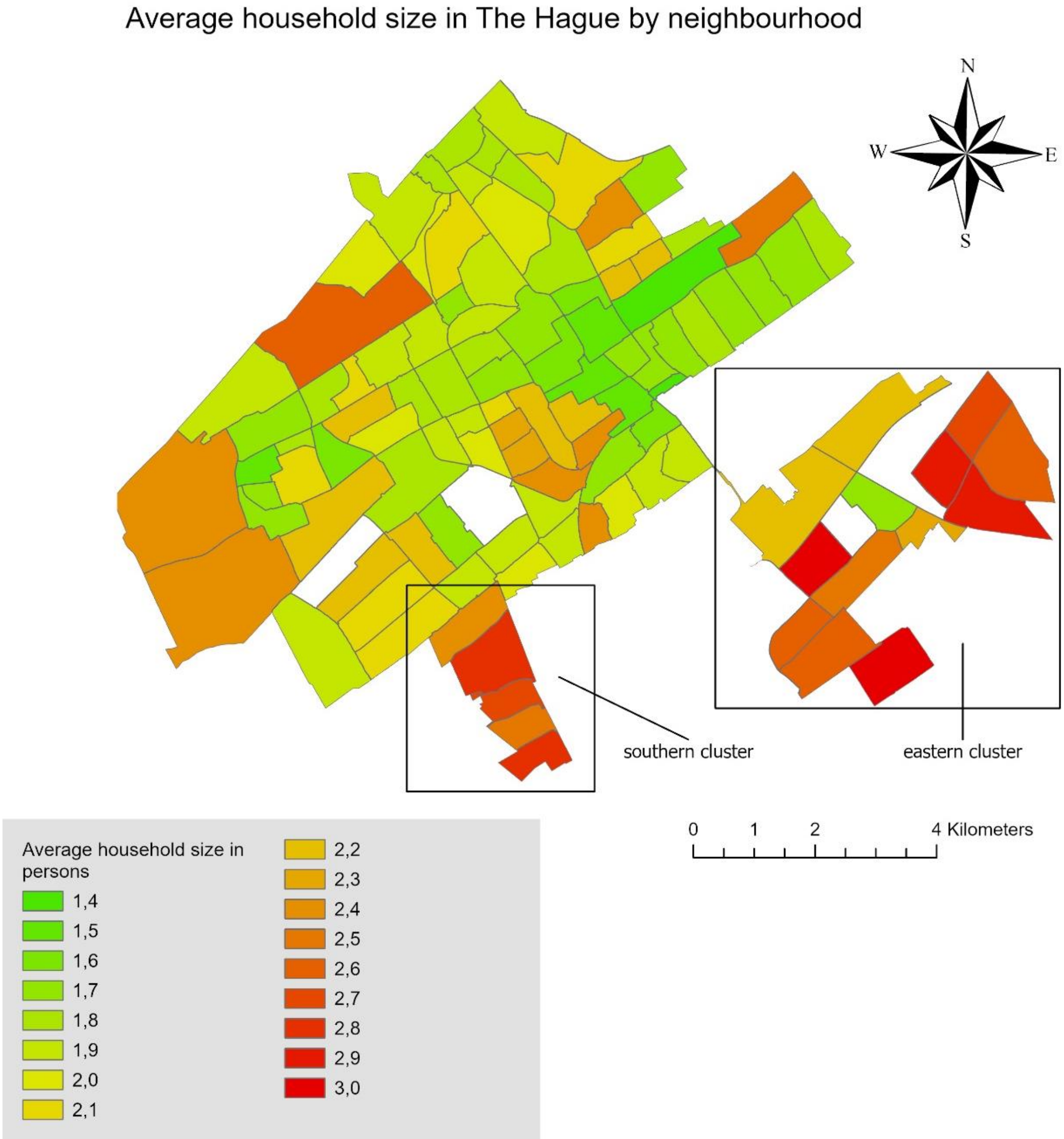

Figure 4.4: Average household size by neighbourhood in the Hague

In figure 4.4 the average household size of every neighbourhood in The Hague is illustrated. A household size larger than 2.0 would suggest the presence of children within the household. Many of the neighbourhoods near and within the centre are observed with relatively low household sizes.

Higher household sizes are observed in two main clusters. This makes sense since most of these neighbourhoods are recently built and designed for larger families, thus having a larger household. Both the southern and eastern cluster, as highlighted in figure 4.4, have several neighbourhoods with larger household sizes.

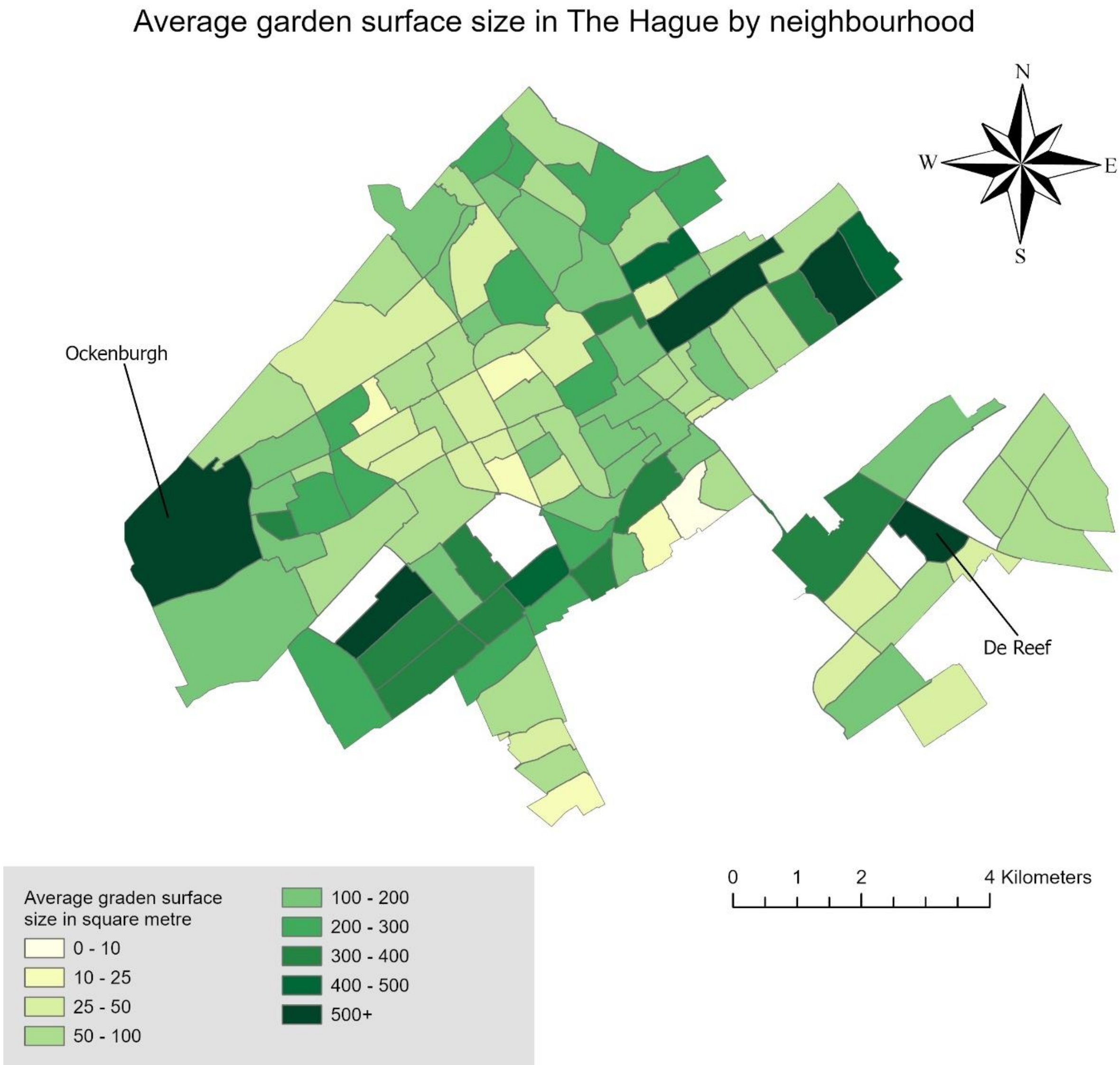

Figure 4.5: Average garden surface size in The Hague by neighbourhood

Figure 4.5 illustrates the average garden surface sizes for every neighbourhood in The Hague. The sizes range from less than 10 metres to more than 1000 metres. The largest gardens are observed in Ockenburgh, and De Reef. As predicted, the city centre has among the smallest gardens in The Hague.

A northern cluster can be observed, where several neighbourhoods have an average garden size of more than 300 metres. Similarly, to the south, another cluster of neighbourhoods has values between 200 and 500+ metres.

4.1.4 General observations

This section addresses the general observations. Two outliers, Bosjes van Pex & Vissershaven, are discussed further in Appendix B.

Firstly, the city centre is observed to have many grey surfaces within their gardens. The further from the centre, the greener the gardens are, which can be found in figure 4.1. The Hague, however, only borders open green areas to the southwest and the north.

The cluster area, as given in figure 4.4, to the east instead show a different result. For instance, the neighbourhoods in the eastern cluster show average values of grey surfaces and some even above the average. The main outliers here are neighbourhoods 111, 112, and 113, which table 4.4 further highlights. These neighbourhoods here consist of mostly townhouses and some apartment blocks. This is reflected in the average value of the buildings, as they are almost double the average value (Eerlijkewoz.nl, n.d.). Moreover, with relatively average values of public green, it is difficult to explain the average amount of grey surfaces within the gardens. Vissershaven, the greyest neighbourhood, has a severe lack of green which could explain their gardens, yet these neighbourhoods do not have this. It could be due to the small garden sizes. The averages are low, which could indicate a potential error in the calculation of the sizes of the gardens. Front lawns were likely calculated separately, thus decreasing the average size. Finally, the household size is relatively high. However, a household size higher than two would likely indicate the presence of children.

Table 4.4: Values of neighbourhoods

Neighbourhood	**Average amount of grey surfaces within gardens**	**Average amount of green in public environment**	**Average value of the building**	**Average garden size**	**Average household size**
De Venen (111)	88	33	348.000	2.6 m^2	2.3
Morgenweide (112)	72	51	368.000	5.5 m^2	2.5
Singels (113)	75	38	369.000	3.9 m^2	2.6

Similarly, to the south, the neighbourhoods show an above-average amount of grey surfaces within the neighbourhood. Figure 4.4 highlights these in the illustrated eastern cluster. These are neighbourhoods 101, 102, 103, 104, and 105. These neighbourhoods are located near the town of Rijswijk, and as such are still very urban.

In general, there is thus a negative relationship between green in the public environment and the extent of impervious surfaces within gardens. The greener the public environment, the fewer artificial surfaces in gardens are observed. Similarly, a higher value of a residential building leads to decreased impervious surfaces in gardens. In addition, the garden size has a similar relationship. Finally, as the household size increases so does the extent of impervious surfaces.

4.2.1 To what extent does vegetation in residential gardens in The Hague improve climate on a neighbourhood level? Urban Heat Island (UHI)

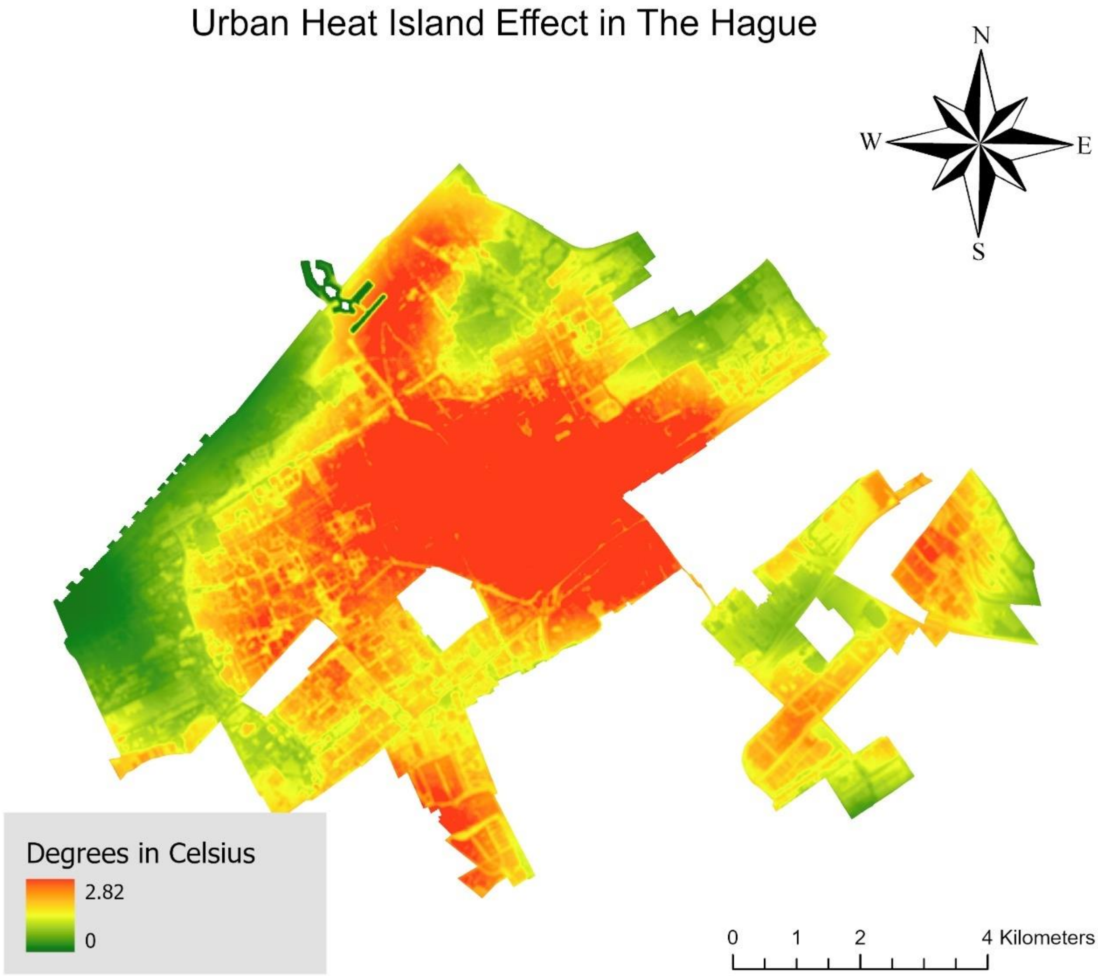

Figure 4.6: Urban Heat Island Effect in The Hague

To understand the effect of vegetation on the Urban Heat Island Effect, initially, it is important to explore the Urban Heat Island Effect. Figure 4.6 illustrates the UHI in The Hague. This is the temperature on a similar day compared to rural areas. As noticed, the highest temperature noted is 2.82 degrees Celsius, which is observed in the city centre. The western outer edges see lower temperatures, especially near the sea. The southern and eastern edges instead see relatively average UHI temperatures since these areas are still quite urban.

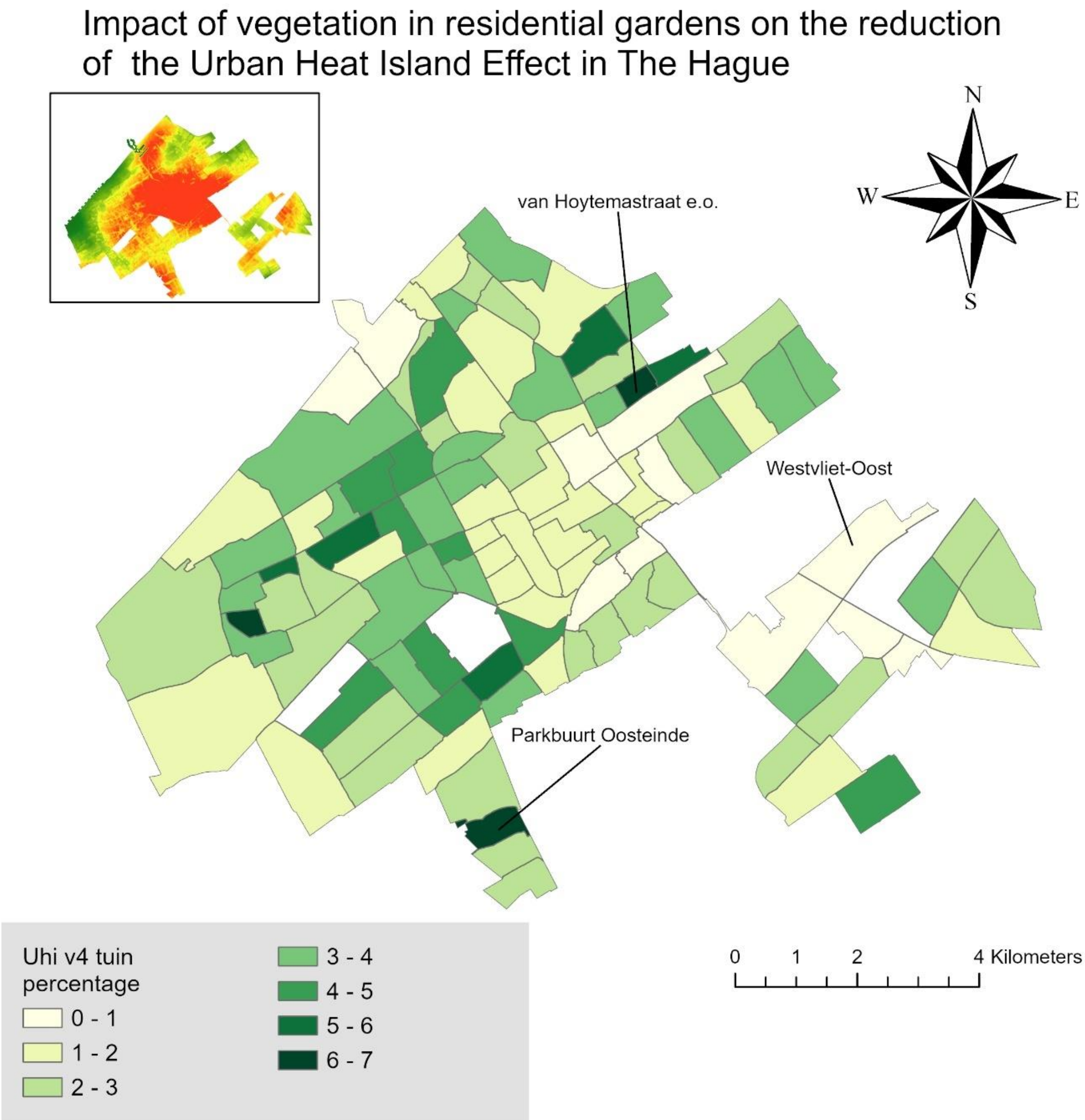

Figure 4.7: Impact of vegetation in residential gardens on the reduction of the Urban Heat Island Effect in The Hague

Figure 4.7 shows the percentage of the UHI reduction residential gardens can have. Here, the current amount and composition of vegetation are used to calculate the effect. In the top left corner, the UHI map of The Hague is shown. This is also replicated in figures 4.8 and 4.9. These percentages indicate the cooling effect of the residential gardens on the total UHI in the neighbourhood. Thus, a neighbourhood with a reduction percentage of 10% and a UHI of 2.5 degrees Celsius has a cooling effect of 0.25 degrees Celsius.

As seen in the scales, this effect is between 0 and 7%. The average reduction rate is 4.1%. The lowest is 0.2% and the highest value is 6.7%. This percentage shows the impact vegetation has on the local UHI effect. Noticeably, many of the neighbourhoods of The Hague have a relatively low percentage. The highest noted value, of 6.7%, is observed in van Hoytemastraat e.o, and Parkbuurt Oosteinde comes in second, with a reduction of 6.15%. The lowest value is examined in Westvliet-Oost.

It is observed that many of the neighbourhoods to the outer ring of the city have low reduction values. Since the calculation for this reduction rate is based on the local UHI intensity, lower intensities mean lower reduction values. Thus, where little UHI is noted, little absolute reduction can be achieved. On the other hand, percentages can give a clearer view of the effects.

Table 4.5: Neighbourhoods and UHI reduction of gardens

Neighbourhood	**Median UHI in degrees Celsius**	**Reduction UHI in percentage**	**Garden area of total surface area in percentage**
Van Hoytemastraat e.o.	1.05	6.7%	33%
Parkbuurt Oosteinde	1.61	6.2%	36%
Ockenburgh	0.21	2.0%	6%
Transvaalkwartier-Noord	2.56	1.8%	14%
Schildersbuurt-Noord	2.62	1.6%	11%
Kijkduin	0.31	1.5%	8%
Average	1.45	2.7%	15.3%

Table 4.5 lists several neighbourhoods analysed. Among them are Parkbuurt Oosteinde and Van Hoytemastraat e.o., which are the highest noted reduction values. Both neighbourhoods are seen having a UHI temperature of between 1 and 1.6 degrees Celsius, and a relatively high garden area of total surface area with 33 and 36%. The average garden share of the total surface area is 15.3%. Thus, these two neighbourhoods are very much above the average.

In addition to these two neighbourhoods in table 4.5, two neighbourhoods with the highest UHI median examined are included, as well as two neighbourhoods with the lowest UHI median. As for the highest, Schildersbuurt-Noord and Transvaalkwartier-Noord, a UHI median of more than 2.5 degrees Celsius is observed. The total reduction of the gardens within these neighbourhoods is, respectively, 1.6% and 1.8%. This is just below the average reduction (2.7%). Moreover, the garden area of the total surface area is also just below the average (15.3%).

Ockenburg and Kijkduin instead see a relatively low UHI median, with 0.21 and 0.31 respectively. Their reducing effect and the garden share of the total surface area are quite low as well. It could be that these neighbourhoods instead have much public green. This notion is further empowered by the geographical location of the two neighbourhoods. These two are located near the sea, where the beaches and dunes could lead to reduced temperatures, thus mitigating the low values noted here.

Table 4.6: Neighbourhoods and garden surface size

Neighbourhood	**Garden area of total surface area in percentage**	**Reduction UHI in percentage**
Waldeck-Zuid	31%	6.0%
Componistenbuurt	29%	5.8%
Vruchtenbuurt	27%	5.4%
Vlietzoom-West	2%	0.5%
Haagse Bos	1%	0.2%
Westvliet-Oost	1%	0.2%

Parkbuurt Oosteinde and Van Hoytemastraat e.o. both have the largest share of gardens of the total surface area. Table 4.6 lists the three other neighbourhoods with the highest values and those with the lowest. The results reveal a direct correlation between the garden area of total surface, and the reduction of UHI. This makes sense as neighbourhoods with few gardens are not likely to see UHI reduction originating from green in these gardens. Yet those with a large share of its surface area stemming from gardens can expect a larger reduction in UHI.

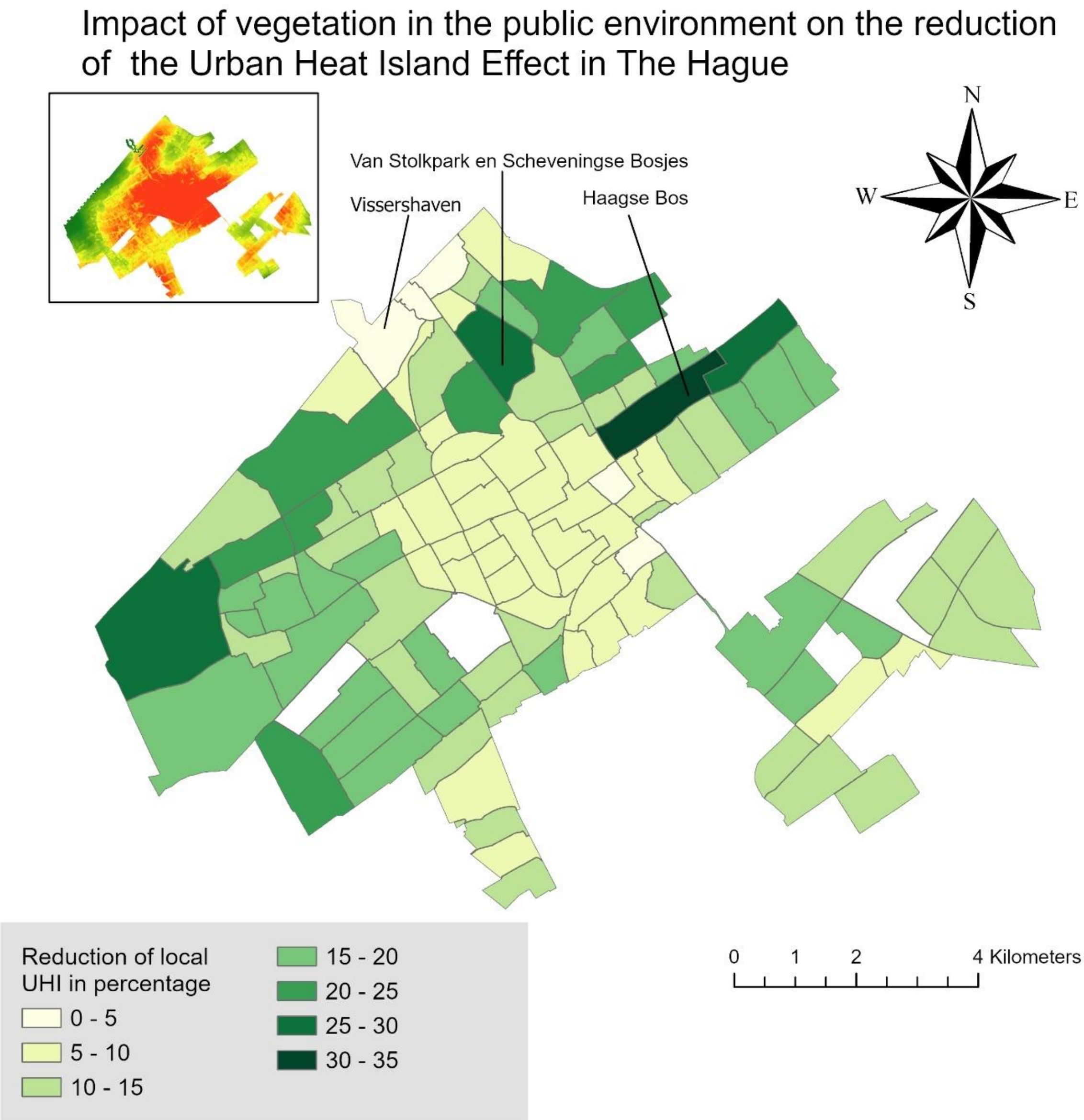

Figure 4.8: Impact of vegetation in the public environment on the reduction of the Urban Heat Island Effect in The Hague

Figure 4.8 illustrates the impact of vegetation in the public environment on the UHI effect. Similarly to figure 4.7, this analyses the current amount and composition of vegetation within the public environment. The reduction rates are much higher than that of residential gardens. This makes sense since the amount of vegetation in the public environment is much higher than that of residential gardens. The reduction percentages are similar to that of figure 4.7 in their function.

Four neighbourhoods are examined having a reduction of over 25% of the local UHI temperature. The highest value is 31% and is examined in Haagse Bos. Van Stolkpark en Scheveningse Bosjes is examined as having a 29.9% reduction. These two neighbourhoods are highlighted in figure 4.8.

Table 4.7 shows the differences between the two neighbourhoods with the most reduction and those with the smallest reduction. As mentioned before, Haagse Bos en Van Stolkpark are the neighbourhoods with the largest relative cooling effect. The UHI values of these neighbourhoods is below average, which is 1.45 degrees Celsius. Oud Scheveningen and

Vissershaven show instead the lowest reductions. Vissershaven sees a reduction of 1.2%, whereas Oud Scheveningen notes a reduction of 3.9%.

Table 4.7: Neighbourhoods and UHI reduction from public environment

Neighbourhood	**UHI Median in degrees Celsius**	**Reduction UHI in percentage**
Haagse Bos	0.88	31%
Van Stolkpark en Scheveningse Bosjes	0.65	29.9%
Oud Scheveningen	1.54	3.9%
Visserhaven	0.99	1.2%
Average	1.45	12.4%

Moreover, most of the city centre sees lower values, as the average is 12.4%. As both figures 4.7 and 4.8 show, the reduction in UHI is also largely reliant on the local UHI intensity. This can be explained: if the gardens or the public green would have a large impact then the UHI would likely not be as strong as indicated on the UHI map.

Table 4.8 Comparison of neighbourhoods in UHI reduction

Neighbourhood	**UHI Median in degrees Celsius**	**Garden UHI reduction in percentage**	**Public environment UHI reduction in percentage**	**Garden area of total surface area in percentage**
Parkbuurt Oosteinde	1.61	6.2%	10.3%	36%
Van Hoytemastraat e.o.	1.05	6.7%	14.1%	33%
Schildersbuurt-Noord	2.62	1.6%	6.9%	11%
Transvaalkwartier-Noord	2.56	1.8%	6.5%	14%
Haagse Bos	0.88	0.2%	31%	1%
Van Stolkpark en Scheveningse Bosjes	0.65	1.4%	29.9%	6%
Oud Scheveningen	1.54	1.9%	3.9%	16%
Vissershaven	0.99	0.3%	1.2%	4%

Table 4.8 highlights the differences between several of the mentioned neighbourhoods. This table highlights the overall low reduction values in Oud Scheveningen and Vissershaven. Vissershaven has only a 1.5% reduction when gardens and public green are combined. This means that there is likely another reason for the relatively low urban heat island intensity. Similarly, Oud Scheveningen has a combined value of around 6%. These two neighbourhoods are adjacent to each other, which could mean that there is an overlapping reason.

Haagse Bos and Van Stolkpark en Scheveningse Bosjes have very high reduction values stemming from public green, yet low values from gardens. This was predicted since the garden area of the total surface area is 1% and 6% respectively. With few gardens in these neighbourhoods, it cannot be assumed that gardens have much effect. Moreover, the combined values of both neighbourhoods are relatively similar, around 31%. This means that around 31% of the reduction of the UHI effect can be attributed to vegetation in the neighbourhood.

Parkbuurt Oosteinde and van Hoytemastraat e.o., whilst having the largest reduction from gardens, only have around average reduction from public green. In addition, the combined values of both neighbourhoods are 16.5% and 20.8% respectively.

4.2.2 To what extent does vegetation in residential gardens in The Hague improve climate on a neighbourhood level? Runoff water

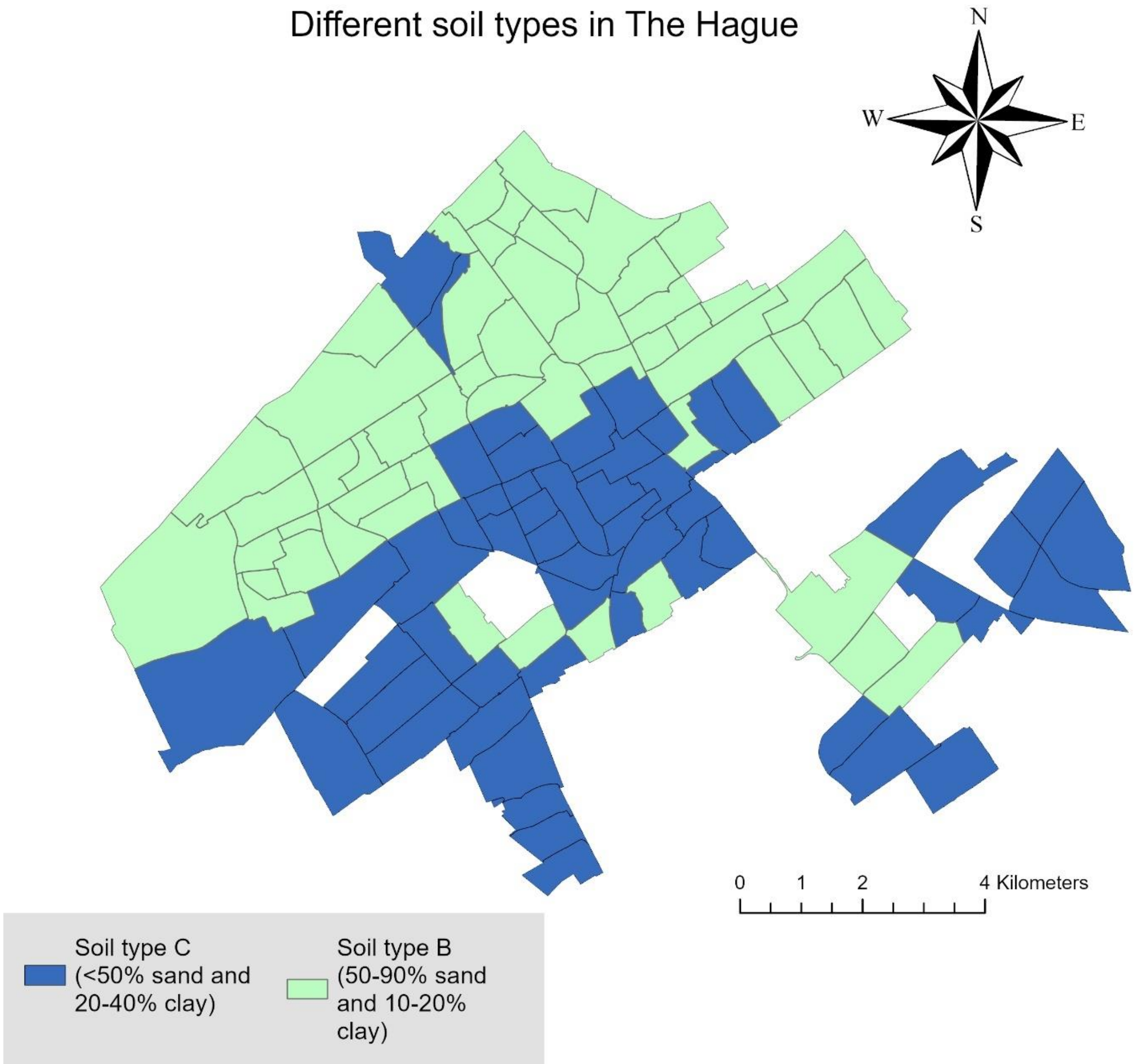

Figure 4.9: Different soil types in The Hague

Crucial to determining the retention potential in The Hague are the different soil types. Using the data from Ross et al., (2018), figure 4.9 was created. Here, for every neighbourhood of The Hague the soil type that was observed the most is listed. This leads to two types of soils, C and B. Soil type B consists of mostly sand (50 to 90%), and between 10 to 20% in clay. C on the other hand, consists of less sand (<50%) and more clay (20 to 40%). This has implications for retention, and the curve numbers as seen in table 3.6. In total, 53 neighbourhoods in The Hague have soil type B, and 54 have soil type C.

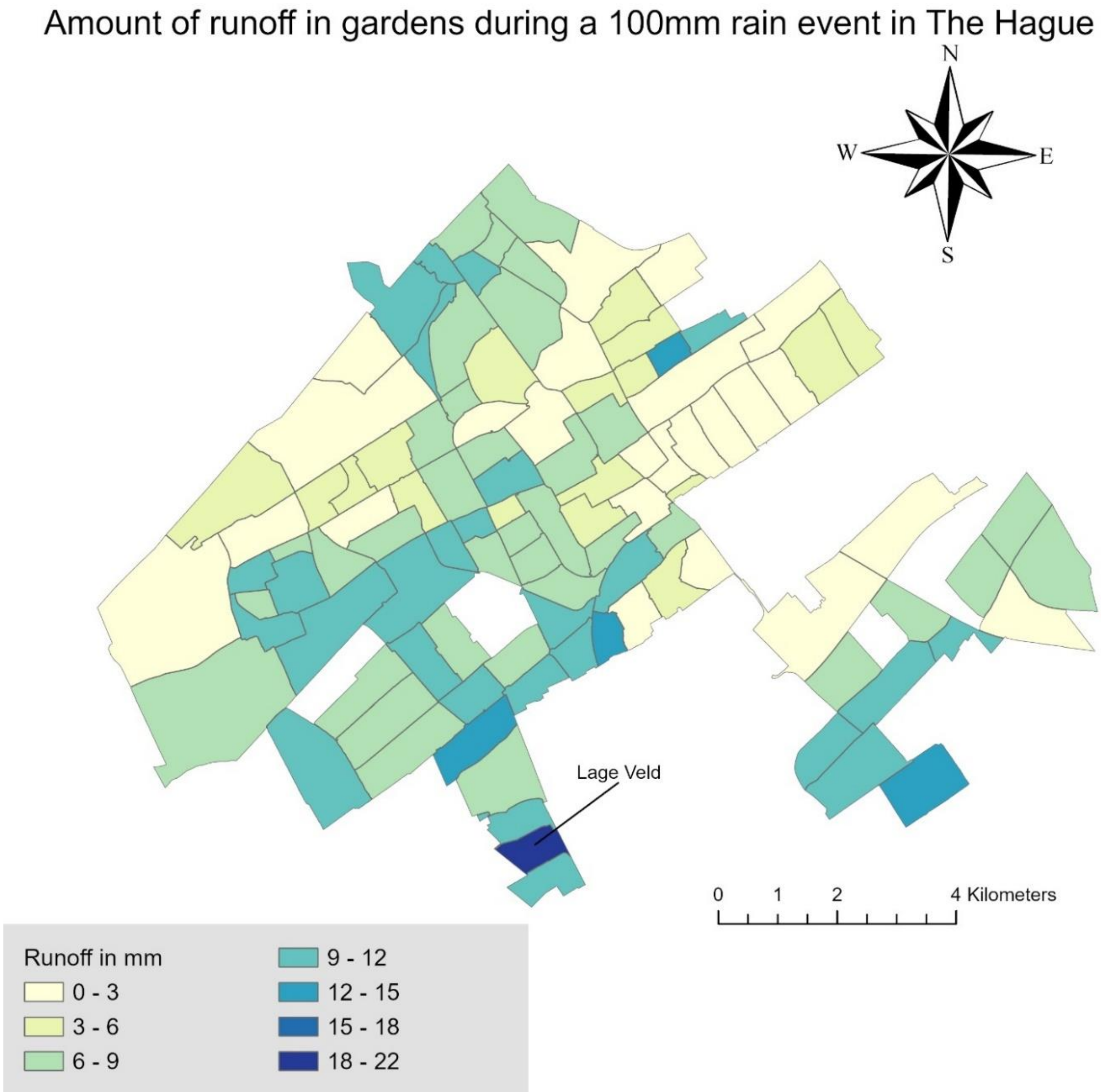

Figure 4.10: Amount of runoff in gardens during a 100mm rain event in The Hague

Figure 4.10 illustrates the amount of runoff in gardens during a 100mm rain event in The Hague. The amount of runoff differs between 0.374mm in Vlietbuurt, to 21.634mm in Lage Veld. The mean is 7.3mm, and the median is 7.9mm. By comparing figure 4.8 and 4.9 the role the soil type plays in reducing runoff is shown. As seen, soil type C is noted having larger amounts of runoff compared to soil type B. This is further emphasized by the data in table 4.9.

Table 4.9: Runoff in gardens

Neighbourhood	**Runoff in gardens in mm**	**Percentage of impervious surfaces in garden**	**Soil type**	**Garden area of total surface area in percentage**
Lage Veld	21.634	83.9%	C	30%
De Bras	13.833	54.7%	C	21%
Marlot	0.428	30.5%	B	1%
Vlietbuurt	0.374	18.5%	B	1%

Neighbourhoods with high runoff values more often have soil type C, whereas soil type B sees less runoff. Table 4.9 shows the two neighbourhoods with the highest runoff, and the two with the least runoff. Lage Veld and De Bras are the neighbourhoods with the highest values, 21.634 and 13.833 respectively. Lage Veld has almost 8mm more than De Bras, which is quite a lot. This can be explained using the extent of impervious surfaces within gardens, and the garden area of total surface area, where Lage Veld has higher values in both cases.

Vlietbuurt and Marlot are the neighbourhoods with the lowest values of runoff noted, 0.374mm and 0.428mm, as seen in table 4.9. Both neighbourhoods have soil type B, which as mentioned before, is more favourable in reducing runoff. In addition, both neighbourhoods have only very few gardens within their area, with only 1% of the total surface area of the neighbourhood consisting of residential gardens. With such a small fraction of the area being in gardens, it is logical that little runoff can be observed in these gardens. More surface area in gardens, more runoff from this area. Therefore, it poses to be interesting to look at neighbourhoods with similar percentages in garden surface areas. Table 4.10 lists 6 neighbourhoods with similar amounts of garden area.

Table 4.10: Runoff compared for neighbourhoods with a similar amounts of garden surface area

Neighbourhood	**Runoff in gardens in mm**	**Percentage of impervious surfaces in garden**	**Soil type**	**Garden area of total surface area in percentage**
Oud Scheveningen	11.338mm	69.9%	B	16%
Waterbuurt	10.562mm	52.5%	C	16%
Morgenstond-West	10.349mm	50.6%	C	16%
Stadhouderplantsoen	8.818mm	50.1%	B	16%
Westbroekpark	7.698	41.4%	B	16%
Zorgvliet	5.842mm	27.6%	B	16%

As examined in table 4.10, Oud Scheveningen has the most runoff out of these six neighbourhoods. This area also has the highest percentage of impervious surfaces within its gardens. Yet this neighbourhood’s soil consists mainly of type B, which is as suggested before, favourable for reducing runoff as it has lower curve numbers. It is likely explained due to the composition of vegetation within the gardens here. Only around 1% of its gardens consist of shrubs, which have the most beneficial effect on runoff.

The two other neighbourhoods with higher values, Waterbuurt and Morgenstond-West, have soil consisting mainly of type C. It is predicted that these neighbourhoods have more runoff, due to soil type C having higher curve numbers associated with its vegetation types. Moreover, these two neighbourhoods have a similar percentage of impervious surfaces in their gardens.

Westbroekpark has a more favourable composition of vegetation compared to Oud Scheveningen, as around 10% of its gardens consist of shrubs. Thus, even with a similar percentage of impervious surfaces it still has almost 4mm less than Oud Scheveningen. This could indicate that the composition of gardens influences runoff. Zorgvliet is noted with the littlest runoff of the neighbourhoods in table 4.10, 5.842mm. Moreover, this neighbourhood notes the lowest extent of impervious surfaces.

4.3 In which neighbourhoods lie most potential for improving local climate through residential gardens?

This section analyses the potential for residential gardens to increase local climate, and in which neighbourhoods this potential is highest. Firstly, the potential for reducing the UHI is discussed. After that, the potential for reducing runoff is elaborated upon. Finally, these potentials are combined to point to several neighbourhoods that could be of interest.

4.3.1 Potential UHI reduction

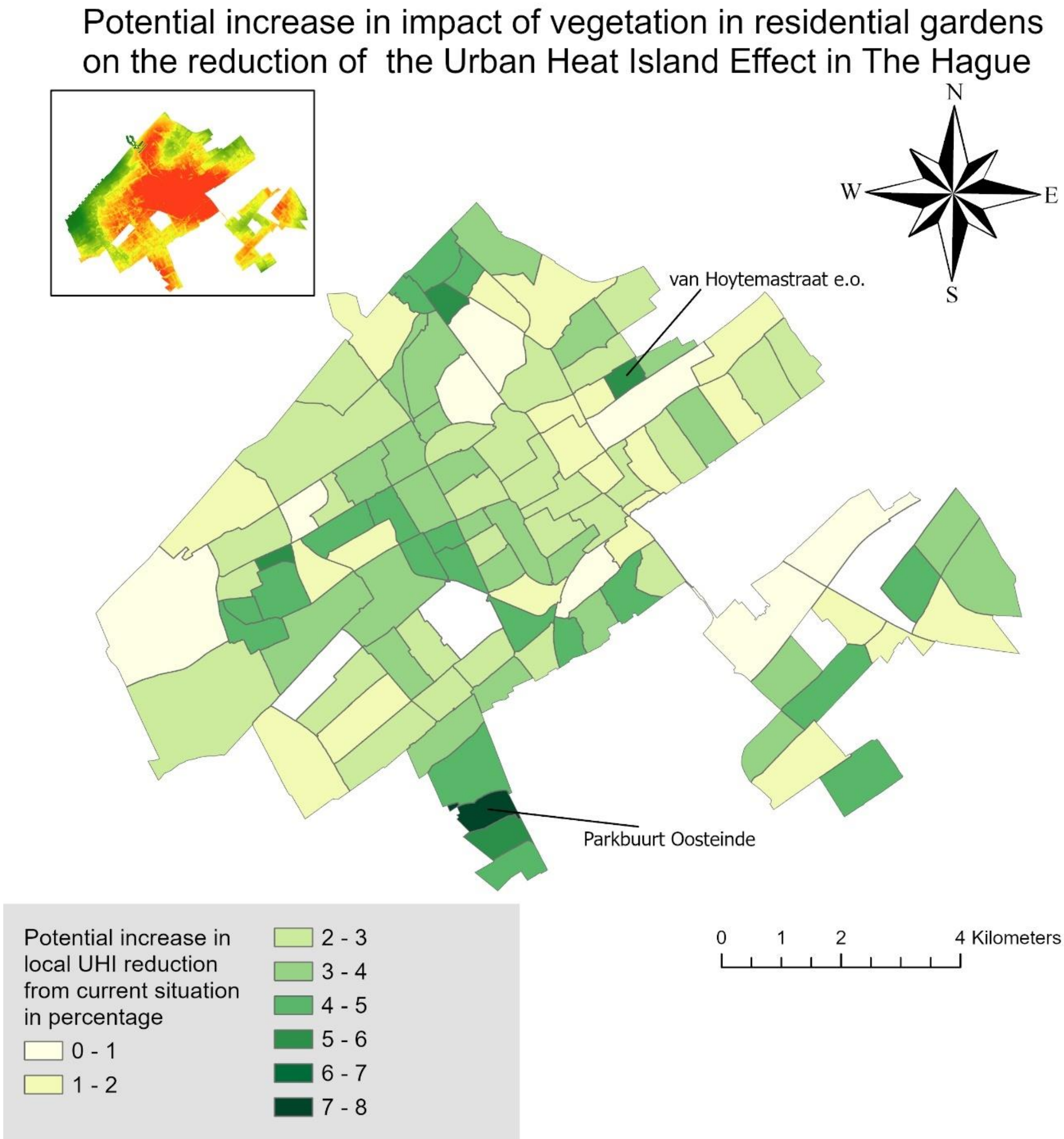

Figure 4.11: Potential impact of vegetation in residential gardens on the reduction of the Urban Heat Island Effect in The Hague

Using the calculations mentioned in chapter 3 the potential for residential gardens was calculated. Figure 4.11 shows the increase in percentages for a situation where gardens consist completely of vegetation. Increases between 0.15% and 7.8% are examined. This means that in the neighbourhood with an increase of 0.15%, the current reduction percentage can be increased by 0.15%. Parkbuurt Oosteinde is noted with the largest growth with 7.8%.

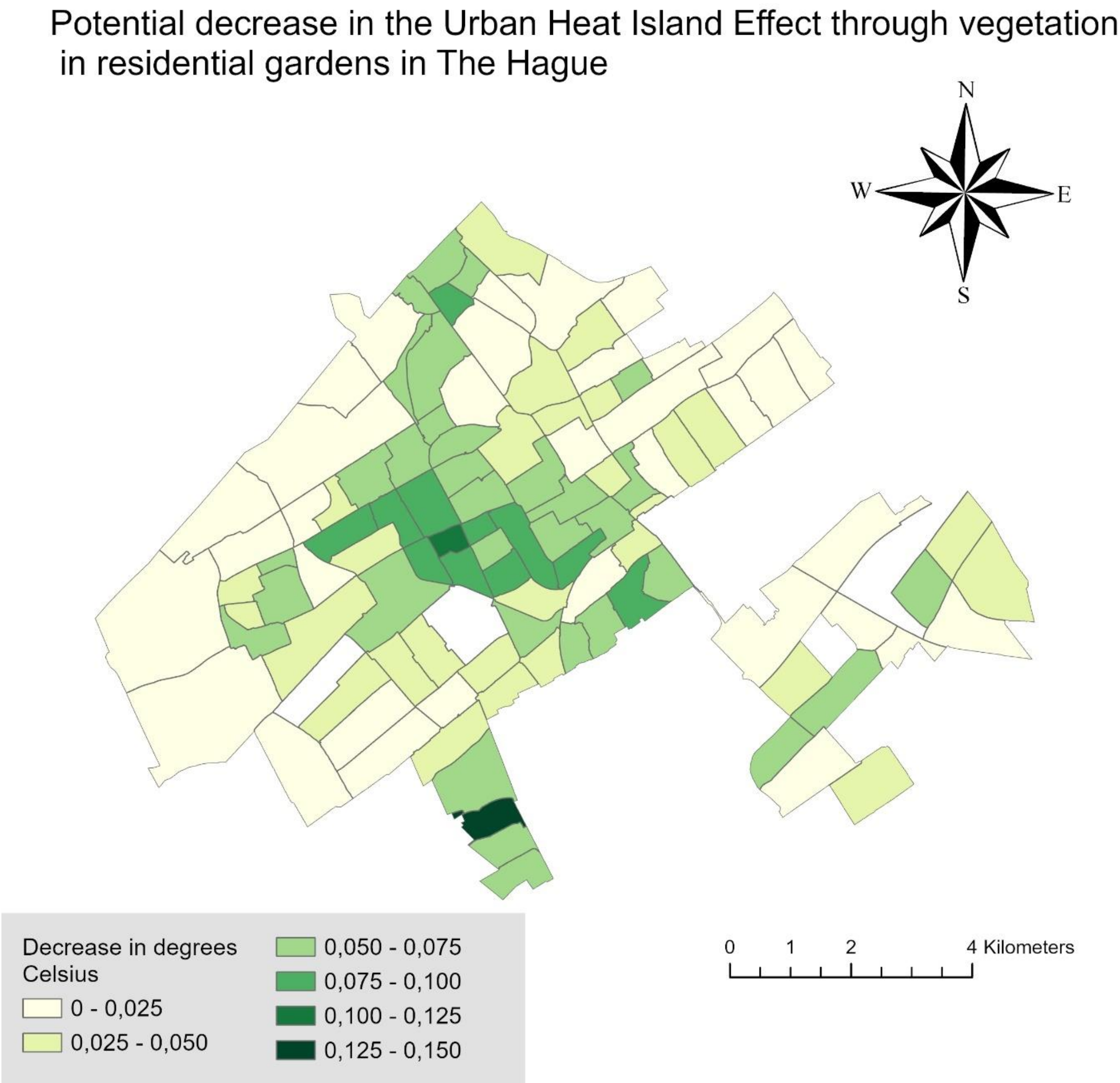

Figure 4.12: Potential decrease in the Urban Heat Island Effect through vegetation in residential gardens in The Hague

Figure 4.12 shows the map of these decreases in degrees Celsius. As shown, Parkbuurt Oosteinde also has the highest decrease in Celsius. The highest decrease in temperature is in Parkbuurt Oosteinde, with a cooling of 0.13 degrees Celsius. An average decrease of 0.044 degrees Celsius is observed throughout the city.

In general, all neighbourhoods note an increase in UHI reduction. This makes sense since more vegetation is considered for these calculations. An average increase of 2.9% is noted. Much of the increases can likely be attributed to the share of the area that belongs to residential gardens of the total surface area.

Table 4.11: Potential increases in UHI reduction of residential gardens

Neighbourhood	**UHI reduction in percentage**	**Potential increase in UHI reduction**	**Total potential UHI reduction in percentage**	**Garden area of total surface area in percentage**	**Percentage impervious surfaces in gardens**
van Hoytemastraat e.o.	6.2%	7.8%	14%	33%	44.6%
Parkbuurt Oosteinde	6.7%	5.5%	12.2%	36%	51.7%
Westvliet	0.2%	0.1%	0.3%	1%	40.8%
Haagse Bos	0.2%	0.2%	0.4%	1%	41.3%

The largest increases are observed in Parkbuurt Oosteinde and van Hoytemastraat e.o., similar to figure 4.6 where the current reduction is illustrated. However, this time Parkbuurt Oosteinde shows the highest value. Table 4.11 shows these values. In addition, the neighbourhoods with the lowest increases are also noted. These are Westvliet and Haagse Bos, where increases of 0.1% and 0.2% respectively are examined.

The neighbourhoods with higher potentials, such as Parkbuurt Oosteinde, all have large amounts of garden surface areas. More than one-third of the total surface area in the neighbourhood belongs to residential gardens. This gives much potential, as when this surface area is optimized it could bring larger reductions as noted in table 4.11. Thus, there is less potential in neighbourhoods with few gardens compared to those with more gardens. In addition, neighbourhoods with gardens that are already relatively green see little increase. For instance, Bosjes van Pex is among the neighbourhoods with the greenest gardens and, therefore, sees little increase if the few impervious surfaces within its gardens are replaced. Figure C.2 in Appendix C gives an overview of the garden area.

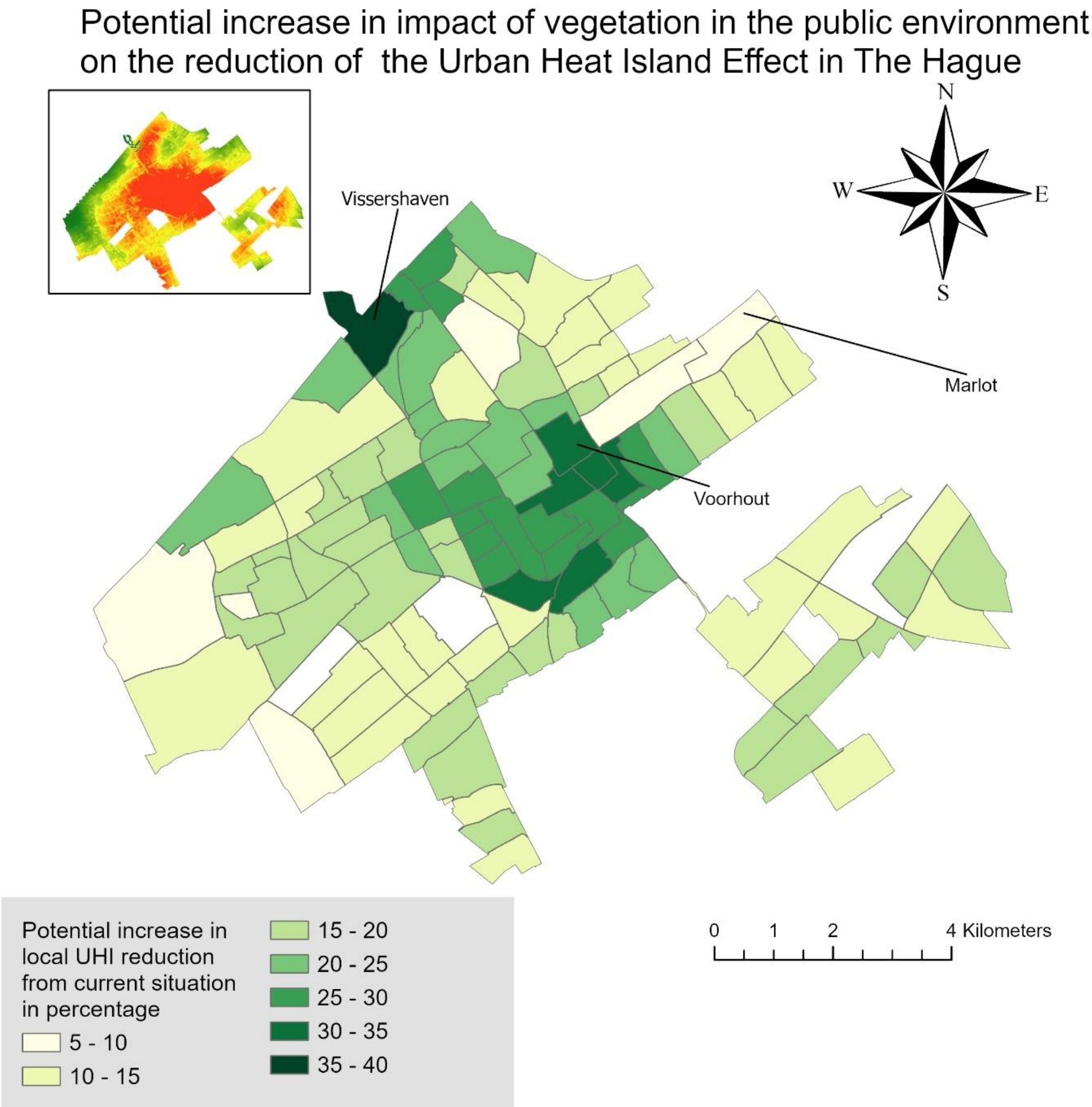

Figure 4.13: Potential impact of vegetation in the public environment on the reduction of the Urban Heat Island Effect in The Hague

Figure 4.13 illustrates the potential impact of vegetation in the public environment on the reduction of the UHI effect. Values between 5.6% and 37.2% are noted across The Hague. An average increase of 18.5% is noted. Similarly to the residential gardens, if a neighbourhood already had a reduction percentage of 10%, and the potential is also 10%, a reduction of 20% could be achieved. These calculations, however, consider a scenario in which all of the public environment transforms into vegetation.

As highlighted in figure 4.13, one neighbourhood sees a large increase in UHI reduction: Vissershaven. This neighbourhood has very little public green, with only 3% of its public environment consisting of vegetation. Therefore, a large increase can be had if this is changed. Another neighbourhood with a large increase in UHI reduction is Voorhout, where an increase of 33.8% is noted. Here, 12% of the public environment consists of vegetation. Another neighbourhood, Oud Scheveningen, has a similar percentage of vegetation in the public environment yet only sees an increase of 28%. It thus suggests that the types of vegetation that are present are key in reducing temperatures. Voorhout has more trees than Oud Scheveningen, and these are crucial in reducing the UHI effect.

Table 4.12: Comparison of neighbourhoods in UHI reduction potential for public green

Neighbourhood	**Potential increase in UHI reduction through the public environment in percentage**	**Current UHI reduction public environment in percentage**
Vissershaven	37.2%	1.2%
Voorhout	33.8%	4.6%
Oud Scheveningen	28.3%	1.5%
Van Stolkpark en Scheveningse Bosjes	7.4%	29.9%
Marlot	5.6%	25.5%

Table 4.12 shows the neighbourhoods with the highest potential for reducing the UHI effect through public green, and the two with the lowest potential for, as well as Oud Scheveningen as mentioned before. This table further emphasizes that neighbourhoods, where public green is already prevalent, have much less potential in reducing the UHI than where it is less prevalent. Marlot has a high current reduction, and therefore a small increase. With this data, it becomes possible to compare the highest potentials in both categories, as given in table 4.13.

Table 4.13: Comparison of neighbourhoods in both UHI reduction potentials

Neighbourhood	**Potential increase in UHI reduction through the public environment in percentage**	**Potential increase in UHI reduction through residential gardens**
Vissershaven	37.2%	1.2%
Voorhout	33.8%	1,8%
van Hoytemastraat e.o.	13.2%	7.8%
Parkbuurt Oosteinde	12.3%	5.5%

Both neighbourhoods with a high potential for the public green show very low potential through gardens. On the other hand, the two neighbourhoods with the highest potential for gardens have a below-average potential for public green (18.5%). It is likely due to the percentage gardens of total surface area that these percentages are so far apart.

It is not the main goal of this study to calculate the potential of the public environment in reducing temperatures. However, this map can help give an overview of what effect vegetation in The Hague has outside of the residential gardens. Thus, these potentials for public green are not considered when discussing neighbourhoods with high potential.

4.3.2 Potential runoff reduction

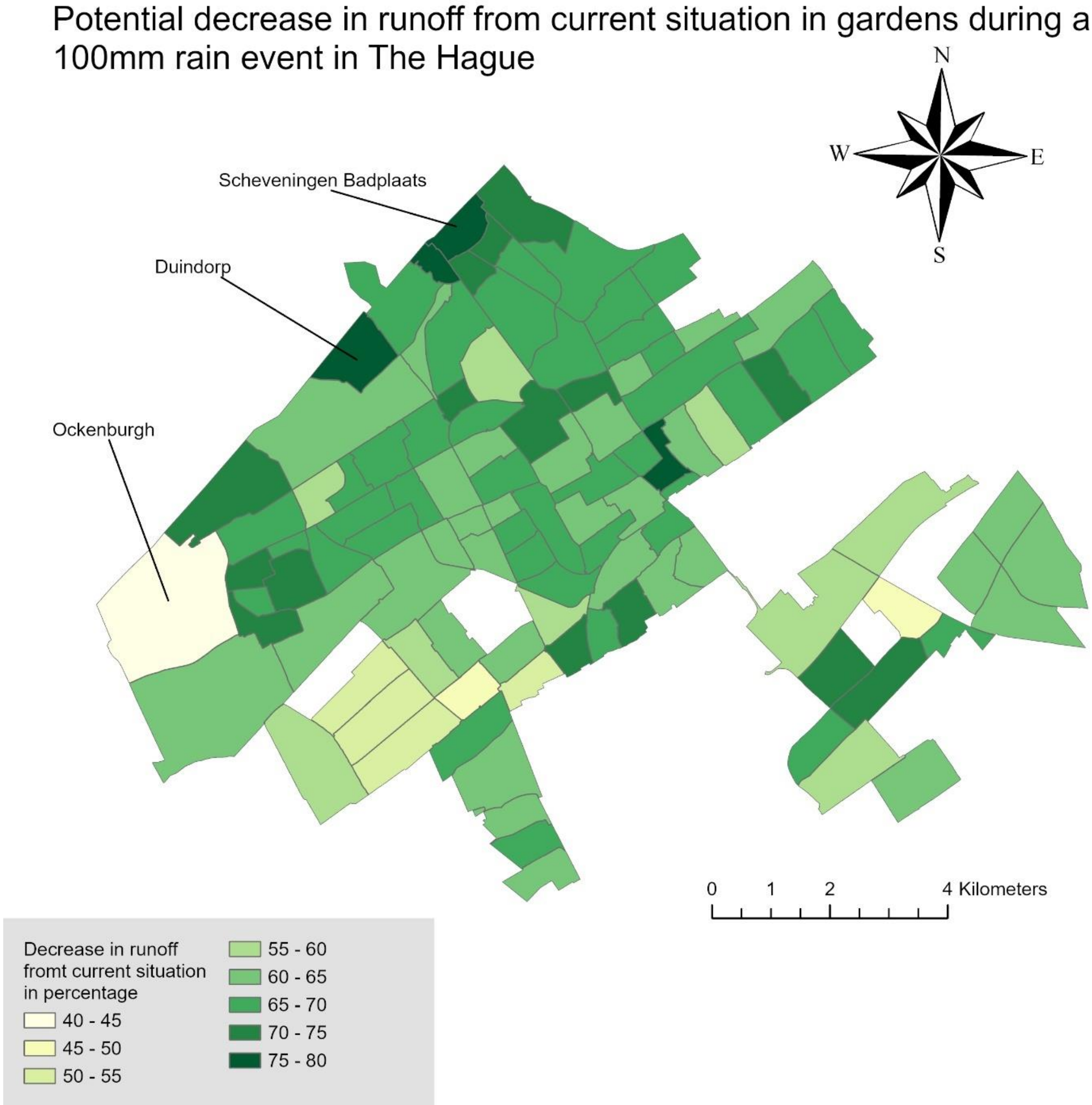

Figure 4.14: Potential decrease in runoff in gardens from current situation during a 100 mm rain event in The Hague

Figure 4.14 shows the potential decrease in runoff during a 100mm rain event in The Hague. This potential is calculated for a scenario in which all impervious surfaces are replaced by vegetation. As observed, the decreases range from 44% to 77%. The average decrease in runoff amounts to 65.1%, and the median to 65.6%. This indicates that there is a lot of potential for decreasing the amount of runoff through residential gardens. On the other hand, this map only shows the percentual increase. Even though it shows the actual potential, it could also be slightly misleading. It can be that an increase of 50% only points to a runoff reduction of 2mm. Table 4.14 reflects upon this, by showing the actual reduction in millimetres. In addition, table 4.15 lists the neighbourhoods with the largest decrease in runoff in millimetres. The map for this data is given in Appendix C, figure C.3.

Most of the northern part of The Hague sees blue, indicating a relatively high potential. Moreover, the highest values are noted in Scheveningen Badplaats and Duindorp. The lowest value is observed in Ockenburgh.

Table 4.14 shows the values of several neighbourhoods. Here, the three neighbourhoods with the highest potential decrease of runoff in percentages, and the three with the lowest potential.

Table 4.14: Potential runoff reduction in gardens

Neighbourhood	**Potential runoff reduction from current situation**	**Potential runoff reduction in mm**	**Amount of impervious surfaces in garden percentage**
Scheveningen Badplaats	76.8%	6.9mm	74.9%
Duindorp	76.5%	1.7mm	73%
Rivierenbuurt-Noord	75.9%	2.6mm	67.4%
De Reef	49.2%	3.8mm	38.9%
Morgenstond-Zuid	46.9%	4.8mm	30.8%
Ockenburgh	43.6%	0.6mm	14%

As mentioned before, Scheveningen Badplaats sees the largest decrease in runoff (76.8%) of the listed neighbourhoods in table 4.14. In addition, the largest actual runoff of the listed neighbourhoods is also in Scheveningen Badplaats, with a reduction of 6.9mm runoff. Morgenstond-Zuid sees a relatively low percentual reduction, yet an average actual reduction with 4.8mm, as the average reduction in millimetres is 4.8mm.

Table 4.15 lists the three neighbourhoods with the most actual millimetres in runoff that could be reduced if all impervious surfaces in gardens are changed into vegetation. Lage Veld sees a reduction of 14.1mm, which is a lot. This is logical, as this neighbourhood has a percentage impervious surfaces of around 80%.

Table 4.15: Potential runoff reduction in residential gardens in mm

Neighbourhood	**Runoff reduction from current situation**	**Actual runoff reduction in mm**
Lage Veld	65.4%	14.1mm
Nieuw Waldeck	72.9%	8.8mm
Kom Loosduinen	72.3%	8.7mm

4.3.3 Potentials combined

With both elements handled separately, it now becomes possible to combine the potentials and discuss neighbourhoods which could have the most effect. Table 4.16 shows these different potentials, and lies them next to each other.

Table 4.16: Potentials of residential gardens compared

Neighbourhoods	**Potential UHI reduction in percentage**	**Potential UHI reduction in degrees Celsius**	**Potential runoff reduction in percentage**	**Potential runoff reduction in mm**	**Garden area of total surface area in percentage**
van Hoytemastraat e.o.	7.8%	0.06˚C	68.2%	8.7mm	33%
Parkbuurt Oosteinde	5.5%	0.13˚C	64.0%	7.8mm	36%
Scheveningen Badplaats	4.5%	0.06˚C	76.8%	6.9mm	12%
Duindorp	2.4%	0.01˚C	76.5%	1.7mm	3%
Lage Veld	5.0%	0.07˚C	65.4%	14.1mm	30%

Table 4.16 illustrates the differences and the similarities that the neighbourhoods with high potential have. Next is an explanation per neighbourhood.

First, Van Hoytemastraat e.o. sees the highest percentual potential in reducing the UHI effect, yet only a just above average decrease in degrees Celsius. Moreover, it has a high potential in reducing runoff and a relatively high actual amount in millimetres with 8.7mm. In addition, this neighbourhood's surface area consists of one-third of gardens. This means that the optimization of vegetation in residential gardens within van Hoytemastraat could be very effective.

Next, Parkbuurt Oosteinde overall sees similar values. This neighbourhood, however, sees a large decrease in UHI reduction in degrees Celsius. This means that there are higher UHI temperatures observed in this neighbourhood, as it is almost double the reduction of van Hoytemastraat. In addition, the runoff reduction is also fairly high at 7.8mm. With 36% of its neighbourhood consisting of gardens, and with these high potential values Parkbuurt Oosteinde could be one of the key neighbourhoods to approach.

Thirdly, Scheveningen Badplaats is observed with the potentially highest percentual runoff reduction with 76.8%. This translates into 6.9mm of runoff that could be reduced. This is relatively interesting since only 12% of the neighbourhood consists of residential gardens. The reduction in UHI temperatures is above average, with a decrease of around 0.06˚C.

Furthermore, Duindorp sees a potentially high percentual decrease in runoff yet a low decrease in millimetres. This is due to the few gardens within the neighbourhood, with only 3% of its neighbourhood consisting of gardens. Moreover, the potential in reducing the UHI effect in this neighbourhood is also relatively low. Thus, even though some of the parameters would indicate that this neighbourhood would be very interesting to optimize it shows that relative values should be analysed critically. Duindorp would thus, according to these results, not be well-suited for further optimization of residential gardens. Instead, the public environment would be a better area to focus on.

Finally, Lage Veld is observed with a 5% potential UHI reduction, or 0.07˚C. In addition, Lage Veld sees the largest reduction of runoff in mm, with 14.1mm, or 65.4%. Moreover, the neighbourhood's surface area consists of 30% of gardens. Lage Veld is therefore one of the key neighbourhoods to be focussed on, if only for the reduction in runoff.

The mentioned neighbourhoods are shown in figure 4.15. As observed, Parkbuurt Oosteinde and Lage Veld are directly next to each other. Moreover, this spread of potentially interesting neighbourhoods shows that both soil type B and C are present. Scheveningen Badplaats and v. Hoytemastraat e.o. are soil type B, and Lage Veld together with Parkbuurt Oosteinde soil type C.

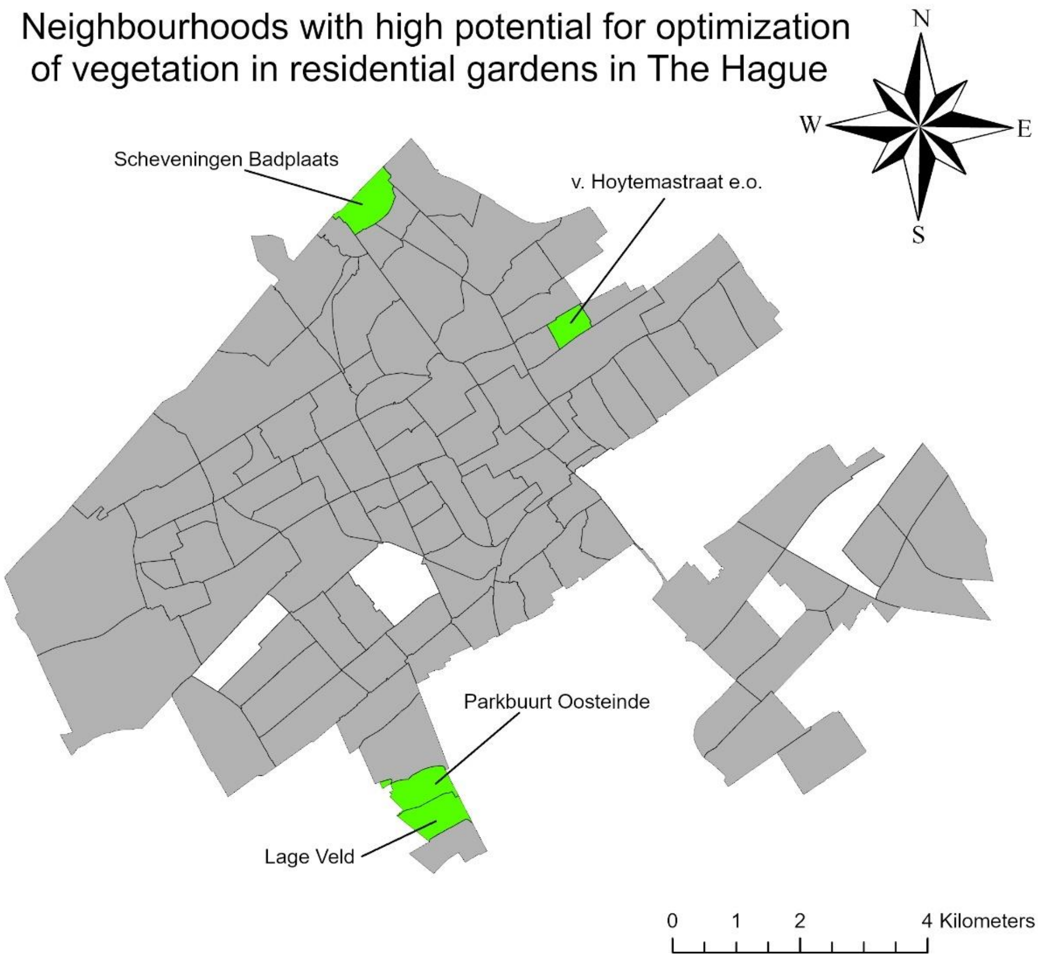

Figure 4.15: Neighbourhoods with high potential for optimization of vegetation in residential gardens

Chapter 5. Discussion

5.1 Discussion of results

Following is a discussion for every sub-question. Starting with the sub-question on what drives vegetation within residential gardens. Then, the sub-question on the impact of residential gardens on the Urban Heat Island Effect and runoff. Finally, the sub-question regarding the potential of residential gardens on reducing UHI temperatures and runoff is discussed.

5.1.1 What factors influence the amount of vegetation in residential gardens in The Hague?

As shown in the results only four of the analysed variables turned out to be statistically significant. This can be due to multiple reasons. The data used could be wrong, and if other data was used other findings could be given. In addition, other settings could reveal other variables to be statistically significant, as other studies show (Luck, Smallbone & O'Brien, 2009; Zhou et al., 2009). However, the variables that are significant do point to several interesting relationships that could be used by policymakers to increase vegetation within gardens. It was, however, unfortunate that the variable on housing types had high correlations with each other. Even when analysed separately, these variables could not be used for statistical analysis. As suggested in the hypothesis, this could have been very interesting and could be useful for policymakers as it allowed them to categorize their approach per type of housing.

Furthermore, the fact that averages per neighbourhood were used could mean that variables such as education are neglected. This is due to the inability to connect individual gardens to their owner's education or income level since this data is not publicly available. For example, a street of 10 houses could see households that there are highly educated with very green gardens. If other households are different in this, this relationship is not observable. This study is based on averages due to a large amount of data and neighbourhoods. Thus, as the hypothesis suggests and the study confirmed, it is not possible to discuss factors such as education and income regarding their effect on vegetation in gardens.

The average value of the residences likely correlates with the size of the gardens to a certain extent. Larger houses are generally more expensive and likely have larger gardens. Yet this correlation was not observed to be problematic in the PCA. Homes in the city centre of The Hague are likely much more expensive, whilst having smaller gardens than cheaper houses outside of the centre due to the scarcity of space in the centre.

Literature, such as Kulberg (2016), suggests that households with children prefer a greener garden, yet here this does not seem true. Instead, greyer surfaces are noted for every increase in the number of persons per household. It could be that due to the relatively high level of scale, this relationship suggested by Kulberg diminishes. Thus, on a household level this might be true, but due to the way averages are calculated that this relationship does not show in this study's results.

Due to several reasons out of scope, the data on public green used for the first sub-question differs from that used for the other two questions. Initially, the data from RIVM is used, and for the other questions data from Cobra is used. In general, this data overlaps fairly. In addition, the method used for calculating public green in the neighbourhood is not the one initially set up. The method that was intended on being used was too much for a study on a city as large as this.

In addition to this, the mirroring effect of vegetation has been difficult to prove in this study. Since the scale of this study is so high, it is hard to notice similarities on a street level.

Moreover, the research approach also did not accommodate for such phenomena. Also, the mirroring effect between public green and vegetation in gardens is difficult to propose, as the correlation between them does not mean that there is causation. Further in-depth studies could help prove this relationship and phenomenon.

Finally, neighbourhoods near the sea are observed having much impervious surfaces, as seen in the northern cluster in figure 4.1. This makes sense, as the salt from the sea would make it more difficult for vegetation to grow (Avis & Lubke, 1985). There are types of vegetation which could work well in such areas, yet these are likely not preferred to be had in residential gardens.

5.1.2 To what extent does vegetation in residential gardens in The Hague improve climate on a neighbourhood level?

In general, there is much more vegetation in the public environment compared to that in gardens. This is expected in cities, as gardens are a rare good in urban areas. However, this does mean that residential gardens only play a minor role in reducing environmental issues. On the contrary, this does not mean that they are to be neglected, however, the biggest increases are to be gained from the public domain. Therefore, the initial expectations of the results align with the outcomes of the study.

The effects noted for both runoff and the Urban Heat Island Effect are relatively low, as gardens are only a fraction of the entire surface area. However, this observation does not consider effects on an individual basis. Vegetation within gardens can have an effect on its residents, which does not show on the neighbourhood level of scale. Trees provide shadow and thus cooling for residents, or reduce the amount of runoff during rain events. Thus, whilst vegetation in gardens might seemingly look to be too little to affect the larger scale, individual households could see positive effects if there is vegetation within their garden. Not only the cooling or retention effect of vegetation can contribute positively, but it also has effects on mental and physical well-being as indicated in literature (section 2.4.1).

Looking back on the hypothesis, gardens do influence local climate as predicted. It can be debated as to what classifies as important, yet the reduction of up to 7% of the UHI or the low amounts of runoff show that gardens are an integral part of the total vegetation within The Hague.

Urban Heat Island Effect

Several neighbourhoods have a relatively low UHI effect and therefore are given a low score in UHI reduction since the gardens can only have a relative effect. Neighbourhoods with quite green gardens, such as Bosjes van Pex, could thus be observed as having little effect on the UHI effect whilst this is not true. The UHI effect has several causes, and lack of vegetation is one of them. The calculation used takes into account the degree of local UHI, which varies between neighbourhoods. The role of vegetation is largely dependent on the UHI in this calculation and therefore could give an inaccurate overview. In itself, the UHI is already reduced by the local vegetation, thus the calculation could be implied as calculating something which already is taken into account. Therefore, it should be acknowledged that the method chosen for the calculation of the effect of vegetation on the UHI is likely not the most suitable method available. As Remme (2017) shows, the calculation of the potential UHI and maximum UHI can warrant an entire study on its own.

Runoff

Curve numbers are many, and thus the choice of which category fits the most suitable curve number is mostly subjective. Therefore, the view the calculations offer could be inaccurate due to misjudgement. It is likely that in reality, the curve numbers differ, however, it is expected that this difference is not too large. Thus the data provided by this study is still useful to measure potential retention for every neighbourhood.

Even within neighbourhoods, the soil types can differ, since the borders of neighbourhoods are not based on soil types. This study appointed the soil type that was the majority in the neighbourhood as the corresponding soil type. A neighbourhood could be for 60% soil type B and 40% soil type C. This nuance was lost in this study due to the scale of the study.

The percentages of impervious surfaces in gardens differ between the two datasets given by Cobra. Waterbuurt, for instance, has a percentage of 60.6% in one, and in one separately calculated 52.5%. This can be due to inaccuracies in the allocations of the labels on the vegetation types, or other errors. To mitigate this inaccuracy, this and the calculations on the UHI used only the vegetation raster data from Cobra.

Finally, the runoff was calculated for a rainfall event of 100mm. Such events do not occur often and thus the amount of runoff is lower in day-to-day scenarios. It could be that in such scenarios the runoff is not as problematic as illustrated in this study's results.

5.1.3 In which neighbourhoods lie most potential for improving local climate through residential gardens?

Both elements of the sub-question show that the share of gardens in the neighbourhood is one of the crucial factors in analysing the potential effects. Neighbourhoods with few gardens can only do little in reducing runoff or temperatures. Instead, focus on neighbourhoods with a higher share of gardens should be focused on.

Secondly, both elements analyse the potential in percentages. By using percentages the potential is easily comprehensible. However, this can lose the urgency with, for example, the UHI reduction. Since the intensity of the UHI is different throughout the city, the urgency is also different. The percentages only show the potential decrease of the UHI and not the actual degrees Celsius. Since the question focussed on the potential, this percentual approach was chosen. This allows for a simple method of observing potentials.

It does need to be acknowledged that the potential is the scenario with the maximum amount of vegetation possible. This means that all surfaces in residential gardens were to consist of vegetation, with a composition similar to the current scenario. This is unlikely, as it cannot be expected that all surfaces in gardens will consist of vegetation. Impervious surfaces, whilst not preferred, are still required for a diverse set of reasons. Therefore, it is unrealistic to expect that this scenario will ever come to fruition. However, this does give a good overview of the potential. More vegetation in residential gardens will nonetheless be important in reducing local temperatures

Moreover, the potential for vegetation in the public environment was calculated to allow a comparison between residential gardens and public green. It shows that in general vegetation is of great importance in reducing temperatures, yet it is not sufficient to fully mitigate the UHI effect in urban regions like The Hague. Instead, vegetation is only a fraction of the equation needed to reduce temperatures, together with factors such as the built environment.

As suggested in the hypothesis, this question is more of a debate on what is preferred. Neighbourhoods with more potential might not be the neighbourhoods that are in dire need of cooling or less runoff. This study only takes into account the potential, and not the urgency or need for climate improvement. On this scale level and with the given time it was not possible to take other factors into account when calculating potential. In addition, the hypothesis suggests that newer neighbourhoods would have more potential. However, the residences in the neighbourhoods that are suggested to have the most potential are mostly built before 2000.

Thus, this hypothesis was incorrect. This could have been expected since Kulberg (2016) mentioned that older buildings most often have larger gardens.

Finally, it is thus wise to focus on neighbourhoods with a large share of their surface area originating from gardens. As listed in table 4.16, this would lead to van Hoytemastraat e.o., Parkbuurt Oosteinde, and Lage Veld. These three neighbourhoods show high potential in both reducing runoff and UHI temperatures, whilst also having a large amount of gardens in their area. Policymakers could address these three to test their ideas, as the effects are likely to be easier to identify here than in other neighbourhoods. This is because the potential effects of some neighbourhoods are high in percentages, yet in absolute terms quite low, such as 0.05 degrees Celsius or several millimetres of runoff reduced.

Whilst Scheveningen Badplaats does have a lot of potential, it is not listed among these neighbourhoods. With only 12% of its total surface area consisting of gardens, compared to the 30+ the other three mentioned neighbourhoods have, it would not be wise to test policy in this neighbourhood. The effects could be difficult to assess. In addition, the location of this neighbourhood could also pose to be difficult. As mentioned, the proximity to the sea can be a challenge for vegetation (Avis & Lubke, 1985).

5.2 Limitations of the research approach

Most of the calculations were done based on averages per neighbourhood. This is one of the methods to accurately measure the values, however, these averages could be skewed. Extreme values could disturb the average. Yet, it is likely that even with these extremes the result is still relatively accurate. Research on a lower level of scale could prove useful for reducing this possibility of inaccuracies. Several extreme values were removed from the study. The highest values in The Hague were observed and judged based on their relevance for this study, such as the gardens of the Royal residence. Yet it is likely that other extremes went unnoticed during the analysis.

The data used sometimes contradicted itself. For instance, the data of the RIVM and Cobra showed large differences between each other in the amount of public green. This can be contributed to different classifications of vegetation to an amount, yet it does however raise questions as to whether some of the results are as valid. Future research on this topic, or research using the established method and model should aim to use a more accurate singular set of data. The data of RIVM is too rough, as the tiles are 10 by 10 metres. The data of Cobra is, in contrast, much more detailed with their 0.25 by 0.25 metres tiles. Unfortunately, this study used data that Cobra itself acknowledged as being less accurate.

The Hague is the only large city in the Netherlands that is located near the coast. This could mean that the coastal proximity has some impacts, which cannot be explained in this study. This study could benefit from a multiple case study, to give more nuance to the results and to be able to argue whether these results are valid for other cities within the Netherlands. Perhaps a city such as Amsterdam has different results as to socio-economic drivers, or the influence of local gardens on the UHI and runoff.

The soil types are aggregated to a neighbourhood level of scale for this study, yet it could be that there are multiple soil types in each neighbourhood. This could give a different view of the situation. For this study, it was not feasible within the associated time to measure this on a smaller level of scale.

5.3 Reflection on the research approach

Looking back on this research, a lot of different topics were explored. From statistical analysis to calculating the potential cooling effect of residential gardens.

Initially, this study was to analyse the entirety of the Netherlands. After some helpful discussion with the examiners, it was decided that this approach was not realistic. The computing power needed to do such calculations was not available nor would the research be as accurate. Instead, by focussing on The Hague it allowed to dive deeper into one case. This study could have benefited from even a lower level of scale, as mentioned before. Perhaps certain streets or areas could have been analysed separately and could have potentially revealed interesting relationships.

This study analysed the UHI reduction and runoff similarly to the section on the factors driving impervious surfaces within gardens, by analysing it for every neighbourhood. Instead, these last two sub-questions could also have been done on a method such as Remme (2017) used, by analysing cells of 30 by 30 metres. Even though this might had given slightly different results, eventually it would come down to the same conclusion. By using the neighbourhoods as a level of scale it becomes much easier for policymakers and other actors to use this data to tackle the impervious surfaces within gardens. Now they can easily identify and point to interesting neighbourhoods.

Figure 4.15 shows four neighbourhoods with high potential for improving climate through residential gardens. These were picked based on their calculated potential. A score-like system that ranks neighbourhoods based on potential could have also been created, to give a better understanding of neighbourhoods outside of these four with the highest potential. Due to time constraints, it was chosen not to pursue this system. Moreover, since little policy currently exists to promote the greening of residential gardens, these four neighbourhoods could give the best indication of whether potential measures work, and what their effect is.

It was decided that when calculating the potential the composition of the vegetation within gardens was to be kept the same as it was. Thus, a garden consisting of grass for 25% of its vegetation was to keep this fraction. It would grow in size and effect, yet not of its total share of the vegetation. Another method would be to simulate certain gardens, thus giving every neighbourhood a similar garden design. This, however, would lead to very similar results all around. It would only be fit for showing the reduction in absolute values, thus degrees Celsius or millimetres runoff. Even then, it would show similar values between neighbourhoods when calculating runoff, with the only difference being the soil type.

5.4 Recommendations for future research

Future research could be done on a different case with a similar research approach to compare the results of this study. It could be that The Hague is very unique in its residential gardens and that other cities might show different results. Moreover, it could further emphasize that certain socio-economic factors drive impervious surfaces in gardens. This then makes it interesting for policymakers to address, as they would have a clearer view of the situation and factors at play.

In addition, future research could be done on smaller levels of scale with other data sets. The Hague is one of the largest cities in the Netherlands, and taking the entire city as its study area proved to be interesting. However, certain nuances do go unnoticed with this level of scale. Exploring the reasons or motivations behind people could be done on a smaller level of scale. For instance, by performing interviews or surveys with residents and asking them why they have impervious surfaces and what would be required to change that. This could lead to the exploration of the relationship between income or education, and vegetation in gardens. As discussed in 5.1, this relationship was not observable in this study.

This study touched upon factors driving impervious surfaces within residential gardens, as has been done in previous studies as well. Studies such as that of Goddard, Dougill & Benton (2010) or of Luck, Smallbone & O'Brien (2009) could be due for an update. It would be recommended to enact such a study once more, perhaps this time in the Netherlands. Kulberg (2016) briefly explored the drivers behind this process, yet more in-depth research behind the driving factors of impervious surfaces in gardens could be conducted. This study showed the relevance of four variables, yet there must be more at play. Perhaps it could be interesting to look at variables that were not part of this study, such as the resident's country of origin.

The mirroring effect mentioned by Kulberg (2016) could be very interesting to study as well in regard to the greening of residential gardens. Test pilots in which some gardens are transformed into full of vegetation could be done to see how residents of the surrounding area respond. In addition, the statistical analysis proved that public green increases vegetation within gardens. It could be interesting to see how gradual changes in public green could promote more vegetation in residential gardens. A study with a longer time frame, such as multiple years, could be done to measure the changes in vegetation. This could be difficult, as people move out of their homes and thus gardens could completely be changed when new residents move in. When done on a larger scale this should still be accurate.

5.5 Recommendations for practice

This study has shown that residential gardens can have an impact on the UHI effect and the amount of runoff. Even though gardens are relatively scarce in urban areas such as The Hague, it would still be wise to aim for more vegetation within these gardens.

Residential gardens are private property. If the municipality, or the government, were to enforce certain rulings regarding residential gardens, such as a percentage of the garden needing to consist of vegetation, it could be poorly received. Even though there are few benefits to impervious surfaces outside of social functions, people still love their gardens and how they designed them. Therefore, strict policies on how gardens should be designed should be avoided. Preferred would be policy motivating vegetation in gardens, such as the financial compensation that is already being given out by several municipalities in the Netherlands. The Hague (n.d.) will compensate those who change their garden, with a total amount of €250.000 available. This is only done in several neighbourhoods and is not focused on vegetation in gardens, but more on making The Hague rainproof through the placement of rain barrels and more. This policy likely needs to be scaled up to achieve useful results, both in the number of neighbourhoods it is available to and the amount of funds available.

In addition, the Netherlands is as of writing deep in its housing crisis and is aiming to build over a million new residences in the coming future (Teije, 2022). It could be wise to already start forming policies for these new residences, such as a required plot of grass or a tree. Residents are not yet connected to their new garden and thus might more willingly accept this vegetation requirement.

Perhaps to raise awareness of the issues concerning abundant impervious surfaces in gardens an information campaign could be set up. It would be interesting for residents to be able to notice the effects of their garden design. It is recommended to focus on the benefits vegetation can have for residents. For example, by mentioning that a single tree in their garden could lead to such a decrease in kWh used by air conditioning, or a reduction in local temperature.

Chapter 6. Conclusion

Looking back on the research question of this thesis: "*How, and where, can vegetation in residential gardens in The Hague improve climate on a neighbourhood level?*", the impact of the vegetation within residential gardens on heat and runoff is not to be underestimated.

Starting with the first sub-question: *"What factors influence the amount of vegetation in residential gardens in The Hague?"*. Four variables emerged as being statistically significant in the case of The Hague. First, the amount of green in the public environment has a positive effect on the amount of vegetation in residential gardens. The more public green, the more vegetation within residential gardens. Next, the value of the building, which has the most impact on the vegetation within the garden. Expensive residences are examined as having greener gardens. The third variable is the average size of the garden. Larger gardens will likely have greener gardens. Finally, the average household size, which has a negative effect on the extent of vegetation in the garden. Larger families will likely have less vegetation in their gardens.

Next, the second sub-question: "*To what extent does vegetation in residential gardens in The Hague improve climate on a neighbourhood level?"*. As for the reduction of the Urban Heat Island Effect values of between 0.18% and 6.7% are noted in The Hague. This means that up to 6.7% of the local median UHI can be cooled through vegetation in gardens. In comparison, public green sees reduction values of up to 35%, whilst there is much more public green than gardens. As for runoff, the projected millimetres that cannot be absorbed by the soil or vegetation ranges between 0.374mm in Vlietbuurt, to 21.634mm in Lage Veld. This shows that the extent of impervious surfaces is crucial in reducing runoff, as gardens with little impervious surfaces see a much lower amount of runoff compared to those with many artificial surfaces.

Thirdly, the last sub-question focussed on the potential of the vegetation within residential gardens: "*In which neighbourhoods lie most potential for improving local climate through residential gardens?*". This section simulated scenarios where gardens and the public environment were to consist completely of vegetation. This is not realistic, however, it does give a clear overview of the potential that could be achieved. The largest increase in the Urban Heat Island reduction value is noted in van Hoytemastraat e.o., with 7.8%. Moreover, the largest runoff reduction is examined in Scheveningen Badplaats, with a value of 76.8%. This means that up to 76.8% of its current runoff could be reduced if gardens were to completely consist of vegetation. In general, the most potential is noted in neighbourhoods with a high percentage of gardens of its total surface area. This leads to three neighbourhoods that are designated as having high potential: van Hoytemastraat e.o., Parkbuurt Oosteinde, and Lage Veld.

Thus, coming back to the main research question. Vegetation in residential gardens can improve local climate on a neighbourhood level. Even though some neighbourhoods only have a few gardens, the vegetation within those gardens is still affecting temperature and runoff. Moreover, the neighbourhoods with more gardens and more vegetation within those gardens are a crucial element of the total vegetation in a neighbourhood. Concluding, this study has shown several drivers behind vegetation in residential gardens, as well as the current and potential impact of vegetation on the Urban Heat Island Effect and runoff within residential gardens in The Hague.

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Appendices

Appendix A: Statistical Analysis

PCA

Table A.1: Correlation matrix housing types

Correlation Matrix[a]

		Eensgezinswoning	Appartement	Benedenwoning	Bovenwoning	Maisonette	Flat	Portiekwoning	Eensgezinshoekwoning	Eengezinstussenwoning	Vrijstaande woning	Twee-onder-een-kap woning	Overige woning	Koopwoningen	Particuliere huurwoningen	Sociale huurwoningen	Eigendom nog niet bepaald
Correlation	Eensgezinswoning	1,000	-,056	,165	,044	,127	-,041	-,133	,913	,944	,418	,551	-,098	,489	-,055	,094	-,062
	Appartement	-,056	1,000	,529	,522	,395	,654	,540	-,143	,089	-,322	-,347	,163	,620	,804	,522	,238
	Benedenwoning	,165	,529	1,000	,923	,266	,014	,140	,028	,288	-,172	-,170	,093	,527	,624	,062	,264
	Bovenwoning	,044	,522	,923	1,000	,261	,018	,098	-,102	,161	-,173	-,181	,144	,434	,700	,010	,344
	Maisonette	,127	,395	,266	,261	1,000	,388	-,099	,137	,211	-,199	-,210	,289	,064	,221	,577	,028
	Flat	-,041	,654	,014	,018	,388	1,000	-,088	-,031	,026	-,185	-,217	,179	,178	,248	,769	,108
	Portiekwoning	-,133	,540	,140	,098	-,099	-,088	1,000	-,188	-,059	-,192	-,193	-,064	,521	,574	-,080	,038
	Eensgezinshoekwoning	,913	-,143	,028	-,102	,137	-,031	-,188	1,000	,796	,399	,547	-,126	,353	-,185	,114	-,169
	Eengezinstussenwoning	,944	,089	,288	,161	,211	,026	-,059	,796	1,000	,159	,275	-,063	,549	,066	,167	-,027
	Vrijstaande woning	,418	-,322	-,172	-,173	-,199	-,185	-,192	,399	,159	1,000	,756	-,085	,035	-,217	-,178	-,009
	Twee-onder-een-kap woning	,551	-,347	-,170	-,181	-,210	-,217	-,193	,547	,275	,756	1,000	-,107	,118	-,242	-,201	-,025
	Overige woning	-,098	,163	,093	,144	,289	,179	-,064	-,126	-,063	-,085	-,107	1,000	-,071	,187	,300	,056
	Koopwoningen	,489	,620	,527	,434	,064	,178	,521	,353	,549	,035	,118	-,071	1,000	,609	-,038	,188
	Particuliere huurwoningen	-,055	,804	,624	,700	,221	,248	,574	-,185	,066	-,217	-,242	,187	,609	1,000	,053	,402
	Sociale huurwoningen	,094	,522	,062	,010	,577	,769	-,080	,114	,167	-,178	-,201	,300	-,038	,053	1,000	-,131
	Eigendom nog niet bepaald	-,062	,238	,264	,344	,028	,108	,038	-,169	-,027	-,009	-,025	,056	,188	,402	-,131	1,000

a. This matrix is not positive definite.

Table A.2: Correlation matrix age groups

Correlation Matrix[a]

		0 - 15 jaar 2022	15 - 25 jaar 2022	25 tot 45 jaar 2022	45 tot 65 jaar 2022	65 of ouder 2022
Sig. (1-tailed)	0 - 15 jaar 2022		,000	,000	,000	,000
	15 - 25 jaar 2022	,000		,000	,000	,000
	25 tot 45 jaar 2022	,000	,000		,000	,000
	45 tot 65 jaar 2022	,000	,000	,000		,000
	65 of ouder 2022	,000	,000	,000	,000	

a. Determinant = ,003

Table A.3: Correlation matrix analysed variables

Correlation Matrix[a]

		WOZ waarde	Gemiddelde huishoudgrootte	Mate van stedelijkheid	Gemiddeld inkomen	Laag-opgeleid	Middelbaar-opgeleid	Hoog-opgeleid	Mediaan bouwjaar	Mean gebouwhoogte	Groen openbaar gemiddelde	Gemiddelde grootte tuin
Correlation	WOZ waarde	1,000	,353	,459	,616	-,658	-,337	,579	-,224	-,216	,182	,063
	Gemiddelde huishoudgrootte	,353	1,000	,496	,239	,121	,022	-,138	,455	-,276	,162	,060
	Mate van stedelijkheid	,459	,496	1,000	,232	-,211	-,042	,087	,346	-,291	,263	,264
	Gemiddeld inkomen	,616	,239	,232	1,000	-,545	-,256	,514	-,265	-,084	,130	,090
	Laag-opgeleid	-,658	,121	-,211	-,545	1,000	,359	-,757	,291	,079	-,009	,025
	Middelbaar-opgeleid	-,337	,022	-,042	-,256	,359	1,000	-,436	,205	-,004	,004	-,128
	Hoog-opgeleid	,579	-,138	,087	,514	-,757	-,436	1,000	-,369	-,012	-,049	,024
	Mediaan bouwjaar	-,224	,455	,346	-,265	,291	,205	-,369	1,000	,091	,191	,062
	Mean gebouwhoogte	-,216	-,276	-,291	-,084	,079	-,004	-,012	,091	1,000	,006	-,083
	Groen openbaar gemiddelde	,182	,162	,263	,130	-,009	,004	-,049	,191	,006	1,000	,141
	Gemiddelde grootte tuin	,063	,060	,264	,090	,025	-,128	,024	,062	-,083	,141	1,000
Sig. (1-tailed)	WOZ waarde		,000	,000	,000	,000	,000	,000	,010	,013	,030	,259
	Gemiddelde huishoudgrootte	,000		,000	,007	,107	,411	,079	,000	,002	,048	,269
	Mate van stedelijkheid	,000	,000		,008	,015	,333	,188	,000	,001	,003	,003
	Gemiddeld inkomen	,000	,007	,008		,000	,004	,000	,003	,194	,092	,179
	Laag-opgeleid	,000	,107	,015	,000		,000	,000	,001	,208	,462	,400
	Middelbaar-opgeleid	,000	,411	,333	,004	,000		,000	,017	,485	,485	,094
	Hoog-opgeleid	,000	,079	,188	,000	,000	,000		,000	,452	,308	,402
	Mediaan bouwjaar	,010	,000	,000	,003	,001	,017	,000		,175	,025	,263
	Mean gebouwhoogte	,013	,002	,001	,194	,208	,485	,452	,175		,474	,198
	Groen openbaar gemiddelde	,030	,048	,003	,092	,462	,485	,308	,025	,474		,073
	Gemiddelde grootte tuin	,259	,269	,003	,179	,400	,094	,402	,263	,198	,073	

a. Determinant = ,012

Table A.4: KMO and Bartlett's Test of analysed variables

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		,642
Bartlett's Test of Sphericity	Approx. Chi-Square	452,822
	df	55
	Sig.	,000

Appendix B: Additional information on outliers

Bosjes van Pex & Vissershaven

Following is an explanation of two of the outliers in grey surfaces in gardens, Bosjes van Pex & Vissershaven.

Bosjes van Pex

Table B.1 Summary of Bosjes van Pex

Average amount of green in public environment	Average value of the building	Average garden size	Average household size
79	400.000€	21.27 m^2	1.8

The lowest noted value is 18.14 which is noted in neighbourhood 81, Bosjes van Pex. For reference, the neighbourhoods are illustrated in figure 3.1. This neighbourhood is located to west. It hosts several apartment blocks, and two streets with townhouses. Two other neighbourhoods, Ockenburgh (90), and Vlietzoom-Oost (106), come close to the average value of Bosjes van Pex but are slightly higher.

When taken a better look at the socioeconomic data on Bosjes van Pex, several interesting values can be noted. Even though it is not taken into account in the regression analysis, the ownership of the homes is mostly one-sided here, with most (177 of 210) being owner-occupied homes. It is likely that the streets with townhouses are completely owner-occupied, and that most of the apartment blocks are as well. This is in line with most other Dutch neighbourhoods. Moreover, the average WOZ-value of homes here is around 400.000€, which is almost 100.000€ above the average of 2022 for The Hague (Eerlijkewoz.nl, n.d.). This relationship is also noted in table B.1, with Bosjes van Pex being a good example of it.

However, it cannot purely be attributed to this variable. The neighbourhood is already quite green without the gardens. This neighbourhood shares the highest noted value of green in the public environment, with Kampen being the other neighbourhood. As for Bosjes van Pex, a large park and a playground is located here. This again proves the relationship observed in table 4.3. The average size of the gardens in Bosjes van Pex is above the average value noted, ranking at place 82 of 107.

Finally, the average household size is among the lower values with 1.8. The lowest noted value is 1.4, and the highest 3.0. It is difficult to report a strong relationship between the this variable and the average amount of grey surfaces for this neighbourhood.

Vissershaven

Table B.2 Summary of Vissershaven

Average amount of green in public environment	Average value of the building	Average garden size	Average household size
4	322.000€	15.26m^2	1.9

As seen in table B.2, the highest value of grey surfaces, 92.73, is observed in neighbourhood 2, Vissershaven. This neighbourhood is home to the fishing port of The Hague, and is thus closely located to the sea. Scheveningen, as is called the district of Vissershaven and surrounding neighbourhoods, is illustrated as very red, thus indicating much grey surfaces within the gardens here. Possible reason for this can be the proximity to the sea, which can cause vegetation to grow more difficult (Avis & Lubke, 1985).

Together with Oud Scheveningen (1) Visserhaven has the smallest amount of green in the public environment, with a value of 4. As suggested before, both neighbourhoods are located near the sea and this proximity could cause plants to see difficult growth (Avis & Lubke, 1985). Moreover, the beaches of Scheveningen are not seen as public green, whilst for recreational activities they could be classified as such. Whilst sand does work well in reducing runoff (Abu-Zreig, Fujimaki & Abd Elbasit, 2020), this cannot be said for reducing heat stress. Finally, this study analyses the role of vegetation and not of different soil types. Therefore, this beach is not taken into account when analysing public green. The small value of green is a good example of the relationship given in table 4.3: the less green in the public environment, the more grey surfaces in gardens.

The average WOZ-value in Visserhaven is 322.000€, which is just around average. With this in mind, it then becomes harder to explain the results. A quite strong relationship is noted in table 4.3, yet is not seen in table B.2. However, when looked at the second highest value of grey percentages in gardens, Laakhaven-Oost (19), a relatively low value of 187.000€ is noted. This neighbourhood exemplifies the relationship between average value and greener gardens, yet Vissershaven does not prove this relationship. Moreover, both two neighbourhoods have a similar average garden size, with the two ranking 64 and 72 out of 107. The biggest difference between the two neighbourhoods is the average amount of green in the public environment, where Laakhaven-Oost has more than triple the amount of Vissershaven, with a value of 13.

As for average household size, Vissershaven's value is relatively average. It is larger compared to Bosjes van Pex, but also marginally. It is therefore difficult to assess the relationship suggested in table 4.3 for this neighbourhood.

Appendix C: Additional maps

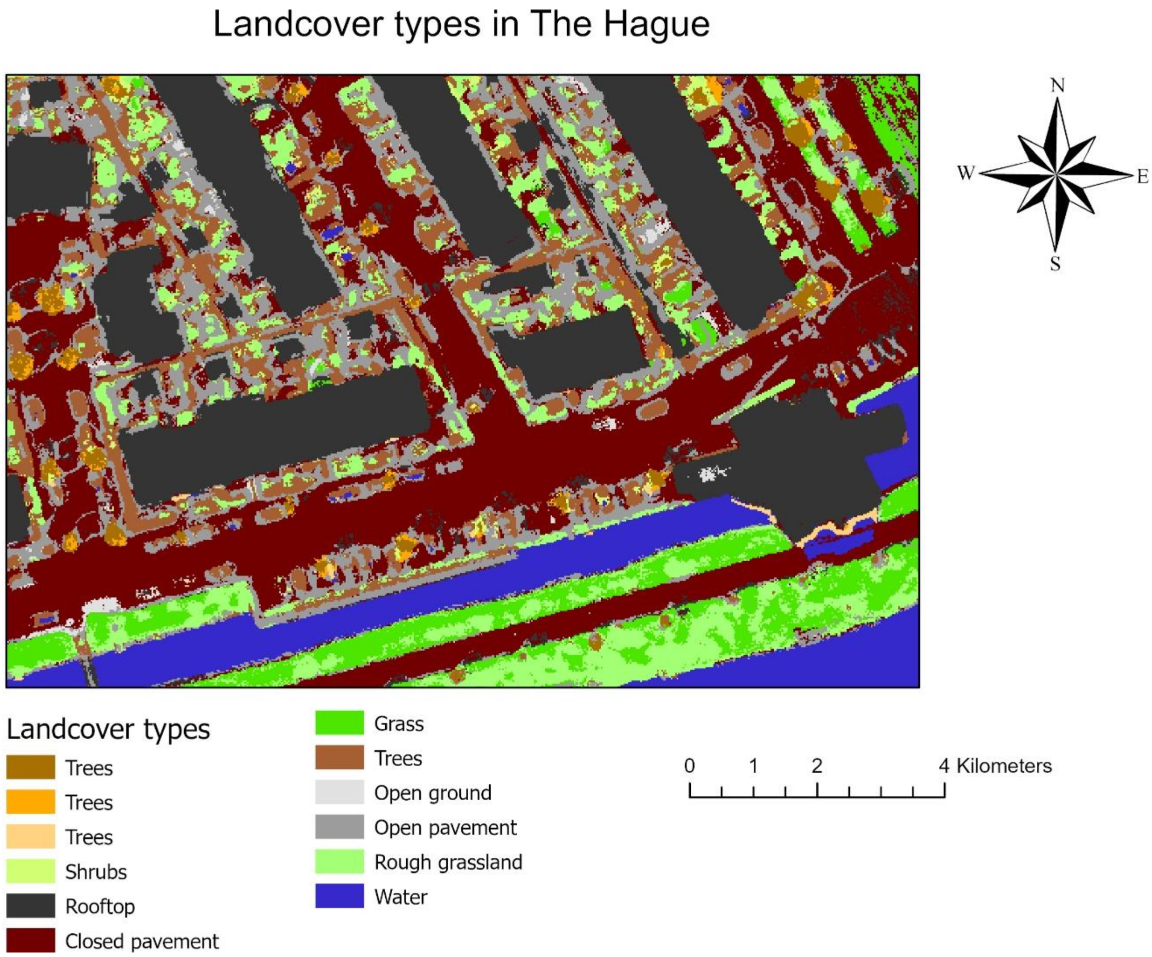

Figure C.1: Landcover types in The Hague

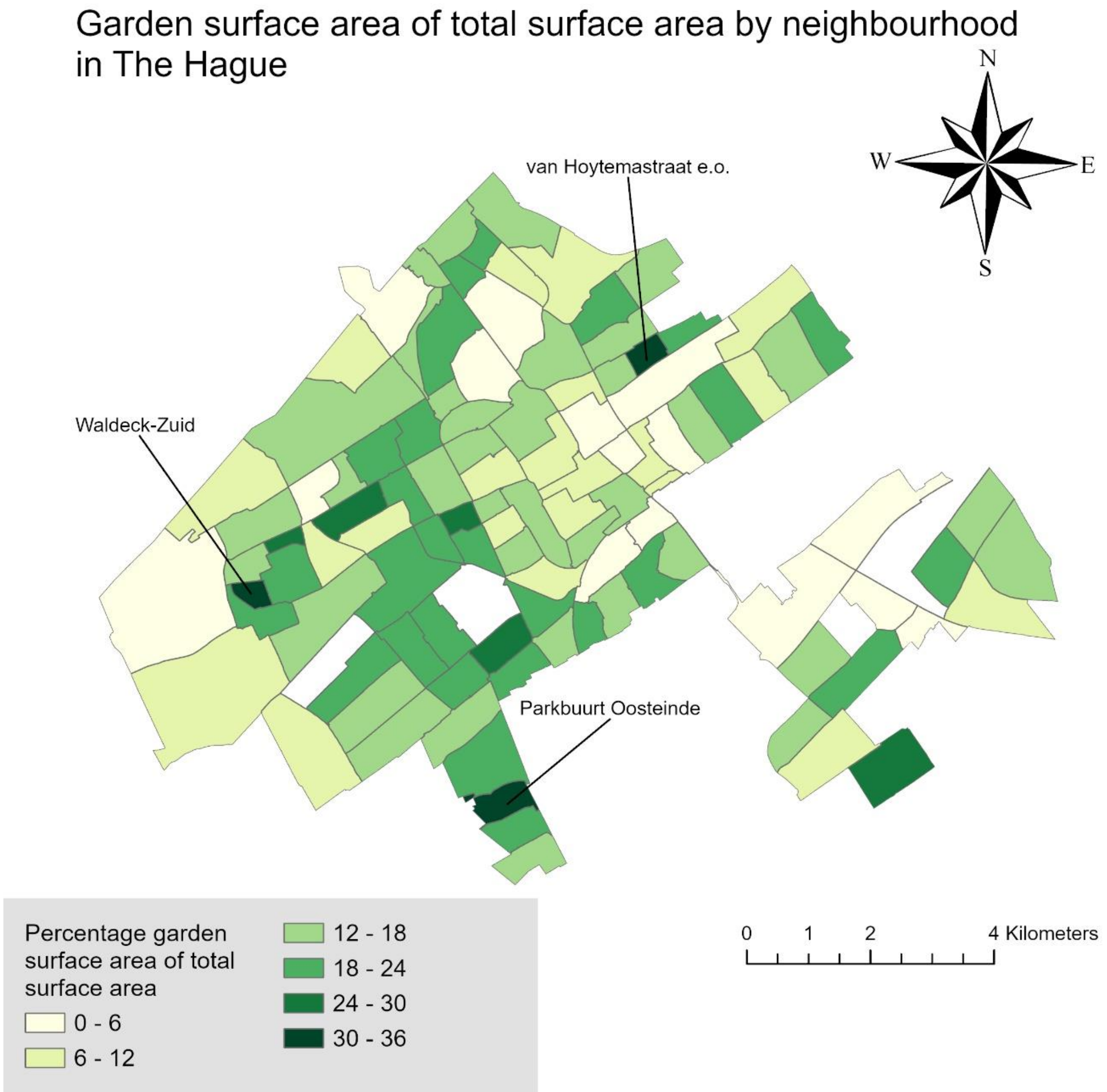

Figure C.2: Garden surface area of total surface area by neighbourhood in The Hague

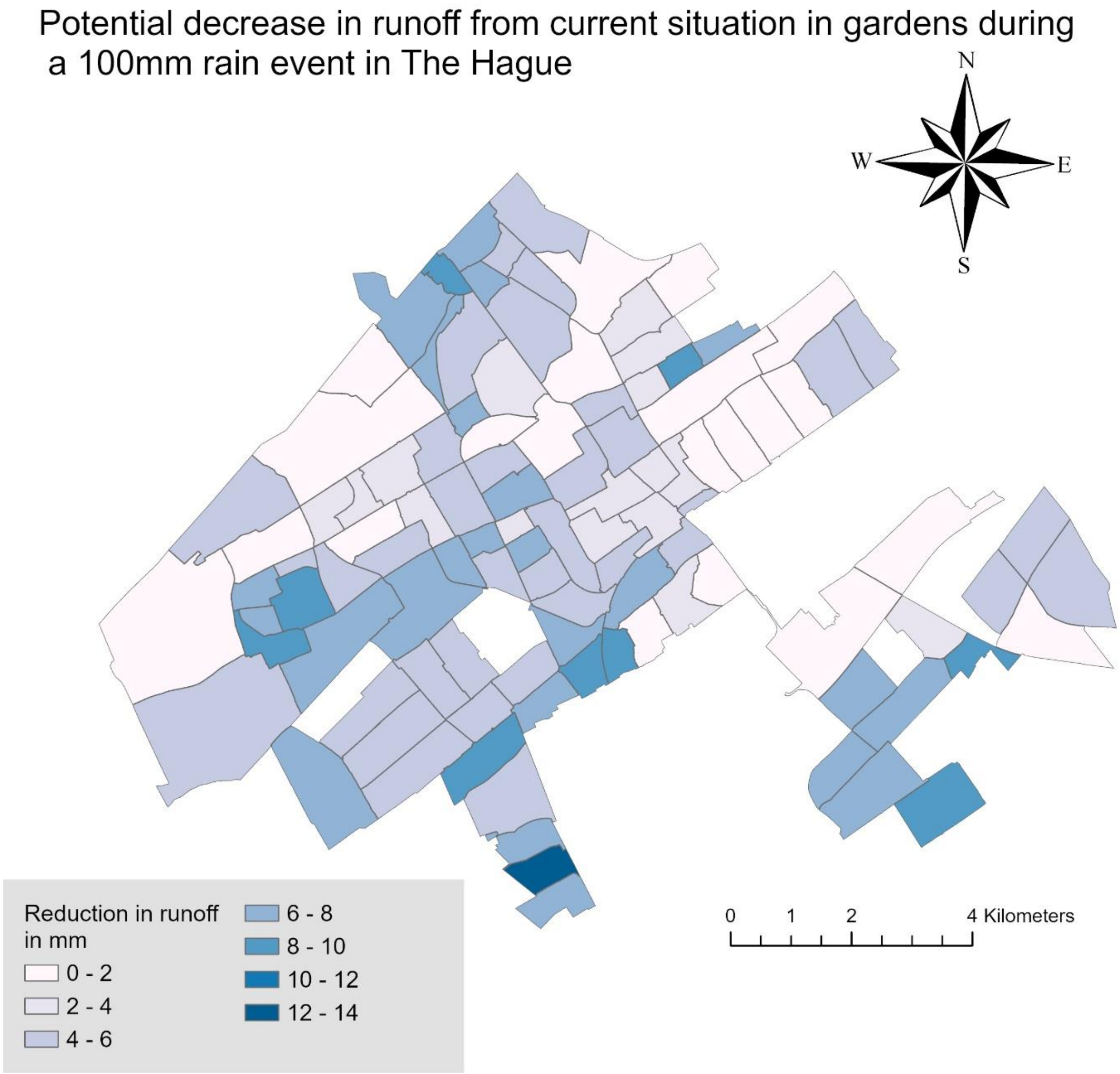

Figure C.3: Potential decrease in millimetres runoff from current situation in gardens during a 100mm rain event in The Hague