The Potential of Nature-based Solutions to Enhance Post-War Neighbourhood Resilience to Climate Challenges: Spatial Adaptations for Overtoomse Veld

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Abstract

Climate Change Related Risks have intensified in urban areas as temperatures and precipitation levels are rising. Within the city of Amsterdam, post-war neighbourhoods experience elevated risks for urban heat and pluvial flooding. Urban areas can benefit from climate adaptation strategies such as Nature-based Solutions. NbS serve to improve the climate resiliency of cities by protecting and restoring ecosystems through nature-inspired urban planning. Open public spaces within Amsterdam's post-war neighbourhoods provide suitable conditions for successful NbS implementation. A systematic literature of 13 local case studies measured the potential for NbS to reduce the Urban Heat Island effect and pluvial flooding within different cities in the Netherlands. A comparative case study analysis determined the most suitable NbS for the specific challenges of Amsterdam's post-war neighbourhoods to be a network of integrated Green, Blue, and Green-Blue Infrastructure. Abiotic surfaces such as asphalt should be replaced by surface materials with greater impermeability and higher albedos. Additionally, more blue and green spaces could be incorporated within existing open areas by adding parks, (street) trees, daylight rivers, and (bio)swales. The additional application of Blue-green roofs could cover more surface area of residential spaces and significantly reduce surface runoff and heat storage.

Keywords:
Post-war neigbourhoods; Urban heat; Pluvial flooding, Nature-based Solutions

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1 Introduction

Extreme weather conditions such as droughts, heatwaves and flash floods are projected to occur more frequently as an effect of climate change. These extreme weather events will have adverse impacts at a global scale (IPCC, 2014). When it comes to urban areas, their dense concentration of physical assets and population increases vulnerability to Climate Change Related Risks (CCRR), intensifying an already pressing matter (Gasper et al. 2011, IPCC, 2014). One of these vulnerabilities is that large cities are subject to the Urban Heat Island (UHI) effect, which increases urban temperatures above that of surrounding areas (Peng et al., 2012). Additionally, the concern of pluvial flooding has grown in urban areas, as rainfall frequency increases and drainage capacities are being exceeded (Pradhan-Salike & Raj Pokharel, 2017). There are still many uncertainties regarding the magnitude and frequency of these CCRR (IPCC, 2007). Climate change poses a serious threat to urban societies (Wamsler et al., 2013) and will inevitably increase the susceptibility of urban societies if no effective adaptation takes place (IPCC, 2007, Moriarty & Honnery, 2015).

The municipality of Amsterdam acknowledges the immediate need for climate adaptation measures. In 2020, the municipality released the Climate Adaptation Strategy plan, which promotes joint collaboration with residents to assure a safe, green, liveable, and attractive city in the future (Gemeente Amsterdam, 2020). The climate plan expresses the role of new urban planning strategies to reposition climate adaptation as the new standard for city development. It stimulates experiments with blue-green roofs and other new public and private initiatives of various scales. The municipality acknowledges heat, drought, pluvial flooding, and fluvial flooding as the four main CCRR for the city. Within Amsterdam, the post-war neighbourhoods are found to have higher probabilities for CCRR than their surrounding districts (Gemeente Amsterdam, 2020).

This research aimed to answer the following question: Which Nature-based Solutions could further enhance the spatial characteristics of Amsterdam's post-war neighbourhoods against increased urban heat and flood risks? The potential modification of existing public areas and open spatial structures (parks, streets, parking areas, and roofs) in post-war neighbourhoods of Amsterdam was investigated by executing a systematic literature review. These case studies examined the potential implementation of Nature-based Solutions (NbS) to reduce two of the four CCRR previously mentioned by the municipality, urban heat and pluvial flooding. NbS strategies are inspired by nature and intend to tackle environmental challenges (Haase et al., 2017) through the delivery of ecosystem services, facilitated by implementation of Blue Infrastructure (BI), Green Infrastructure (GI) and Blue-Green Infrastructure (BGI) (Albert et al., 2019, Bush & Doyon, 2019). The possible implementation of NbS in post-war neighbourhoods is important to consider, as post-war neighbourhoods are characterised by their low building density, which has great potential for climate change resiliency (Cortinovis et al., 2022, De Knegt et al., 2024, Havinga et al., 2020). This research was directed toward breaching the research gap for climate resiliency development in post-war neighbourhoods with low building density and unutilised open space.

In the following sections, this paper will first examine the historical and topographical background of the study area (section 2). Following this, the theoretical framework identifies and contextualises the perspective from which the central concepts are investigated (section 3). The resulting methodology outlines how these essential theories and methods are applied to direct data collection and analysis. (section 4). This guides the analysis process of NbS implementations amongst the selected studies (section 5), followed by a discussion of the key NbS traits and their potential improvements (section 6). Subsequently, the limitations of the research are discussed (section 7). Finally, the paper will conclude with a summary of the findings and suggestions for future research (section 8)

2 Background

Post-war city expansion began in the 1950's while the majority of construction was completed by the end of the 1960's (Mens, 2020), as the urgency for residential housing resulted in fast paced construction with limited building materials (Oerlemans & Ham, 2008). After World War II, city expansion focused on restoring the contact between people and nature (Blom et al., 2004). Therefore, neighbourhood planning was characterised by the construction of uniform building blocks surrounded by extensive public space (Blom et al., 2004). Within these greater public spaces, the General Expansion Plan of Amsterdam (Figure 1) allotted four types of nature areas: sports and playing areas; school gardens; 'natural beauty'; and parks (van Hellemondt, 2021). As a result, post-war neighbourhoods generally had a lower building density compared to traditional urban planning (Havinga et al., 2020). The Overtoomse Veld, situated in Amsterdam New-West, is one of the neighbourhoods developed as part of the General Expansion Plan of Amsterdam.

Post-war districts such as Overtoomse Veld are characterised by elevated surface temperatures and pluvial flood risk when compared to surrounding areas, as mapped in Figure 2 and 3 (Gemeente Amsterdam, 2020). These maps indicate that especially in the west of the city, urban heat and pluvial flooding risks rank from moderate to extreme (Gemeente Amsterdam, 2020). These areas have many treeless, grassy areas and impervious pavement such as asphalt covering streets, parking spaces, and schoolyards (Germanà et.al, 2022). These features result in a lack of sufficient places for cooling, which may contribute to a considerable increase in temperature (Kleerekoper et al., 2019). Additionally, post-war neighbourhoods are more likely to be situated in flood susceptible areas (van de Ven et al., 2010). Their design allows for limited water storage, infiltration, and drainage, leading to increased surface water collection during heavy rainfall (Kleerekoper et al., 2019). The reasons for relatively high possibilities for CCRR in these post-war neighbourhoods (Gemeente Amsterdam, 2020) should be further discussed. Additional research could help establish a link between the spatial methodology of post-war city planning and the increased likelihood of adverse impacts. When considering climate resiliency strategies for the city, the spatial emphasis on open public areas in districts such as Overtoomse Veld serves as potential for climate adaptation through structural modification (Germana et.al, 2022).

Figure 1, The General Expansion Plan of Amsterdam 1934, highlights residential expansion in red and increased public spaces in green (Van Eesteren, 1934).

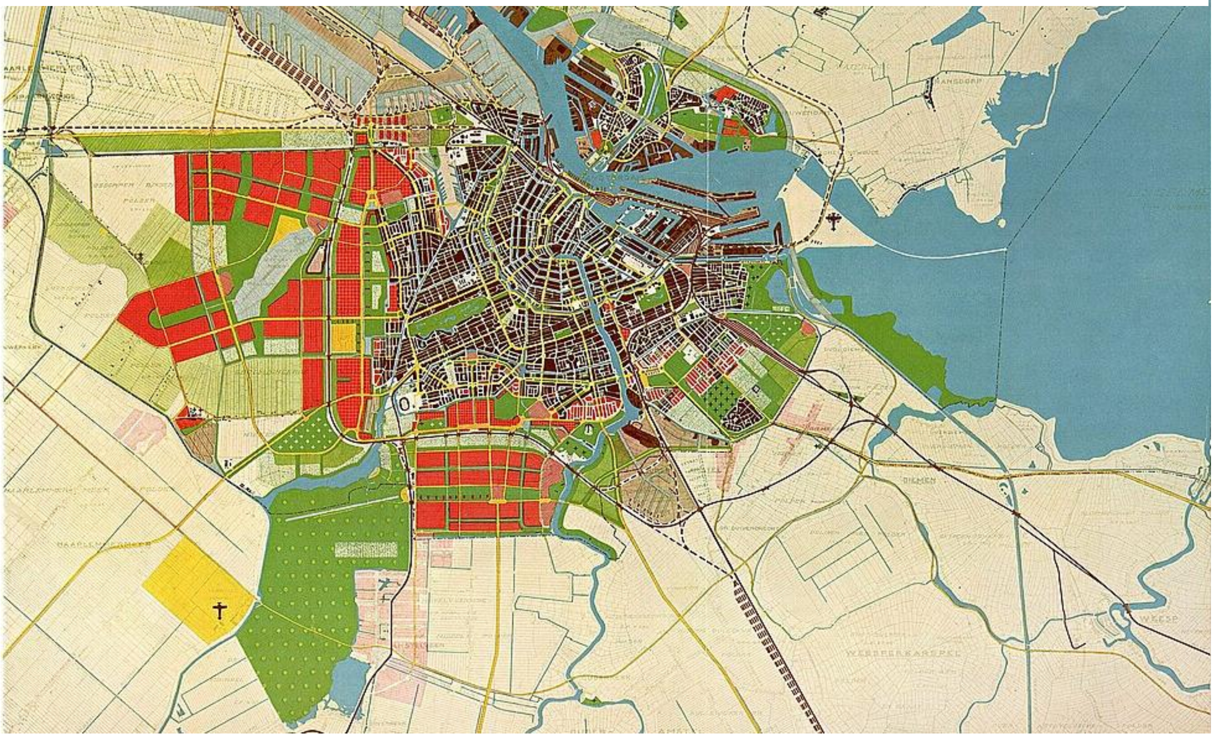


Figure 2, Map of urban heat risks for neighbourhoods in the municipality of Amsterdam, (adapted from Gemeente Amsterdam, 2020).

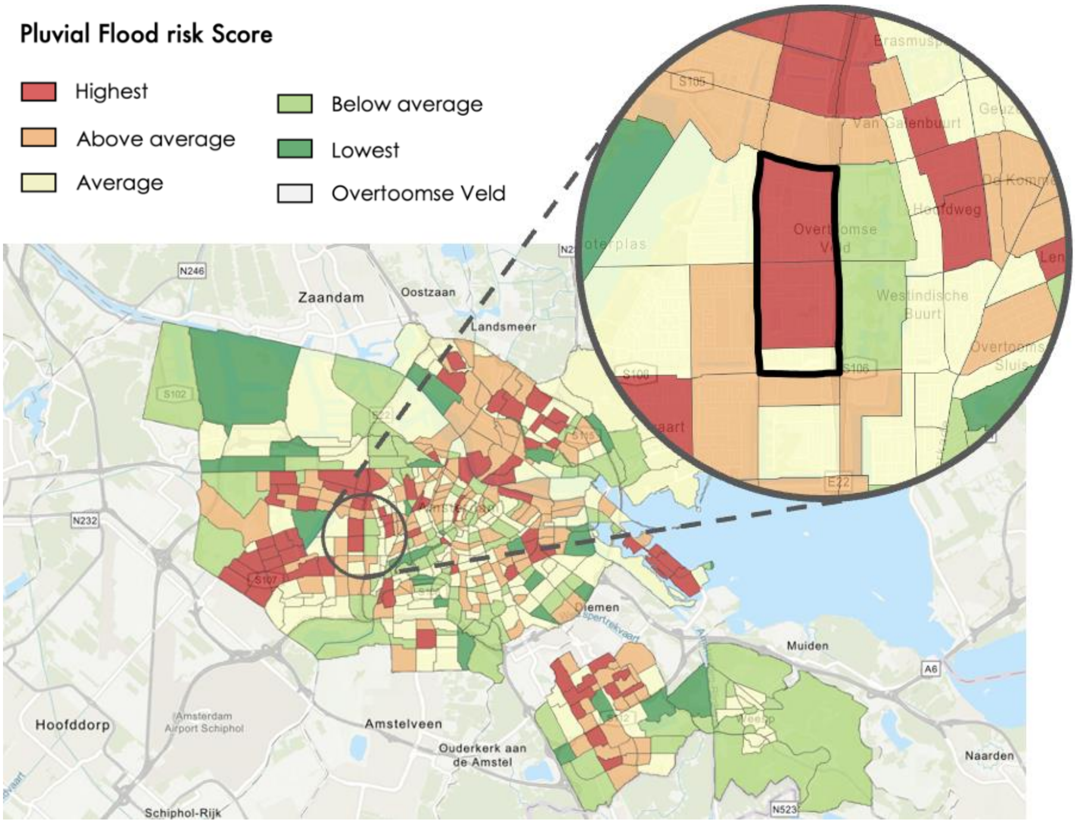
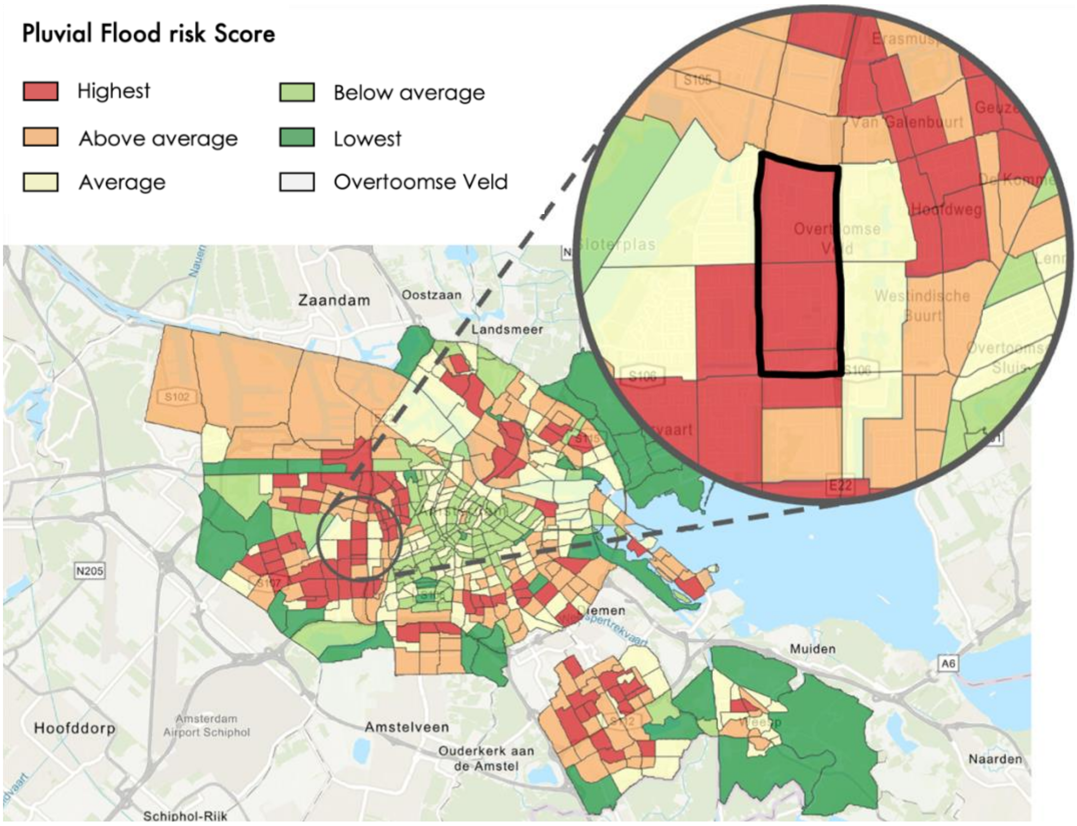


Figure 3, Map of pluvial flood risks for neighbourhoods in the municipality of Amsterdam, (adapted from Gemeente Amsterdam, 2020).



3 Theoretical Framework

This research is based on the following understanding of the main concepts: Climate Change Related Risks, Urban heat, Pluvial flooding and Nature-based Solutions.

Detailed observation of temperature and precipitation trends by several research groups have shown that the planet's average surface temperature is rising and that Climate Change Related Risks such as intense rainfall and flooding occur at higher frequencies (Council et al., 2011, Abbass et al., 2022). Climate scientists identify anthropogenic activities, human behaviour as the driving force of global warming in the 21st century (IPCC, 2014, Council et al., 2011).

Urbanisation significantly influences the local weather as a result of the extensive modification of surface and atmospheric characteristics at local scale (Oke et al., 2017). Solar energy and anthropogenic heat have been determined as the primary sources of rising surface temperatures (Memon et al., 2009). The correlation between urban areas and increasing local surface temperatures in comparison to their surrounding rural areas has been established as the Urban Heat Island effect (UHI) (Memon et al., 2009, Zeleňáková et al., 2015). UHI can be examined as the modification of the energy equilibrium in urban areas (Susca et al., 2011, Zeleňáková et al., 2015). A shift in the energy equilibrium occurs as a result of the land use changes caused by urbanisation (Nonomura et al., 2009, Zeleňáková et al., 2015), where the reduction of vegetation and increase of impervious surfaces limits the amount of evapotranspiration and latent heat flux[1]in urban areas (Chapman et al., 2017, Zeleňáková et al., 2015). Green and blue spaces allow for the release of latent heat through the process of evapotranspiration, where energy stored in the form of heat is removed as water evaporates from plants, canopies, or water bodies (Targino et al., 2018, Qiu et al., 2013). The increase of hard, abiotic surface materials in urban areas such as paved surfaces and buildings cause more solar energy to be transformed into sensible heat[2] rather than released in the form of latent heat (Hoelscher et al., 2016, Chapman et al., 2017). The increased conversion of solar energy into sensible heat (Stache et al., 2021) is caused by the low albedo (reflection) of these urban surface materials (Kleerekoper et al., 2012). The materials absorb the short-wave radiation from the sun, this produces higher surface temperatures, as they act as non-reflective covers that trap heat at the earths surface (Faragallah & Ragheb, 2022). Building materials such as black top asphalt are heat-storing surfaces used in urban areas of the Netherlands (Echevarria Icaza et al., 2017).

The increase of the earth's average surface temperature also leads to a disruption of the terrestrial water cycle, resulting in changing precipitation patterns (Guan et al., 2024). Warmer air can hold more water vapour, creating favourable conditions for intense precipitation events (Trenberth, 2011). Land use changes of urban development also affect the water balance as vegetated soils are replaced by impermeable surfaces (Wheater & Evans, 2009). An increase in total impervious area (TIA) is the main development factor that alters the hydrological cycle of a landscape (Sohn et al., 2017). The TIA of urban areas acts as a barrier by increasing surface runoff and limiting water retention and evapotranspiration (Avashia & Garg, 2020). During intense precipitation the storage capacity of water is exceeded, leading to increased runoff (Wheater & Evans, 2009). Pluvial flooding occurs when the volume of the runoff exceeds the conveyance capacity of the sewer system (Bulti & Abebe, 2020).

The concept of Nature-based Solutions is often used as an umbrella term to describe a broad range of actions aiming to protect, manage, and restore ecosystems in order to address societal changes (Fang et al., 2023). NBS address environmental challenges through planning solutions inspired by or replicated from nature that aim to increase the resistance of cities to future threats (Štrbac et al., 2023). These development activities include the modification of ecosystems through Green Infrastructure (GI), Blue Infrastructure (BI), Green-Blue Infrastructure (GBI) (Sowińska-Świerkosz & Garcia, 2022, Štrbac et al., 2023). Blue and Green Infrastructure refers to the interconnected networks of natural elements into

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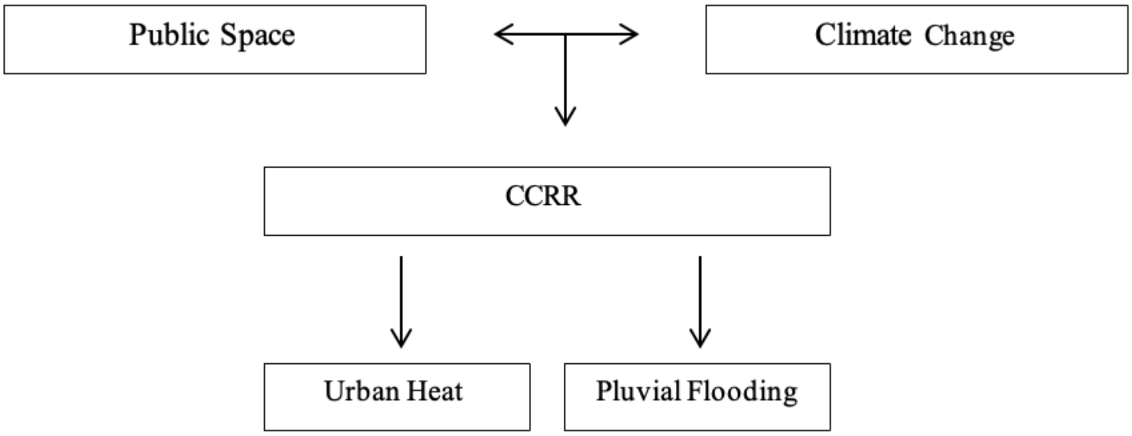
[1] Latent heat flux is the flux of heat from the Earth's surface to the atmosphere that is associated with evaporation of water.

[2] Sensible heat is the heat released or absorbed by a substance resulting in a change of temperature.

the urban environment such as green spaces and water (Pinto et al., 2023, Sowińska-Świerkosz & Garcia, 2022). Green Blue Infrastructure can be described as combination of vegetation-based (trees, grass, etc.), water-based (ponds, lakes, ditches, etc.), and engineered (buildings, green roofs) structures, that serve to mitigate the impact of climate risks on urban areas (Lamond & Everett, 2019).

The main concepts and their relation to one other are clarified in the conceptual model, providing a structured framework, used to analyse the literature constantly.

Figure 4, Conceptual model.



4 Methodology

4.1 Scientific Literature Review

In this research a quantitative secondary data analysis was performed through a systematic literature review. The consolidation of case study data measuring the implementation of Nature-based solutions for urban heat and pluvial flooding in the Netherlands aimed to recognise the possible contested or common relationships between case findings. A comparative analysis of thirteen region-specific case studies was completed to synthesise the various methodologies, theories, and quantitative data points to propose climate resiliency measures for urban areas, specifically post-war neighbourhoods in the Netherlands. The goal of this research, similar to much of the reviewed publications, was not to make cities completely disaster resistant but rather to work toward disaster resilience (Wamsler et al., 2013).

4.2 Data Collection

To account for the transparency and reproducibility of this scientific literature review, the three research criteria for article selection were: (1) each source must present a region-specific case study within the Netherlands; (2) they must be published from 2018 onwards; and (3) they must be cited fifteen or more times in other peer-reviewed academic publications. Identifying the geographic limitations of the case study research minimised data collection risks by acknowledging the local scope of the data. These source inclusion criteria ensured the efficacy of the selected literature to propose functional climate resiliency strategies for the Overtoomse Veld neighbourhood in Amsterdam.

The limited quantity of published case studies fitting these inclusion criteria represented the research gap regarding optimal NBS climate adaptation measures pertaining to urban spaces in the Netherlands. This research attempted to broaden the scope of data for urban climate resiliency on a local level, to fit the specific needs of the geographical and socioenvironmental position of the Netherlands.

The collection process utilised Scopus and Google Scholar as its main databases. During the collection process three main keywords were used to collect the sources for the literature review. The three main keywords used to collect data include: Nature-based Solutions, Urban Heat, and Pluvial Flooding. During the data collection process, field related terms were used to utilize as many relevant studies as possible. These three keywords helped pinpoint the current climate related risks and corresponding adaptation measures utilised in urban areas of the Netherlands. The keywords structured the collection of case studies that outline the effects of Nature-based Solutions on the CCRR in question.

Table 1, The three keywords and field related terms used for the data collection of this research.

Keyword	**Field related terms**
Nature-based Solutions	Green Infrastructure, Blue Green Infrastructure, Green Blue Grey Infrastructure, Ecosystem services
Urban Heat	Urban Heat Island effect, Urban Surface Temperature, Sensible Heat, Latent Heat
Pluvial Flooding	Urban Flooding, Stormwater Management, Stormwater Runoff, Surface Runoff

4.3 Data Analysis

The assessment of primary data regarding urban heat and pluvial flooding served to examine two significant CCRR in metropolitan areas of the Netherlands. As previously mentioned, the municipality of Amsterdam identifies heat, drought, pluvial flooding, and fluvial flooding as the four main risks for the city (Gemeente Amsterdam, 2020). Focusing on two of these four risks allowed for an in-depth analysis of each of the two risks and their complexities.

4.4 Ethics

All data used during this study was accessed through the affiliated subscriptions of the University of Groningen. Due to the nature of the data no privacy or confidentiality risks were identified, meaning that no specific measures were needed to account for these concerns during the research process.

5. Analysis and Results

The data collection identified 13 papers that met the inclusion criteria. The case studies' were distributed over the country, the highest number of studies were found in Amsterdam (5), followed by Eindhoven (3), Utrecht (1), The Hague (1) and three other studies performed a case study on multiple locations within the Netherlands. Eleven papers studied the effect of NbS on UHI, eight papers studied the effect of NbS on pluvial flooding, of which six papers studied the effect of NbS on both UHI and pluvial flooding.

5.1 The potential of less dense urban structures

Three of the analysed studies determined the greater potential for less dense urban structures to become more climate resilient towards CCRR such as the UHI effect and/or pluvial flooding. Visser et al. (2020) shows that there is a relationship between surface UHI development and urban density in Amsterdam. Less dense urban structures allow for the greater integration of NbS (De Knegt et al., 2024). De Knegt et al. (2024) measured significantly decreased temperatures in new urban developments designed with a nature inclusive approach. They also found the capacity for vegetative expansion to be limited in existing highly urban areas due to less available free space. Cortinovis et al., (2022) concluded that less dense cities offer more opportunities for the implementation of Nature-based Solutions, particularly for NbS that requiring space on the ground.

Two other studies established a positive correlation between the surface area of NbS and its mitigation capacities. Costa et al. (2021) found differences in NbS efficiency on pluvial flood mitigation to be heavily dependent on the surface area of the implemented NbS. The research performed by Paulin et al. (2020) found a direct relationship between the extent of vegetated cover and its ability to reduce flooding, due to an increased rainwater storage capacity.

5.2 The effect of NBS on UHI

Eleven studies discussing the possibilities of NbS to reduce the UHI effect were reviewed. Four studies tested the impact of a singular NbS implementation on the expansion UHI, while seven cases tested different combinations of NbS implementations on UHI. Most of the studies created different NbS scenarios and modelled their impact during hot days, to determine the cooling ability of the implementations compared to the current situation. Other studies performed empirical tests to establish the cooling ability of a specific implementation.

Table 2, The main characteristics and results of studies on NbS and UHI

Reference	Study area	Research aim	Methodology	Global challenge(s)	Main result
Ascenso et al. (2021)	Eindhoven	Understand the effect of NbS on temperature and air quality in an urban setting.	Modelling three NbS scenarios and analysing their impacts in comparison to the baseline scenario.	Urban heat	Increasing green areas in cities limits low albedo surface materials that promote storage of energy during the day, which is released at night in the form of longwave radiation. Urban temperatures can be reduced by limiting energy storage.
Augusto et al. (2020)	Eindhoven	Assess the short-term and medium-to long-term	Modelling the impact of NbS over three	Urban heat	The increase of NBS in the form of green/blue spaces have a local cooling effect

		impacts of NBS on urban heat fluxes.	different timespans.		on surrounding areas, as they are found to be effective in reducing the net storage heat flux and the sensible heat flux.
Busker et al. (2022)	Amsterdam	Assessing the effectiveness of blue-green roofs in reducing peak discharge by utilising a smart forecast-based action system.	Modelling hydrological model and simulating the effects of blue-green roofs.	Urban heat and pluvial flooding	Blue-green roofs perform much better than green roofs. They are found to have a greater evapotranspiration performance than green roofs and thus cool, considerably more than green roofs.
Cirkel et al. (2018)	Amsterdam	Investigating the effect of water availability on actual evaporation and the distribution of energy between the latent heat flux and the sensible heat flux for rooftops.	In field measurement of evaporation and energy fluxes for three different plots. Compared to modelled values.	Urban heat and pluvial flooding	Sedum has a higher cooling capacity than other rooftop vegetation e.g. grass/herb. Blue-green roofs have the ability to store precipitation water and passive capillary irrigation. The additional water used for irrigation significantly increases evaporation and decreases latent heat flux during hot dry periods.
Cortinovis et al. (2022)	Utrecht + (Malmo and Barcelona)	Assessing the potential benefits and co-benefits of scaling up Nature-based Solution implementation strategies.	Analysing and simulating six different Nature-based Solutions scenarios, across three different countries in Europe.	Urban heat and pluvial flooding	Less dense cities over more opportunities for implementing NbS. Increasing tree cover is preferred over additional low vegetation, as tree planting along streets or in urban parks produces a greater positive impact on heat mitigation, especially in residential areas.
De Knegt et al. (2024)	The Netherlands	Assess the impact of utilizing NbS at a national scale to address multiple environmental challenges.	Modelling a nature-inclusive scenario based on fifteen different NbS and comparing its impact on six environmental challenges to the baseline scenario.	Urban heat and pluvial flooding	The increase of vegetation cover in new urban areas, built with a nature-inclusive approach, can significantly reduce urban temperatures during heat waves.
Jacobs et al. (2020)	The Netherlands	Assessing the thermal effects of small urban water bodies on their environment.	Modelling the thermal effect of sixteen reverence situations, which are based on the analysis of existing waterbodies.	Urban heat	The local cooling effects of small water bodies can be considered negligible. However, the immediate surroundings of small water bodies can become cooler by means of shading from trees, fountains or water mists, and

					natural ventilation. Only for water bodies allowing a fetch of ~200 m or more a noticeable thermal effect can be achieved near their borders.
Klok et al. (2018)	Amsterdam	Identifying which urban spaces are experienced and measured as most comfortable during hot days in Amsterdam.	Micro-meteorological measurements and assessment of PET in combination with field surveys.	Urban heat	Shading by buildings or trees has a great cooling effect on the urban environment, without clear difference in shading by buildings or trees. The cooling effect of green urban spaces (grass and shrubs) and small water bodies in cities is likely to be small.
Paulin et al. (2020)	Amsterdam	Demonstrating the utility of the NC-Model for assessing urban ecosystem services to support urban planning.	Workshops with decision-makers and professionals to compose different GI scenarios, which were modelled and analysed.	Urban heat and pluvial flooding	Vegetation typology and vegetation density are the two factors that reduce the UHI effect. Increasing tree cover in the form of new parks, expansion of existing parks, and increased net abundance of vegetation in existing parks has the most significant urban cooling effect.
van Oorschot et al. (2021)	The Hague	Informing decision makers and urban planners on priority areas for GI development.	Modelling green infrastructure implementations and their impact on air pollution, heat stress and storm water runoff.	Urban heat and pluvial flooding	It is important to simultaneously consider urban cooling and flood reduction when planning for Green Infrastructure. Trees were found as most efficient land cover to reduce the UHI effect**,** when compared to ‘other GI’ and grasslands.
Visser et al. (2020)	Amsterdam	Assessing the interplay between urban expansion and the development of a subsurface heat island.	Subsurface temperature data collection and modelling of urban development.	Urban heat	The average road surface temperature of streets made from bricks or concrete is significantly lower than that of streets made from asphalt or asphalt with a low albedo.

Three studies tested the cooling capacity of BI in the form of urban water bodies to reduce the UHI effect. Augusto et al. (2020) found that a cooling effect was produced by NbS implementation in the form of blue spaces, emphasising the notable impact on sensible heat fluxes reduction. The size of water bodies was found to positively correlate to the magnitude of latent heat flux and subsequent evaporative cooling effect. Jacobs et al. (2020) found small water bodies to have a slight cooling potential, with a more noticeable heat reduction in the immediate surroundings. The geographical typology can enhance the cooling effect of small water bodies due to shading from trees, water mist, and natural ventilation (Jacobs et al., 2020). They also found large water bodies with a wind fetch greater than 200 meters to have a significant cooling effect. Although, they measured all water bodies to have a slight warming effect during the night. Klok et al. (2018) determined no significant cooling effect from small urban water bodies.

Nine studies examined the capacity for GI, such as vegetation change, low albedo surface reduction, increased tree coverage, and additional parks, to reduce the UHI effect. Ascenso et al. (2021) determined the reduction of low albedo surface materials (that promote energy storage), paired with the increase of green spaces in cities, to decrease the total energy stored and subsequently decrease urban heat. Visser et al. (2020) found roads constructed out of abiotic and low albedo surfaces such as asphalt to have higher ground surface temperatures than other pavement types such as bricks and light concrete. Paulin et al. (2020) determined the cooling ability of additional urban greenspaces to be dependent on two main factors: the vegetation density and vegetation typology. Augusto et al. (2020) concluded increased vegetation density to have a significant effect on increased evapotranspiration and latent heat flux. De Knegt et al. (2024) identified that an increase in vegetation density significantly reduced urban temperatures during heatwaves. Cortinovis et al. (2022) found green roofs to have a limited heat mitigation capacity.

Paulin et al. (2020) found the increase of vegetation and tree coverage through the addition of new parks and expansion of current parks areas to greatly improve urban cooling. Van Oorschot et al. (2021) measured greater tree coverage to reduce the UHI effect. Cortinovis et al. (2022) concluded both tree planting along streets and in urban parks to produce the greatest impact on heat mitigation, especially in residential areas. Klok et al. (2018) found small urban green spaces with grass and shrubs to have little cooling effect. They did, however, find a connection between shading by trees or buildings and a lower temperature in urban environments. Jacobs et al. (2020) identified the potential cooling effect of trees when shading small urban water bodies.

Three studies discussed the influence of BGI on the UHI effect. Cirkel et al. (2018) found water availability to have an effect on the distribution of net incoming energy. Adding a blue layer (capillary irrigation system and water storage) to existing green roofs strongly reduces the sensible heat flux and significantly increases latent heat flux in the form of evapotranspiration. They found that an increased availability of water delayed evapotranspiration reduction and the subsequent decrease of latent heat flux during hot and dry periods. Busker et al. (2022) found blue-green roofs to perform better than green roofs in evapotranspiration performance, due to increased water availability. Augusto et al. (2020) discovered that the combination of blue and green NbS at surface level reduces sensible heat fluxes and increases the cooling effect of surrounding areas through the implementation of daylight rivers, de-paving, and requalifying green spaces.

5.3 The effect of NbS on Pluvial Flooding

A total of eight studies analysed the capacity for NbS to reduce pluvial flooding. Three studies tested the effect of a particular NbS on pluvial flooding, while five studies tested collections of different NbS implementations. Most of the studies created different NbS scenarios and modelled their impact during extreme rainfall, to determine pluvial flood response compared to the current situation. Other studies performed empirical tests to establish the runoff reduction of a specific implementation.

Table 3, The main characteristics and results of studies on NbS and pluvial flooding.

Reference	Study area	Research aim	Methodology	Global challenge(s)	Main result
Boogaard and Lucke (2019)	The Netherlands	Determine the saturated surface infiltration rate of 16 existing permeable	Testing permeable pavement and their water infiltration capacity on	Pluvial Flooding	Permeable pavements can help reduce runoff volumes and discharge rates from paved surfaces as long as they are well maintained.

		pavement installations in the Netherlands	sixteen different locations.		Infiltration rates of permeable pavements may decrease over time due to clogging or due to the pre-saturation of the surface.
Busker et al. (2022)	Amsterdam	Assessing the effectiveness of blue-green roofs in reducing peak discharge by utilising a smart forecast-based action system.	Modelling hydrological model and simulating the effects of blue-green roofs.	Urban heat and pluvial flooding	Blue-green roofs that operate on the basis of forecasts can capture larger amounts of rainfall during extreme precipitation than original blue-green roofs and especially more than green-roofs. Large-scale implementation, can reduce drainage bottlenecks and pluvial flood risk in urban areas. An average of 13 % of the surface area of the *Overtoomse Veld* is potentially suitable for the implementation of blue-green roofs.
Cirkel et al. (2018)	Amsterdam	Investigating the effect of water availability on actual evaporation and the distribution of energy between the latent heat flux and the sensible heat flux for rooftops.	In field measurement of evaporation and energy fluxes for three different plots. Compared to modelled values.	Urban heat and pluvial flooding	Green roofs with grass/herbs vegetation have a great potential to reduce storm water runoff due to the higher evaporation. Adding a blue layer for storing precipitation and capillary irrigation results in less discharge to the sewer system. It also allows for more diverse and natural vegetation. However, under the Dutch climatic conditions, additional irrigation is needed for the survival of such a vegetation during dry spells.
Cortinovis et al. (2022)	Utrecht + (Malmo and Barcelona)	Assessing the potential benefits and co-benefits of scaling up Nature-based Solutions implementation strategies.	Analysing and simulating six different Nature-based Solutions implementation scenarios across three different countries in Europe.	Urban heat and pluvial flooding	Full-scale deployment of green roofs shows the greatest potential to reduce surface runoff, Although, street trees are more efficient than green roofs in providing runoff reduction when solely focusing on the unit-area efficiency. Planting street trees maximizes interventions in residential areas and is the best single strategy to provide multiple benefits.
Costa et al. (2021)	Eindhoven	Comparing the effectiveness of contrasting,	Modelling three Nature-based Solution scenarios	pluvial flooding	The implementation area of green car parks and green roofs has a direct relation

		stakeholder selected scenarios of NBS for flood risk mitigation in a flood prone and highly urbanized area.	and analysed for a range of different flood statistics.		with the reduction of urban flooding. For water storage on the street, the same trend is not observed. Although, the implementation of swales and bioswales increases water storage in green and residential areas. This showed to have the greatest impact on the reduction of total flood area.
De Knegt et al. (2024)	The Netherlands	Assess the impact of utilizing NbS at a national scale to address multiple environmental challenges.	Modelling a nature-inclusive scenario based on fifteen different NbS and comparing its impact on six environmental challenges to the baseline scenario.	Urban heat and pluvial flooding	Restoring streams, adding natural banks, and ditches increases water infiltration. The increase in water retention decreases flood probability in flood prone areas.
Paulin et al. (2020)	Amsterdam	Demonstrating the utility of the NC-Model for assessing urban ecosystem services to support urban planning.	Workshops with decision-makers and professionals to compose different GI scenarios, which were modelled and analysed.	Urban heat and pluvial flooding	Completing the main tree network by connecting green areas, and transforming the current vegetation to different typologies (e.g., converting different low vegetation typologies into shrub typologies) has the highest potential to limit the rainwater in the drainage system due to water storage by vegetation.
van Oorschot et al. (2021)	The Hague	Informing decision makers and urban planners on priority areas for GI development.	Modelling green infrastructure implementations and their impact on air pollution, heat stress and storm water runoff.	Urban heat and pluvial flooding	Stormwater runoff is relatively high in neighbourhoods located in or around the city centre. A positive correlation was found between tree coverage and the reduction of stormwater runoff, due to their high evaporative cooling ability.

Two studies assessed the impact of BI on pluvial flooding. Costa et al. (2021) identified the addition of natural water storage in the form of swales and bioswales to have a significant impact on the reduction of flood probability. De Knegt et al. (2024) found increasing water infiltration by restoring streams, adding natural banks, and ditches to be an effective way to decrease flood probability in flood prone areas.

Seven studies tested the impact of GI on pluvial flooding. Van Oorschot et al. (2021) found tree cover to have a significant impact on the reduction of stormwater runoff. Paulin et al. (2020) identified the positive impact of adding more trees and shrubs to complete the main tree network, enhancing water storage by vegetation, and limiting rainwater in the drainage system. Cortinovis et al. (2022) found the addition of more street trees and trees in urban parks to have a substantial effect on runoff reduction. They determined additional tree cover to have a great impact in residential areas due to their optimal unit-area efficiency, especially compared to green roofs, which require more surface area to be as effective in reducing surface runoff.

Boogaard and Lucke (2019) found permeable pavements to increase infiltration rates and subsequently reduce runoff volumes and discharge rates. During periods of frequent rainfall, infiltration rates might be reduced due to pre-saturation of the surface. Cortinovis et al. (2022) found the use of concrete-reinforced lawns for parking areas to have little benefit in terms of surface runoff reduction. Costa et al. (2021) identified a slight reduction in flood probability for the vegetated grid pavement of open car parking. Although, they found a direct correlation between the increase in permeable surface area and increase in flood reduction.

Cortinovis et al. (2022) determined green roofs to have a substantial impact on reducing surface runoff, due to their ability to be implemented on a large scale. Costa et al. (2021) also found green roofs to have a significant effect on reducing surface runoff due to their great implementation area compared to other NbS, although they mention that greening all flat roofs may be unrealistic. Cirkel et al. (2018) found green roofs vegetated with grass/herbs to have a greater potential than green roofs vegetated with sedum to reduce storm water runoff due to the higher evaporation. However, under the Dutch climatic conditions, additional irrigation is needed for the survival of such a vegetation during dry spells.

Two studies tested the impact of BGI on pluvial flooding by measuring water retention levels of blue-green roofs compared to solely green roofs without water basins. Cirkel et al. (2018) determined the additional blue layer in blue-green roofs to be an effective measure to store precipitation, reducing the overall stormwater discharge. Busker et al. (2022) found the large scale implementation of blue-green roofs to reduce drainage bottlenecks and pluvial flood risk in urban areas. Their study mentions that 13% of the surface area in *Overtoomse Veld* is potentially suitable for the implementation of blue-green roofs.

6. Discussion

The effectiveness of BI to reduce urban heat differed across case studies. The general trend indicates that BI can reduce the UHI effect, although it is up for discussion whether BI leads to significant decrease in urban surface temperature. The effectiveness of BI in urban areas is dependent on other factors, such as their surrounding geographical typology (Jacobs et al., 2020) and the wind fetch size of the water body (Augusto et al., 2020, Jacobs et al., 2020). Especially the wind fetch is found by other studies to be of great importance to increase the cooling ability of BI in urban areas (Chen et al., 2023). Additionally, the total cooling effect of BI in urban areas can be doubted as is BI found to have a cooling effect during the day but also a slight warming effect at night (Jacobs et al., 2020). The warming effect of urban BI due to the release of sensible heat during night is also established by several other studies (Athukorala & Murayama, 2021, Gunawardena et al., 2017, Moyer & Hawkins, 2017, Steeneveld et al., 2014). However, the reviewed studies that discussed the impact of BI on pluvial flooding did find a greater positive effect of BI implementation. The increased water storage and water infiltration provided by additional swales, bioswales (Costa et al., 2021), natural banks, ditches and restored streams (De Knegt et al., 2024) were found to significantly reduce pluvial flood probability. Similar findings were reported by (Sobiera et al., 2022, Tsatsou et al., 2023), emphasising the high potential for stormwater management in the form of BI to reduce pluvial flooding.

The reviewed studies that focused on the implementation of GI in urban areas generally indicated a positive correlation between additional urban greenspaces and the reduction of the UHI effect. Creating additional green spaces reduces the presence of low albedo surfaces, limiting heat absorption (Ascenso et al., 2021, Visser et al., 2020). The reduction of the UHI effect due to a decrease in low albedo surfaces has also been confirmed by other studies (Despini et al., 2021, Morini et al., 2018). Additionally, the reviewed studies that focussed on pluvial flood reduction due to GI implementation established more green spaces in the form of concrete-reinforced lawns (Cortinovis et al., 2022) and vegetated grid pavements (Costa et al., 2021) to have a small effect on flood probability. Although, the increased infiltration rates and decreasing surface runoff can be further enhanced with greater implementation of permeable surfaces (Costa et al., 2021). Similar studies confirmed that permeable pavement can be effective storm water reduction (Kayhanian et al., 2019, Li et al., 2019).

Many different vegetation typologies were discussed with in the reviewed studies but predominantly trees were found to have the highest potential to reduce urban temperatures, due to their evaporative cooling ability (Cortinovis et al., 2022, Paulin et al., 2020, van Oorschot et al., 2021) and their additional shading (Jacobs et al., 2020, Klok et al., 2018). Many other studies that focussed on urban GI implementation found the additional transpiration and shading provided by increased tree cover to also have a great potential cooling effect (Fu et al., 2022, Saaroni et al., 2018, Wang et al., 2015). The reviewed studies also established the greater evapotranspiration provided by the increased tree cover to significantly reduce stormwater runoff. The addition of more trees in urban parks (Paulin et al., 2020, Cortinovis et al., 2022) and along streets (Cortinovis et al., 2022) was also found to increase water storage by vegetation. Other studies also found the increased urban green spaces to facilitate greater water infiltration, evapotranspiration, and natural water storage, limiting pluvial flooding (Liu et al., 2014, Yao et al., 2015).

Within the reviewed studies limited research was performed on the cooling effect of green roofs. Although, a small heat mitigation capacity of green roofs was established by (Cortinovis et al., 2022). The reduction of urban heat as a result of green roof implementation are greatly recognised by other studies (Bevilacqua et al., 2017, Lynn & Lynn, 2020). Jamei et al. (2021) found green roofs to significantly reduce both urban surface and air temperatures. The reviewed studies mainly discussed the potential of green roofs to limit pluvial flooding. Green roofs were predominantly found to be the most effective GI implementation to reduce runoff (Cirkel et al., 2018, Cortinovis et al., 2022, Costa et al., 2021). Although, this result might be overestimated due to the accounted potential implementation area of green roofs (Cortinovis et al., 2022) as greening all flat roofs may not be realistic (Costa et al., 2021). Cortinovis et al. (2022) assessed the runoff reduction of green roofs to be lower than that of trees based on unit-area efficiency. Other studies found green roofs with a small implementation area to reduce runoff, although the severeness of this reduction was found to increase with greater implementation area (Versini et al., 2015). Mentens et al. (2006) recognised that green roofs can already reduce annual runoff when implemented on 10% of the roofs, even in already relatively green urbanized areas.

The reviewed studies recognised BGI implementation to have a very substantial effect on urban cooling. Combining blue and green infrastructure reduces urban heat storage and increases urban cooling through the implementation of blue-green roofs (Busker et al., 2022, Cirkel et al., 2018), daylight rivers, de-paving, and requalifying green spaces (Augusto et al., 2020). Other studies confirm the potential ability of combined blue and green infrastructure to reduce the UHI effect (Gobatti et al., 2023), although concerns are raised about the availability of implementation surface within urban areas (Žuvela-Aloise et al., 2016). The reviewed studies found blue-green roofs to significantly reduce the absorption of incoming solar energy and increase evaporative cooling (Busker et al., 2022, Cirkel et al., 2018). The successful reduction of urban heat by implementing blue-green roofs is also confirmed by similar studies (Almaaitah et al., 2022, Föllmi et al., 2023). Additionally, reviewed studies found blue-green roofs to greatly increase precipitation storage and reduce stormwater runoff. The implementation of blue-green roofs is possible for 13% of the surface area in Overtoomse Veld (Busker et al., 2022), possibly reducing the neighbourhood's drainage bottlenecks and pluvial flood risk. Other studies also discovered blue-green roofs to increase flood prevention, although the implementation resulted in a slightly less drastic change (Almaaitah et al., 2022, Pelorosso et al., 2021).

7. Limitations

The data collection and analysis on Nature-based Solutions was targeted towards two of the main CCRR in the Netherlands, UHI and pluvial flooding. The reviewed literature serves to study NbS that reduces these two risks but does not aim to address climate adaptation planning outside of these climate change concerns, such as drought or fluvial flooding.

The three research criteria for article selection: geographical scope, seven year publication window, and academic citation minimum reduced data availability, generating a limited sample size of case studies. It is important to note that data collection strategies across the therteen case studies are also not uniform, as most case study developed their own simulations independent from one another using different NbS senarios and spatial analysis tools.

The case studies also do not analyse urban policy or the potential barriers to modifying and executing new urban planning, which might hide the potential shortcomings of NbS when applied in a real-world setting.

8. Conclusion

Assessing the impact of Nature-based Solutions in the Netherlands, based on reviewing thirteen local case studies, provided valuable information regarding the possible climate resiliency of post-war neighbourhoods in the Netherlands. The systematic literature review established that the possible implementation of NbS (1) has an increased potential in post-war neighbourhoods and the implementation (2) can reduce urban heat and pluvial flood probability.

During the original design of post-war neighbourhoods an increased focus was laid on the role of public space, creating less dense neighbourhoods compared to traditional urban areas. The reviewed studies found this low building density to potentially allow for the greater implementation area of Nature-based Solutions. A positive correlation was established between the greater surface area of NbS and its ability to mitigate Climate Change Related Risks such as the Urban Heat Island effect and pluvial flooding.

A mix of different NbS is recommended to utilise local opportunities within the Overtoomse Veld, ensuring a wide range of benefits. The open spatial characteristics of the Overtoomse Veld can be enhanced by removing abiotic surface materials, reducing heat storage and surface runoff. All asphalt should be removed or replaced, if necessary, by surface materials with greater impermeability such as concrete reinforced lawns or surface materials with higher albedo such as bricks. Additionally, more room needs to be made for blue and green spaces, through the implementation of urban parks, (street) trees, daylight rivers, (bio)swales, and ditches. Especially, increasing tree cover in streets and urban parks was found to have the highest potential to reduce urban heat and pluvial flooding. Completing the tree network enhances evaporative cooling, cooling by shading, and water storage by vegetation. Additional daylight rivers, (bio)swales, and ditches significantly decrease pluvial flood probability, by further increasing stormwater storage and water infiltration. Besides the implementation of Nature-based Solutions in the open space, the implementation of blue-green and green roofs on top of existing structures should also be considered. Utilising flat roofs, when possible, maximises NbS implementation area, substantially increasing urban cooling and water storage while reducing the absorption of incoming solar energy. Combining these NbS could increase shading, evaporative cooling, natural water storage, and water infiltration, while also reducing surface runoff and heat storage. This establishes the potential of the open post-war neighbourhood structures to reduce urban heat and pluvial flood probability.

The next step would be to test this combination of NbS implementations, to evaluate their reduction of urban heat and pluvial flooding in practise. Further research is needed to unveil the local climate implementation policies, which could limit the feasibility of NBS implementation in post-war neighbourhoods of Amsterdam.

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