Quantifying Nature-based Solutions for The Hague

- A comparative analysis of spatial assessment methodologies -

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"Nature used to be thought of as something that needs to be protected outside of the city, whereas in reality, cities are one with nature" - Julie Ulrich

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Glossary

InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
NC	Natural Capital
GI	Green Infrastructure
BI	Blue Infrastructure
UHI	Urban Heat Island
ES	Ecosystem Service(s)
NbS	Nature-based Solution(s)
GIS	Geographic Information System
LULC	Land Use Land Class
AOI	Area of Interest
ha	Hectare(s)
CC	Cooling Capacity

Abstract

With a global trend towards urbanisation, the resilience of humanity against economic, social and environmental challenges increasingly shifts from rural to urban areas. Where green and blue infrastructure are expected to mitigate some of the impacts of heat waves or storm events for the urban environment, current assessment methodologies to prove so are lacking.

To illustrate the viability of urban Nature-based solutions as alternatives to existing grey infrastructure, this research first looked into assessing the benefits of 4 urban ecosystem services (ES), namely Urban Cooling, Stormwater Runoff Catchment, Carbon Storage and Coastal Protection services. With The Hague as the area of interest, the research was successful in demonstrating positive impacts towards climate resilience for each of the 4 studied ES. First, the presence of urban natural infrastructure was shown to reduce the urban heat island effect by up to 1.5 °C. Green urban areas were further revealed to catch over 50 % of stormwater runoff for major storm events as well as being responsible for the majority of urban carbon storage. Lastly, coastal forests and dunes were proven to be a contributing reason in keeping the overall coastal exposure risk towards inundation and erosion at low to moderate levels.

While the initial results of the ES analysis speak for themselves, further evaluation of the employed methodologies revealed major concerns in terms of output consistency and transparency between different tools, such as InVEST and Natural Capital. As the outputs of seemingly analogous models varied greatly and a certain obscurity towards methodological background processes persisted, the results of urban specific assessment models of current ES mapping and evaluating tools require further validation in order to be universally acceptable. The conclusion of this study can help advance the inclusion of urban nature-based solutions into urban policy and planning exercises, while simultaneously raising awareness towards the need for further development of common urban specific ES assessment methodologies.

1. Introduction

With headlines about climate change, droughts and biodiversity loss as well as the resulting environmental, economic and social pressures dominating our everyday news, it is no secret that in the coming decades, much of the world will undergo substantial environmental changes (Bulkeley, 2013). In recent years, direct and indirect negative consequences of the alteration and destruction of the natural world are directly observable, contributing to major recent natural catastrophes, such as the global Covid-19 pandemic (Cadham, 2020) or the devastating wildfires in Australia, South America and California (Jones et al., 2020). Opposed to previous decades, the consequences of recent natural disasters are increasingly felt in urban regions, as worldwide roughly 3 out of 5 major cities are at high risk of natural disasters (United Nations, 2018a). With over 55% of the global community living in cities already today, and new, global urban development projects the size of Paris being built every week over the next 40 years (United Nations, 2017a; United Nations, 2018b*)*, urban areas will be the centers of attention when it comes to directly mitigating negative climate impacts on the human population.

Cities have always been man-made creations showcasing human ingenuity and creativity concerning the emergence of an environment, able to sustain life for an elevated number of people. Over the last decades, most of such infrastructural achievements, such as wastewater systems, have mainly been of artificial nature, and can generally be classified as 'grey infrastructure' (NWRM, 2015). Although natural infrastructure, such as green urban areas or waterways have always been present in cities around the world, be it in the form of parks or canals, the role of nature in European and American cities has traditionally been a functionally limited one (Virtudes, 2016; Naturvation, 2020a). While in the past, being accredited with qualitative benefits for the sanity of citizens or giving structure to the urban fabric, green and blue urban infrastructure only recently emerged as viable urban mitigation strategies towards negative climate impacts such as global temperature rise or stormwater flooding and are more and more considered as additions or alternatives to traditional grey infrastructure (Dong et al. 2017).

Despite recent findings and a rising interest in the abilities of natural infrastructure to render cities more resilient towards future climate challenges (IUCN, 2016; Staddon et al, 2018), actual implementation into urban policy and planning agendas is still lacking (Wallace, 2007). According to Biwer (Naturvation, 2020a), reasons range from a lack of local knowledge towards the benefits of urban ecosystem services (ES) to the fear of implementing something new. Apart from the absence of actual implementation, methodologies for the quantitative impact assessment of urban nature-based solutions (NbS) remain just as rare (Kabisch et al. 2016; Wallace, 2007).

Thus, in order to strengthen the implementation of NbS within cities as well as to improve the awareness towards relevant urban ES assessment tools, this paper concentrated on two different methodologies to evaluate the benefits of four different urban ES for the city of The Hague. By the construction of 3 different scenarios, the validation and comparison of results and the highlighting of relevant differences and shortcomings, the current abilities of urban NbS and the tools to assess them have been analysed from a multitude of angels.

2. Knowledge Gap & Research Questions

This study addresses several knowledge gaps. First (1), although the advantages of assessing nature in the city for policy and planning related exercises are not unheard of, their implementation into actual agendas is still lacking. As this often comes back to a simple lack of knowledge both for the role of urban ecosystems as well as their further development into NbS, this study first looked into clarifying both topics by the creation of a theoretical framework.

Second (2), coming from the desire for an adequate assessment of urban NbS as well as a bigger variety of urban ES assessment tools, relevant characteristics of different urban models and tools have been analysed and discussed. Thereby, this paper helps to articulate a more concrete understanding of what is the current state of affairs in terms of urban NbS assessment methodologies.

Third (3), relating to the scarcity of research into evaluating the background methodology as well as usability of outputs for common urban ES mapping and valuation tools, the performance of the employed methodologies has been reflected upon.

Considering that the geographical location for this research was limited to the city of The Hague and that the current knowledge gap relates to shortcomings in the assessment of urban NbS as well as universal methodologies to assess them, the main research question reads as follows:

'What are the benefits of nature-based solutions supporting the city of The Hague into approaching current and future urban challenges and how can they be adequately assessed?'

Whereas the final sub questions are worded as:

(1) 'What are the benefits of local ecosystem services for the urban environment?'

(2) 'How can we adequately assess the benefits of urban nature-based solutions?'

(3) 'What are the uncertainties in urban ecosystem service modelling?'

3. Theoretical Framework

In this chapter, a theoretical framework regarding the key features of urban ES and NbS as mitigation strategies for urban challenges is presented. Further, 2 different quantitative assessment methodologies for the valuation of urban ES are being expanded on, concluding with a rundown of some main characteristics for the study area. As this research consists for the most part of a technical report, it is essential to first understand the intentions of the tools before bothering with the technical details of the specific models.

3.1 Nature Based Solutions & Ecosystem Services for the urban environment

Urban ecosystems are most often defined as areas where built infrastructure covers a major part of the available land surface, and where the main origin of ES come from green infrastructure (GI), or less commonly, blue infrastructure (BI), yet drawing clear boundaries between urban and rural ecosystems can often prove difficult (Nedkov et al., 2017; Gomez-Baggethun et al., 2013). According to the Millennium Ecosystem Assessment (2005), ES are the benefits that people obtain from ecosystems. While ES can generally be classified into 4 different major categories; provisioning, regulating, habitat and cultural, urban environments primarily depend on services relating to human health and security, such as leisure activities, local cooling, and runoff mitigation (Gomez-Baggethun et al, 2013). Many conclusions in previous literature come down to the fact that locally generated ES have a substantial impact on the quality-of-life in cities and should absolutely be kept in mind for any urban planning exercise, now and in the future (Bolund & Hunhammar, 1999). Gomez-Baggethun & Barton (2012) as well as Guo, Zhang & Li (2010) already stated nearly a decade ago that with densification of settlements, human populations are only ever more dependent on a healthy natural capital around them. In recent years, the awareness around urban ES has risen, especially considering many cities' area expansions, allowing for a bigger variety of different land use categories. With a greater geographical area, the quantity of possible services falling within their boundaries as well as the need for site specific provision of services to urban dwellers increases (Gaston, Avila-Jimenez & Edmondson, 2013). Not only do healthy urban ecosystems ultimately lead to higher overall urban environmental sustainability, they further boost mental and physical well-being of citizens while rendering the city more resilient against negative climate impacts (Baggethung & Barton, 2012).

As far as ES go, while they do represent the general benefits that humanity can obtain from nature, they do not necessarily stand for directly employable solutions in terms of current and future urban challenges, as these often require a policy or planning intervention first. As for introducing interventions based on ES concepts to the urban environment, NbS depict another, fairly recent development in exploring the benefits of ES. The IUCN (n.d.) defines NbS as actions to protect, sustainably manage and restore a multitude of different kinds of ecosystems, while addressing urgent societal challenges relating to climate change, food or water security and natural disasters. NbS are explicitly defined to provide prosperity for citizens and biodiversity at the same time. For urban environments, NbS, depict an approach potentially able to decrease the vulnerability to a changing environment and enhance resilience, notably in times of a looming climate crisis (Kabisch et al. 2016). Generally, NbS are seen as a step up from ES in the sense that they provide more inclusive and societal relevant co-benefits than ES alone. Raymond et al. (2017) specifically mention co-benefits such as the improvement of local area attractiveness, health, quality of life and the creation of green jobs. Urban NbS do not simply represent a further exemplification on ES, but aim to represent employable solution approaches for cities such as by proposing the employment of green roofs, urban forests, alternative stormwater management systems or urban agriculture (Rugani & Almenar, 2020). According to Nesshöver at al. (2017) a further main perk of NbS in comparison to other, similar concepts are that NbS represent a prime example for transdisciplinary research concerning the study and design of solutions based on nature, and are able to beat alternatives in terms of long term planning. Despite the benefits, it is argued that assessments and further developments of NbS in action are needed in order for them to establish themselves as a viable alternative to grey infrastructure. Kabisch et al. (2016) demonstrated with the help of workshops incorporating experts from research, municipalities and society, a multitude of scenarios in which NbS are relevant, such as in climate and health mitigation and adaptation services, but are not actively employed yet. Based on these results, they expressed the need for assessing the benefits of NbS in action, which is of particular interest for the urban environment. Raymond et al. (2017) further express their regret over the small number of frameworks that exist to assess such benefits, yet which are needed to guide the successful implementation of NbS in society. Lastly, considering NbS are a relatively recent concept and are only in the process of being framed, there is currently a strong need to deepen the general understanding of NbS by assessing and confirming the principles that NbS are grounded in (IUCN, n.d.)

3.2 Ecosystem Services applied in this study

3.2.1 Urban heat mitigation

Globally elevated temperatures are the main and foremost consequence of the current global warming trend. With the climate universally expected to rise between 1.8°C and 4 °C during this century (UCAR, 2020), heat mitigation will become a main issue for many countries around the world, with the number of cities exposed to extreme summer temperatures of 35 °C or beyond, tripling over the next 30 years and effecting over 1.6 billion people (C40 Cities, 2018). As global temperatures rise, cities suffer especially hard due to the so-called Urban Heat Island (UHI) effect. The UHI effect is the phenomenon of urban air temperatures being, sometimes significantly, higher than that of the surrounding rural areas, due to factors relating to air pollution, heat storage by building materials, low albedo, low air turbulence and less evapotranspiration due to soil sealing (Santamouris, 2001; Oke, 1987). Urban heat waves are not only unpleasant to bear and responsible for higher electricity usage due to greater air conditioning use, but are being regularly accredited for having an impact on the mortality of thousands of people in the Netherlands alone. For example, during the 2003 heat wave, 1300 people were reported to have died as a direct result of elevated air temperatures (Garssen et al. 2005).

While, in order to mitigate the UHI effect, it is possible to modify the building materials into having higher albedo or lower heat storage, or to change the overall layout of buildings into allowing more air turbulence (Bouyer et al. 2011), green and blue Infrastructure have been shown to be the most effective tools to reduce ambient air temperatures (O'Malley et al. 2015). Of both natural infrastructure types, GI is said to reap the most benefits of any single intervention type, by acting on 3 different levels. GI is being praised for providing immediate but spatially limited heat relief through shade projection, enabling evapotranspiration-based cooling on an urban canopy-layer scale and improving convection efficiency by increasing surface roughness on the urban boundary layer scale (Gunawardena et al. 2017). As a single measure, BI is less effective. While BI is contributing to an overall cooler climate during daytime hours, due to the BI-linked evapotranspiration-based cooling, the immediate effects are generally less visible and less significant than those from GI (Jacobs et al., 2020; Gunawardena et al. 2017). Furthermore, BI profits greatly from a combination with GI in its immediate vicinity, as a positive correlation has been observed in past research (Hongyu, D., 2016). Urban NbS approaches incorporating the reduction of city temperatures can involve the creation and densification of green roofs, private & public park areas or street tree coverage.

3.2.2 Urban flood mitigation

With rising temperatures, floods in rural and urban areas alike will increase, as global warming does not only affect experienced air temperature but is a driver for many other natural changes. While it is currently debated if storm frequency will actually change over the coming years, it is proven that at least storm intensity has the potential to increase significantly. With each degree of warming, the air's ability to hold water vapor goes up by 7%, resulting in more intense precipitation events than before (Center for Climate & Energy Solutions, 2014). Since the beginning of this millennia, flood related damages reached an amount of tens of billions of dollars globally, with thousands of fatalities annually (Hirabayashi et al., 2013). Over the last 100 years, precipitation in the Netherlands increased by over one fourth alone (Buishand et al., 2013). Intense precipitation events are especially challenging for urban regions, which are experiencing up to 5 times the amount of surface runoff than rural environments (Copeland, 2014). As stormwater systems are generally designed after historical climate data, extreme weather events of modern times regularly overwhelm the dated grey infrastructure solutions (Tavakol-Davani et al., 2016; Lennon et al., 2014). Not only are cities more severely hit by storm events, urban areas also provoke such events in greater numbers than surrounding rural areas, due to the previously mentioned UHI effect and a modified surface roughness, as well as elevated aerosol density created by urban air pollution (Haberlie et al, 2014; Buishand et al., 2013).

Where grey infrastructure is not able to keep up, green and blue infrastructure are capable of taking over some of the load. Stormwater runoff mitigation of GI works in several ways. For once, the canopy layer of trees is able to retain a portion of the precipitation on its leaves and barks, which will partly evaporate over time and partly be fed to the soil layer (Arbor Day Foundation, n.d.). Furthermore, GI takes up water directly from the soil, being lost to evapotranspiration as well. Lastly, depending on the circumstances, the soil surrounding GI areas is able to retain a considerable amount of precipitation, up to 90% in some cases, which is partly stored by GI and partly responsible to recharge the groundwater table (Fazio, 2010). Additionally, due to the ability of BI to act as water reservoirs, green and blue infrastructure work in tandem by reducing the overall stormwater runoff to the combined stormwater sewer systems, resulting in reduced flood risks and overall less pollution to the water bodies (Denchak, 2019). In most cases, GI alternatives are even up to 30% cheaper to construct than grey infrastructure equivalents (Kloss & Calarusse, 2006). While many urban NbS such as green roofs and urban parks have a multitude of simultaneous benefits, depending on the specific ES addressed, special care needs to be taken into designing the NbS. As such, rain gardens, situated along street and sidewalks, are specifically designed to collect rainwater runoff from adjacent grey infrastructure (EPA, 2020) , while bioswales are natural alternatives to stormwater drains by either storing or carrying rainwater runoff to a nearby sewer inlet (NRCS, 2005).

3.2.3 Carbon storage

Elevated greenhouse gas emissions (GHG) are one of the most talked about climate issues of our time. Not only are they a key driver for global temperature rise, but are, for an ever-larger part, of anthropogenic nature. As of the year 2010, human GHG emissions peaked at 49 GtCO2eq/yr, a plus of 80% since the year 1970, and have not stopped growing since (Blanco et al., 2014). Due to its sheer abundance, carbon dioxide (CO2) is the most important GHG. While other GHG are several times more potent in trapping heat than carbon dioxide, CO2 is released by many natural and anthropogenic processes, and remains up to 10x longer in the atmosphere than methane (IPCC, 2014). With over 70% of global CO2 emissions being able to be backtracked to urban environments, cities themselves are a major source of anthropogenic CO2 emissions (United Nations, 2019). While former research suggested that the geographical source of CO2 emissions does not significantly influence where and how populations are influenced by it, more recent studies suggest the existence of CO2 enriched ‘domes’ over cities, having adverse effects on health and well-being of citizens by increasing local ozone and particulate matter concentrations (Jacobson, 2010).

The ability of trees and other GI to store and sequester carbon is widely known. For the USA, the net carbon sequestration of the forest sector made up for a total of 10% of nationwide CO2 emissions in the year 2005 alone (Woodbury et al., 2007), speaking at least for the importance of intact rural natural infrastructure. While cities are the most significant factor for CO2 pollution, they are traditionally regarded as only a very small carbon sink themselves. It is for this reason that overall, little research exists in exactly how much carbon storage an urban environment can deliver. Only in the last decade, some researchers started to acknowledge that the many kinds of green in cities might have a bigger effect on CO2 storage and sequestration than previously thought (Davies et al., 2011). Considering these findings, one way to further ameliorate the carbon dioxide uptake capability of an urban environment is through enhanced urban GI. GI is directly or indirectly connected to the 4 major carbon storage pools explored in this study; *aboveground biomass*, made up of living plant mass above ground (e.g. trunks, leaves, etc.), *belowground biomass*, composed of living root systems, *soil organic matter*, made up of the organic component of soil and heavily influenced by the presence of plant life while also representing the largest terrestrial carbon pool, and finally *dead organic matter*, including dead wood as well as litter. Specific urban NbS providing carbon storage, overlap with previous interventions where woody alternatives, such as street stress or urban forests, demonstrate the most effective natural solutions for carbon storage.

This paper concentrates on CO2 storage alone, as sequestration calculations are only rational in case of scenario works spanning over a multitude of years into the future, whereas this research is concentrating on a momentary extract in time only.

3.2.4 Coastal protection

As of 2017, over 40% of the human population lived less than 100 km away from any given coast (United Nations, 2017b). While it was and still is tradition to build human settlements next to the sea, taking advantage of the proximity to shipping routes or food availability, coastal cities will have to carry a double burden when it comes to climate change. Next to issues discussed in earlier paragraphs, such as elevated air temperatures or severe precipitation induced flooding, global sea level rise will be the main contributor concerning negative climate impacts for coastal areas. It is expected that by the year 2050, 570 major coastal settlements, or 800 million people will be affected by a sea level rise of 0.5 meters (C40 Cities, 2017). In the longer run, more than 90% of all coastal areas will be negatively affected by a rising sea, such as trough destructive erosion or flooding (World Economic Forum, 2019). Rising water levels in combination with mechanics responsible for increased inland flooding have a second consequence for coastal areas, in the form of serious storm surges. Storm surges are coastal flood events that can extend over hundreds of kilometers along the coast and might be present from several hours to days (Woth et al. 2006).

There exist many different coastal protection methods. Where seawalls, bulkheads or jetties are man-made constructions and classify as grey infrastructure (Climate ADAPT, 2015), coastal forests and foremost sand dunes are generally seen as natural infrastructure and can be of partly artificial or completely natural nature (Matias et al. 2005). Both types of interventions aim to prevent upland erosion and storm surge flooding by physically blocking the advancement of water and serving as a border between areas directly affected by the sea, and inland areas. While dunes, as an addition or alternative to grey infrastructure, have been known and employed for a long time already, recent eco-engineering projects go one step further in utilizing natural processes to secure the coastlines. As an example for a coastal protection specific nature based solution, the Dutch 'Zandmotor' project, located to the west of The Hague, aims to use natural wind and water movements to spread sand along the coastline, representing an important process into securing the coast from erosion (Zandmotor, 2020). Further NbS often deal with the introduction of GI such as coastal forests, mangroves or coast-near seaweed, all able to mitigate erosion or storm wave severity (Ruckelshaus et al., 2016; Silva et al., 2017). For urban areas, hybrid solutions, unifying natural and built infrastructures, often have the most benefits for coastal communities (Sutton-Grier et al., 2015).

3.3 Quantitative assessment methodologies

3.3.1 Importance of urban quantitative assessment methodologies

At the basis for the need for adequate knowledge about nature's contribution to the urban environment stands the triple bottom line, aiming to shed equal light on the financial, ecological and social dimensions of projects. In the case of urban development strategies following a triple bottom line approach, the inclusion of NbS strategies enables stakeholders to consider a wider variety of possible approaches, adjustable to the locally given needs and resources (Taylor & Fletcher, 2006). As such, overcoming urban challenges can only be done via incorporating solutions both in planning and policy agendas. Ruth and Baklanov (2012) mention in their research about urban climate science that planning, policies and investments are foremost responsible for shaping designs of urban spaces, structures and neighborhoods, thus defining how land inside of the city is used and taken care of. Kabisch et al. (2016) demonstrated not only a strong need for science and policy plans to incorporate NbS, but further discussed key characteristics for such agendas, such as the need for stronger evidence on the effectiveness of NbS in climate change adaptation and mitigation or the need for governmental implementation of NbS by forming integrated networks of society and practitioners. Wallace (2007) states that ecosystem values are often not well accounted for in decisions concerning the transformation of natural resources and that in this context, the general idea of NbS offers an important opportunity to settle for a methodology underpinning the most efficient use of biodiversity, GI and other natural resources. Although the research is already over a decade old and advancements have been made into developing fitting tools and frameworks, the ideas still stand as of today. Gomez-Baggethun et al. (2013) express the need for NbS to be further researched on a case study basis and need to be included into policy agendas, coming back to the diverse and often exclusive values that urban ES have to offer. According to Ulrich (Naturvation, 2020a), the current landscape of urban and non-urban ES assessment tools is an uneven playing field, as the valuation of benefits of natural infrastructure in cities is lagging behind, often neglecting nature driven solutions when it comes to decision making processes.

Besides these testimonies and the constant need for circumstance specific NbS assessment tools, there is furthermore a demand for tools and frameworks that are usable by different kinds of users, that facilitate assessment of possible benefits and that lead to overall greater utilization of NbS in the decision-making processes (Nemec & Hearne, 2013; Kabisch et al., 2016; Daily et al., 2009). ES and NbS assessment frameworks, such as developed by Raymond et al. (2017) or commonly referenced ES assessment services such as IPBES (IPBES, 2020) do exist, yet often suffer from a lack of deployment when it comes to urban environments. This lack of use is often attributed to the different requirements cities pose to ES and the non-existence or limited amount of urban ES, addressable within the tools. As such, anticipation is high for current and future ES and NbS assessment methodologies to be specifically tailored to urban environments and bridge the gap between urban grey and green/blue infrastructure approaches, giving nature in cities the attention it requires in order to be relevant in future policy and planning activities.

3.3.2 Urban Ecosystem Service Assessment tools in this study

Although a multitude of ES assessment tools exist, many of them lack general accessibility and usability for urban centric purposes. A review of 17 ES assessment tools by Bagstad et al. (2013) found many of today's tools to be lacking in one or more regards, as well as no single tool to be extensive enough to potentially guide a complete ES assessment process, from a first screening over to modelling finishing with a proper final valuation. While the research does not specifically look into the urban applicability, it does mention urban growth scenario modelling being supported by at least the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) tool. For the purpose of this research, the landscape scale modelling and mapping step in an ES assessment process is the most compelling single phase and harbors the widest variety of uses for different stakeholders, be it for policy makers rating alternative solutions to economic, social or ecological issues or the private sector seeking guidance in extrapolating sustainability motivated actions.

Based on the conclusion by Bagstad et al. (2013) as well the employment of InVEST in multiple international spatial urban ES assessment studies (Veerkamp et al., 2020; Bosch et al., 2020), the primary ES assessment tool employed in this study is InVEST. The InVEST tool is a compilation of different open-source software models used for mapping and valuing different ES. After the Natural Capital Project (2020a), the multi-service, interchangeable structure of InVEST delivers an effective tool for a multitude of stakeholders by harmonizing environmental and economic intentions. The modelling and mapping focus of InVEST allows decision makers to compare and assess quantified trade-offs along with alternative management scenarios so that it starts from a common point of knowledge. InVEST models are spatially-explicit, by using maps and associated information as input sources and producing maps as outputs. Results are in either biophysical or economic terms. While InVEST possesses a complete user interface, not requiring any special skill set, results need to be viewed in a mapping software, such as ArcGIS (2020a), requiring at least intermediate skills in the Geographic Information System (GIS) software. In terms of urban applicability, InVEST currently enables the application of 2 urban explicit models, namely the *Urban Cooling model* and the *Urban Flood Risk Mitigation model,* as well as the application of 2 models applicable, but not limited to the urban environment, which are the *Carbon Storage model* as well as the *Coastal Vulnerability model* (R. Remme, personal communication, 2020).

In order to isolate and highlight possible shortcomings of InVEST, as well as show the need for more case studies to employ multiple assessment methodologies for the same area of interest (AOI) (Bagstad et al., 2013; Daily et al., 2009), this research applied a second urban spatial assessment tool. Based on the geographic position of The Hague as and the limited amount of assessment tools specifically for the urban environment, the choice fell on the Natural Capital model. After Paulin et al. (2020), the Natural Capital (NC) tool is a collection of spatially explicit models, meant for the mapping and quantification of ES in the Netherlands. The NC models aim to back the integration of ES into Dutch policy and planning exercises as well as urge the benefits of ES as a possible solution for meeting national and international environmental policy targets. Benefits of the NC model approach are its contribution to the quantification of ES in the Netherlands, the explicit consideration of thematic and spatial details and heterogeneity at the regional and local levels. Building on pre-existing process-based modelling approaches, the NC model combines the use of customizable, publicly available input data with scale-dependent connections between ecological, social and economic influences, determining the origin and consumption of ES. In order to successfully employ the tool, basic programming skills as well as intermediate skills in GIS software are a prerequisite. Specifically, for the urban environment, the NC tool possesses a subset of urban ES models, of which 2, the *Urban Cooling model* as well as the *Urban Water Storage model* find use in this study.

The use of multiple tools in this research is supported by a scenario-based modelling exercise, proven to fit well into GIS and environmental modelling centric endeavors. Not only does a scenario-based spatial model exercise allow for simple modifications based on land cover classes, the modularity of scenario structuring enables the application towards a wide variety of areas and applications (Kahyaoğlu-Koračin et al., 2009).

3.4 The Hague as a case study

With 545.000 inhabitants, The Hague (or 's-Gravenhage) is the 3rd biggest city in the Netherlands, as well as the capital of the province of South Holland. The total area of the city extends over 98 km^2, of which 11km are bordering with the North Sea at the westerns coast of the Netherlands (Den Haag, 2020). The city area itself is made up of a diverse landscape, ranging from Natura 2000 protected dune areas near the coast or major biodiversity relevant park and wood areas, such as ‘Haagse Bos’, to a relatively dense and grey infrastructure dominated city core area (Geo Informatie Portaal, 2020).

With regards to climate-related issues focused on by this research, The Hague poses an interesting case study for a multitude of reasons. For once, the presence of very diversified neighborhoods and the heterogeneity of different Land Use Land Classes (LULC) when it comes to culture, structure and nature represents a challenging environment in terms of quantification and modelling of ES. Thus, The Hague as the AOI promises to showcase the ability of a single model to adequately depict the different conditions each neighborhood faces and illustrates an important factor when it comes to local and national policy and planning issues. Further, the geographical location of the city, ranging from sea areas, nature reserves, woods, parks and canals to densely constructed residential and port areas, enables a multitude of different ES to be analysed. Although no additional NbS have been modelled as part of this research, existing NbS inside of the AOI, such as in the forms of parks or canals, serve as an indication for the general benefits that urban NbS pose.

Lastly, an urban ES assessment study for The Hague makes an interesting addition to past research done for the Netherlands and The Hague itself. Studies about perceived ES by Buchel & Frantzeskaki (2014) and about the dynamics of urban ecosystem governance by Frantzeskaki & Tilie (2014), both done for the city of Rotterdam (Netherlands), together with the contents of this study, pose an interesting basis for future research relating to Dutch ES assessment and governance decisions. Additionally, 8 years back, the municipality of The Hague released a climate action report (Den Haag, 2012) addressing many of the climate change related issues discussed so far. Not only are the UHI, urban flooding, coastal storm surges and air pollution main points of concern, but the municipality further divides the AOI into dense urban core regions, less dense suburban and coastal areas, reflecting a subdivision of the AOI, ultimately enhancing priority area localisation. Possible mitigation strategies reviewed in the report already embraced the use of NbS, such as greenification of public and private spaces as well as the re-naturalization of sealed areas.

4. Methodology

The research approach used in this study consisted foremost of case specific, quantitative analysis for different urban ES, preceded by a literature review on the content and importance of such an analysis as well as it’s contribution to the effective employment of NbS. Furthermore, the methodologies of the tools as well as their results were quantitatively and qualitatively compared to each other as well as to previous research. Additionally, throughout the research, limited feedback from relevant experts was referenced to. Due to the nature of this study, much of the research resembles a technical report and needs to be kept in mind as such. While many variables of the following methodologies are user definable, the very definition of a ‘tool’ means that the core concepts of each model are pre-defined, and cannot nor should be changed. For each model, a methodological explanation of the modelling process as well as connected spatial analysis procedures are elaborated on. As far as possible, scientific reasonings and sources for key methodological mechanisms per model are touched upon. Additionally, the methodology behind the relevant data acquisition and processing is illustrated in the beginning of this chapter, while an elaboration on how the different scenarios came to be is revealed in the final sub-chapter of this part.

4.1 Data

All spatial data manipulation in this study has been done with the ArcGis desktop application (v. 10.6.1). A coherent GIS workflow chart for each specific methodology presented in this chapter can be found in Appendix 9.8. In order to successfully run any spatial data analysis or modelling exercise, a lot of input data is required. While some of the same data is needed for a multitude of models, such as LULC information or building footprints data, many inputs are only required for one specific use case alone, linking to the distinct purpose of that model, such as soil runoff coefficients or coastal seaweed occurrences. Quantitative data used for this study came from many different sources, where the very most part of spatial data is available by open source access either from national or international data repositories. Further data came from peer reviewed research papers and could either be employed directly or after a transformation, which included a unit or spatial orientation change or translation from numerical information to a spatial data layer.

When it comes to spatial data analysing and modelling, the chosen spatial resolution plays an important role in the final accuracy of the analysis and output data. According to Grilo et al. (2020), spatial resolution is an important factor, especially when it comes to the assessment of benefits for green and blue urban spaces. High spatial resolution data is especially important in very heterogeneous urban environments, as it can address a multitude of issues coming from different stakeholders in an often small area. While high spatial resolution does have benefits, major drawbacks include the limited availability of high resolution data and the extended processing time for modelling exercises. As the output maps of both modelling tools in this study are given in Raster files, the spatial output maps were set to a resolution of 10 m x 10 m. Individual 10 x 10 m cells contain enough information for small scale green, blue and grey infrastructure to be visible, without holding back processing times too much.

Both tools define the output map resolution as the resolution of the LULC input file. While the NC tool expects every input map to be in a raster format as well as to be the same resolution, InVEST expects a mix of shape and raster files as inputs, where raster files are allowed to be of a different resolution than the LULC file. It is indispensable for the proper functioning of the NC tool that all input maps are, next to the same resolution, also the exact same spatial extent, size and coordinate system. Map files provided in different resolutions, sizes or coordinate systems were transformed with suitable Arcmap tools (e.g. resampling, project). The spatial orientation of all spatial data files is set to RD_New. As many international data sources come in either ETRS1989 or WGS_1984, based on the best fit of features against aerial imagery (ESRI, 2020), the transformation 'Amersfort to ETRS NTv2', respectively 'Amersfort to WGS_1984_NTv2' was chosen. The AOI for each model and tool was set to The Hague (CBS, 2019b) and served as the clip feature that every map was clipped to, unless indicated otherwise in the model description (e.g. InVEST coastal vulnerability model).

As far as possible, spatial as well as non-spatial data needed by both tools (e.g. LULC coverage, rainfall, ...) originated from the same source. Again, for exceptions, please refer to the specific model descriptions. In order to deliver an overview of the total spatial and non-spatial input data needed to run all relevant models, as well as where to acquire them, a table has been forged containing the names of all spatial data files, resolutions as well as associated sources (Appendix 9.1). The units of final outputs for both tools were chosen to be equivalent (e.g. Air temperature in °C as opposed to cooling capacity (CC) for urban heat mitigation models). In a further step, output data has been averaged to the different neighborhoods of The Hague (CBS, 2019b). By presenting final data outputs averaged to neighborhoods, planning and policy makers will have an easier time identifying priority areas by intersecting areas of interest based on different priorities and values, ultimately helping in addressing the demand vs supply gap, a contributing reason for why ES mapping in policy making is still lacking (Wolff, et al. 2015; Baro et al. 2016).

4.2 InVEST Modelling

The InVEST version employed in this study is v.3.8.4, while the most current version as of writing is v.3.8.9. The software can directly be downloaded for free on the Natural Capital website (Natural Capital Project, 2020a). All InVEST related documentation consulted for the purpose of this research was either taken out of the accompanying user guide (Natural Capital Project, 2020b), from past research (Veerkamp et al., 2020; Bosch et al., 2020), or from personal communication with InVEST affiliated staff members (R. Remme, D. Fischer & D. Denu, personal communication, 2020). Data values for InVEST that were not explicitly consisting of their own spatial data input files (e.g. evapotranspiration, coastal forest, geomorphology, …) were provided either in the model interface itself (e.g. cooling distance of parks, fetch distances, …), or as part of lookup tables, assigning certain values (e.g. shade, crop coefficient, exposure ranking, …) to specific spatial data classes, such as LULC classes.

4.2.1 Urban Cooling

The InVEST urban cooling model is designed to estimate heat mitigation by occurrence of vegetation. The model takes into account the provision of shade, increased air cooling by evapotranspiration and albedo, as well as the distance to major green areas, such as urban parks. Additionally, the model acknowledges the reduced energy consumption resulting from the outdoor cooling effects and the subsequent reduced need for air conditioning. First of all, a LULC file covering the whole AOI has to be provided. As many further data values are directly linked to a specific LULC, it is of utmost importance to be confident in the content and accuracy of the provided file. For this research, the LULC file was taken from Copernicus (2020), and dates to the year 2018.

In the beginning, the *CC* index for each pixel is calculated, where the combination of shade, evapotranspiration (*ET*) and albedo for each pixel results in a final *CC* score between 0 and 1. Based on results of Phelan et al. (2015), shade has the highest impact on cooling, therefor default weights are set to 0.6, 0.2 and 0.2 respectively and is written as follows:

$$CC = 0.6 \cdot shade + 0.2 \cdot albedo + 0.2 \cdot ET$$

Although city specific weighting based on local conditions is usually recommended in case studies like this (Bosch et al., 2020), for the sake of comparability between tools, the values were fixed to default values for this research.

Shade is equal to the total percentage of tree coverage for each LULC class, determined through global tree cover density data (Copernicus, 2018). By the application of Zonal Statistics (ArcGIS, 2020b), the content of 2 different datasets, the LULC class data and their respective tree coverage values, were spatially compared to each other. Resulting values in percentages (%) were then translated to a score between 0 and 1, and assigned to each LULC individually (Appendix 9.2). InVEST only takes into account trees of 2 meters or more, thus excluding the possibility of integrating shrub or grass coverage. As greenery coverage depends on the scenario, values in Appendix 9.2 are only valid for the base scenario. For the ‘how to’ creation of alternative scenario values, please consult chapter 4.4.

Similarly, Albedo was equally determined and written as a value between 0 and 1, depending on the average reflectivity of the associated LULC. Values were taken from Stewart and Oke (2012), where LULC, such as road and associated land, are given a higher albedo value the more reflective the surface type of the LULC is (such as pavement) (Appendix 9.2).

The evapotranspiration index is composed of a normalized value of potential evapotranspiration, provided by a spatial data file (Trabucco & Zomer, 2019) with a resolution of 570 x 570 m, where in turn, the potential evapotranspiration (*ET*) value (ET_0) for each pixel is multiplied by the crop coefficient value (*Kc*) of the pixel's LULC, defined in the Biophysical table, and divided through the maximum evapotranspiration value (ET_{max}) for the AOI. The ET is calculated as follows:

$$ET = \frac{Kc \cdot ET_0}{ET_{max}}$$

Considering evapotranspiration is highly influenced by irrigation, all vegetated areas in this study are assumed to be sufficiently irrigated.

Crop coefficient values were taken from multiple studies (Doorenbos et al., 1992, Allan et al. 1998, Bosch et al. 2020) and are translated into an urban context by matching it to LULC and choosing values representative of the period of interest (Appendix 9.2). Again, values in Appendix 9.2 are only valid for the current scenario, as *KC* values change with the absence of greenery.

Additionally, the InVEST urban cooling model is able to take the building intensity of an urban area into account, playing a crucial role in heat storage and elevated night time temperatures in cities (Gunawardena et al. 2017). Based on the nationwide building footprint database BAG3D (Tu Delft, 2020a), each LULC receives a building intensity value between 0 (no coverage) and 1 (full coverage), representing the total percentage of each LULC taken up by building structures (Appendix 9.2). This is done by spatially intersecting the BAG3D data file with the LULC data file and calculating the total area coverage of buildings per LULC. Thus, according to InVEST, CC is calculated as:

$$CC = 1 - \text{building intensity}$$

In order to account for the enhanced cooling effect of large green spaces, set to a size of 2 hectares (ha) or above (Zardo et al., 2017 and McDonald et al. 2016), a special heat mitigation (*HM*) index is calculated for major green urban areas. In order to possibly account for these, the model searches first for the amount of green spaces available around each pixel (*GAi*). For pixels unaffected by large green spaces, the *HM* is equal to the *CC*. For pixels that do fall into an area with large green spaces, a distance-weighted average of the *CC* and *HM* is calculated. In the biophysical table, LULC for which such a calculation is carried out are marked by either a 1 or a 0 depending on whether they are defined as a green space or not (Appendix 9.2).

$$HM_i = \begin{cases} CC_i \text{ if } CC_i \geq CC_{parki} \text{ or } GA_i < 2ha \\ CC_{parki} \quad \text{otherwise} \end{cases}$$

Based on Aram et al. (2019), the distance within a cooling effect of large parks can be expected, was set to 350 m and calculated for each grid cell individually. Thus, *GAi* is defined as follows:

$$GA_i = cell_{area} \cdot \sum_{j \in d \text{ radius from } i} g(j)$$

Cell area is the area of the grid cell in terms of ha, where *g(j)* is 1 if grid cell j is green space, otherwise it defaults to 0. LULC defined as green spaces are green urban areas and forests, and are categorised as such in the biophysical table. Green grid cells do not have to be directly connected in order for them to count as large green areas, but are added together within the defined radius resulting out of the estimated cooling distance of large parks.

The CC of larger green areas on the surrounding areas is finally assessed by estimating the overall number of green grid cells within the cooling distance (d_{cool}) and correcting the CC of grid cells that have above 2 ha of green space surrounding them.

$$CC_{park,\, i} = \sum_{j \in radius\ from\ i} g(j) \cdot CC_j \cdot exp\left(-\frac{d(i,j)}{d_{cool}}\right)$$

Lastly, urban air temperature based on the heat mitigation effect index as well as the UHI effect are estimated. For the case of The Hague, the average air temperature from 4 rural weather stations was compared to the average air temperature of 5 urban weather stations (Appendix 9.2) for the 27/08/2019, where the resulting difference is the observable UHI. The 27/08/2019 was chosen on purpose, as it represents one of the hottest days of 2019 as well as the hottest day of a week-long heat wave, creating a best-case scenario in terms of severity for analysing heat mitigation efficiency of natural infrastructure.

$$T_{air\_nomix} = T_{ref} + (1 - HM) \cdot UHI_{max}$$

T_{air_nomix} represents the resulting air temperature before any air mixing takes place, T_{ref} the urban reference temperature, *HM* the heat mitigation index, set between 0 and 1 and UHI_{max} the maximum UHI effect. Due to air mixing, these temperatures are spatially averaged. Actual (mixed) air temperature, T_{air}, is derived from T_{air_nomix} by employing a Gaussian function with a kernel radius *r*, representing the maximum distance for air mixing to occur. For this study, this distance was set to 500 m, based on findings from Schatz & Kucharik (2014). Additionally, final average air temperature and temperature anomaly are estimated for the entire AOI, based on averages per cell.

In addition to the actual air temperature values in °C, the value of the heat mitigation service can further be measured by calculating energy savings from the reduced electricity consumption of air conditioning. This can be seen as a co-benefits analysis. Although the Netherlands only has a relatively minor distribution of active cooling systems, around 5 % or less according to the IEA (2018), the overall energy need per city might still be of interest. The model uses a relationship between energy consumption and temperature (Santamouris & Cartalis et al., 2015) to calculate energy savings for each building type (b). Alternatively, this value will be multiplied with the cost per kWh.

$$Energy\ savings\ (b) = c(b) \cdot (T_{ref} + UHI_{max} - \overline{T_{air,\, i}})$$

$$Cost\ savings\ (b) = cost(b) \cdot (T_{ref} + UHI_{max} - \overline{T_{air,\, i}}) \cdot cost\ (b)$$

C(b) is the local estimate of energy consumption increase per each degree of temperature (kWh/*C) and need to be provided in kWh/deg_C/m^2, where ($T_{ref} + UHI\_max$) is the maximum temperature for the city over the period of interest and T_{max} - ($T_{air,i}$ *°C)*, is the average difference in air temperature created by building type b referencing the air temperature obtained in the previous step. The value m_2 is the polygon footprint of that specific building type. For the Netherlands, the increased energy usage per °C is estimated to be around 0.5% (Santamouris, & Cartalis, 2015), coming from the relatively small AC relevance in the Netherlands. Energy usage for non-residential as well as for residential buildings were provided by CBS (2019a) and CBS (2020) respectively.

If costs are provided for each building category, the equation is altered, where *cost (b)* is the estimate of energy cost per kWh for building category b. Energy prices were provided by the European Commission (2019). Building types are for the most part defined in the BAG3D dataset and were divided into 2 categories. All building types relating to households, such as 'apartment' or 'house' were attributed to residential buildings, while all further types, such as 'office' or 'industry' were defined as non-residential. For missing building types, which was the case for around 34% of the dataset, the LULC category on which the building in question is located got adopted as the building type. The LULC categories were also divided into 'residential' or 'non-residential' types, based on whether the LULC description classified them as residential area (e.g. Urban fabric) or a commercial/industrial area (e.g. Industry). In order to test the precision of this methodology, known building types in the BAG3D file were compared to 'would be' building types based on the LULC cover, where the explicit BAG3D building types were found to be less than 4 % different than if simply LULC functions would have been adopted as the building type, ultimately proving the adequate precision of this approach (Appendix 9.7).

Lastly, within InVEST, the calculation of work productivity loss, based on the Wet Bulb Globe Temperature (WBGT), is possible. Based on temperature cut off values and the type of work and productivity loss in relation to ambient heat, higher temperatures can scientifically be linked to less worker productivity. However, as based on the high temperatures and high humidity of over 70% for the 27/08/2019 (Wunderground, 2020), the calculated WBGT for the current scenario on this specific day is already higher than the minimum cut-off value for maximum unproductivity, and it is furthermore unclear on how to introduce the occurrence of climate controlled office buildings into this calculation, it was decided to leave the productivity loss calculation out of this study and to not further explore this sub-model.

4.2.2 Urban Flood Risk Mitigation

The InVEST Urban Flood Risk Mitigation model aims to investigate the role of natural infrastructure into mitigating the negative impacts of riverine, coastal and stormwater flooding. The main mitigation processes analysed were reduction in runoff production, slowing of surface flows, as well as the creation of space for water. As an additional measure, potential economic damage was estimated. After, once again, having provided a LULC file (Copernicus, 2020), the watershed vector was determined. A watershed (or drainage basin) is a single area in which all streams, rivers and reservoirs flow into one single waterbody or outflow. For the urban environment, the watershed can be substituted with the sewershed area. Although more than 1 sewage treatment plant and stormwater overflow exist for the combined stormwater/sewage system of The Hague, omitting stormwater into multiple different water bodies, for the sake of simplicity of this study it was assumed that all city wide stormwater sooner or later ends up in the same water body. According to the Geo Informatie Portaal (2020), the sewage system of The Hague covers the entire municipal area, based on the simplified common drainage basin hypothesis assumed, it was decided that the spatial municipal border file (CBS, 2019b) is able to serve as an adequate sewershed area for this model.

The main formula of this model consists of the runoff (Q) equation, which is characterised by land use type and soil characteristics and is calculated via the Curve Number method. The runoff equation writes as follows:

$$Q_{p,i} = \begin{cases} \frac{(P-\lambda S_{max,\,i})^2}{P+(1-\lambda)S_{max,\,i}} & if \;\; P > \lambda \cdot S_{max,i} \\ 0 & otherwise \end{cases}$$

P is the design storm depth in mm. In order to arrive at a design storm depth, the amount of precipitation needs to be multiplied with the stormwater time of concentration.

The design storm for this study is based on the Den Haag Klimaatatlas (Den Haag, n.d.) and is assumed to release 70 mm of precipitation per hour. Although such amounts of precipitation are extreme and not very common, they could be much more frequent in a climate change influenced future (Westra et al., 2014). In order to arrive at a stormwater time of concentration, one has to chose a specific methodology. For this study, FAA's Time of Concentration (T_c) is used.

$$T_c=1.8\left((1.1 - C)\frac{{L_c}^{0.5}}{{S_c}^{0.33}}\right)$$

C represents the rational runoff coefficient. Based on the LULC map, the overwhelming part of The Hague is made up of residential areas. Based on Imnoeng (2014), the mean rational runoff coefficient for a residential area is 0.52, which has been adopted in this study.

Lc represents the longest flow path. In order to determine the longest flow path, first of all, the watershed area has to be known, for which we decided for the municipal area of The Hague. Next, the flow path itself needed to be defined. In this instance, the longest flow path was assumed to be the longest path water can flow from entering the AOI (as precipitation) to the arrival to the final waterbody, represented by a stormwater overflow exit indicated on the sewage system map (Geo Informatie Portaal, 2020). This was decided for, as in the case of a major storm event of 70 mm rainfall/hr, the sewage system would most certainly be overloaded. For the calculation of the longest above ground water flow, it is advisable to make use of the Hydrology Toolset within ArcGIS (ArcGIS, 2020b). First of all, flow direction for each cell needed to be determined. This can either be done with the Hydrology Flow direction tool, or with the RouteDEM tool, which is provided in the InVEST download package. As an input, these tools need a digital elevation map, such as AHN3 (PDOK, 2020b). Further, a routing algorithm needs to be decided for. In this case, the D8 algorithm was chosen due to its simplifying methodology of creating only 1 single major flow path (Seibert & McGlynn, 2007). The resulting output map then was fed to the Hydrology flow length tool, at last calculating flow paths for the analysed watershed. Based on the combination of this map together with the sewage system map, it was possible to determine the longest flow path for the city of The Hague, from precipitation to exiting through an overflow discharge point, resulting in a rounded length of 2000m.

Sc stands for the flow path slope. This is the average slope for the watershed. By running the output of the Arcmap slope calculation trough Zonal Statistics (ArcGIS, 2020b) for the municipal area, an average slope for the AOI was calculated. The slope tool needs to be provided with a digital elevation map (PDOK, 2020b) and be told to use percentage rise as the metric of interest. In order to progress, resulting 'no data' areas, such as the footprint of buildings, which are left blank in the AHN3 file, needed to be changed to 0 by the Reclassify tool (ArcGIS, 2020b). Finally, the resulting map could be once again analysed by Zonal Statistics, producing, in a first instance, an average slope for The Hague of 4%. As an average of 4 % is relatively steep for a Dutch urban area, the map was possibly corrupted by the inclusion of dunes in the AOI boundaries. It was then decided to leave out the dune area in the slope calculation, as the runoff coefficient is specifically set to urban areas only. This finally resulted in a mean slope of 2 % for the urban area of The Hague.

The time of concentration thus resulted in 53.5 minutes for the design storm event for The Hague. Multiplying the *Tc* with the amount of precipitation of 70 mm finally resulted in a design storm depth of 62.3 mm per hour.

Next, $S_{max,i}$ is the potential retention in mm where $\lambda \cdot S_{max}$ is the minimum rainfall depth in order to initiate runoff. For simplification, λ equals 0.2. S_{max} is a function of the curve number (*CN*) which depends both on the LULC as well as the type of soil.

$$S_{max,\,i} = \frac{25400}{CN_i} - 254$$

In order for the model to overlay the LULC map with a soil type map and attribute a specific *CN* number to each pixel, runoff numbers for each LULC type as well as a soil type map for The Hague needed to be provided. Based on an extensive Dutch soil type map (Tu Delft, 2020b), a simplified soil type map could be forged, only containing hydrologic soil type groups A, B, C and D. Based on the definitions and characteristics of these 4 groups (Abraham et al. 2019; Purdue Univ., 2015a; Purdue Univ., 2015b; ESF, n.d.) as well as the soil type descriptions provided in the soil type map, a classification has been forged, organizing a multitude of different soil types into one of 4 hydrologic soil type groups (Appendix 9.3). Next, in the biophysical table, each LULC class needed to be provided with a specific *CN* number for each possible hydrologic soil type. Based on LULC values and curve numbers from the USDA report (1986), each Urban Atlas LULC value was likewise matched to a curve number for each of the 4 hydrologic soil groups (Appendix 9.3).

After runoff per pixel has been calculated in an earlier step, runoff retention per pixel (R_i) is calculated next.

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

Out of this result, it is possible to calculate runoff retention per pixel (R_{m3i}) in cubic meters (m^3), with pixel area in square meters (m^2).

$$R_{m^3\,i} = R_i \cdot P \cdot pixel.area \cdot 10^{-3}$$

Lastly, the plain runoff volume per pixel (Q_{m3i}) is calculated as well.

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

Now, in order to calculate the potential service of natural infrastructure (*Service.built*), in terms of avoided damage to build infrastructure, the monetary sum of a potential 'worst case' damage to build infrastructure is calculated by multiplying the building footprint area within the watershed with the potential damage values per m^2 per building type (*Affected.Build*).

$$Service.built = Affected.buidt \sum_{watershed} R\_m3_i$$

The build infrastructure file with building functions used, is the same build infrastructure file as described in subchapter 2.3.2.

For the damage loss table, potential flood damage per m^2 per building type was obtained through a European Commission (2017) report on flood damage, namely 717 €/m^2 for residential and 106 €/m^2 for non-residential building types. As the entirety of The Hague was assumed to be one watershed, the final monetary flood damage number is expected to be overshooting by a lot, as in the case of storm flooding, certain sub watersheds would flood earlier and more intensely than others, of which none were calculated as part of this study.

4.2.3 Carbon Storage

The InVEST carbon storage model aims to estimate the carbon stored in the 4 major carbon pools; aboveground biomass, belowground biomass, soil, and dead organic matter. The model is not urban specific, but can be applied to the urban environment (R. Remme, personal communication, 2020). As no 'future planning' LULC scenarios were available nor specifically manufactured for this study, it was not possible to apply carbon sequestration for this model or calculate a potential monetary service benefit, as such outputs rely on the carbon sequestration results. In order for the model to calculate the total carbon stored for the AOI as well as per LULC class, biophysical values needed to be provided, describing the carbon density in megagrams/ha per pool and per LULC class. Most data for non-urban LULC classes could be taken directly from table 4.23 of Bouwer et al. (2018), as they applied the same carbon storage model with the same exact pools and similar LULC types. For urban LULC classes, such as green urban areas or urban fabrics, the paper assumed a carbon storage capability of 0 for every pool. However, this does not necessarily reflect reality, keeping in mind the urban shade values calculated in 2.3.1.

As not many studies on urban carbon storage have been done yet, from here on data needed to be experimentally created. By overlaying tree coverage data with LULC data, it was determined that green urban areas are 20 % less dense in terms of GI than forests in the same AOI. For carbon densities of 50, 13, 90 and 15 Mg/ha for above ground, below ground, solid and dead organic matter pools (Bouwer et al., 2018) and a 20% carbon density loss for green urban areas, green urban areas were coming out to 40, 10.4, 72 and 12 Mg/ha respectively.

While major green urban areas in The Hague, such as Haagse Bos, could be assumed to have similar conditions concerning environmental pressure and ecosystem health than nearby forest areas, the same cannot necessarily be said for trees along roads or in predominantly soil sealed urban areas, as research likes to diverge on this topic. On one hand, urban street trees are often said to suffer from heat or water stress (Dale & Frank, 2014), while on the other hand they might profit from urban emission, such as enhanced nitrogen or carbon levels (Carreiro & Tripler, 2005). In order to decide for a methodology, the results of Tang et al. (2016) about carbon storage capabilities of urban street trees have been taken as a guideline. In their research, they compared the abilities of urban street trees to local forest trees to effectively store carbon. Their results ultimately showed that, for the same species of trees, carbon storage potential of urban street trees does vary from their rural counterparts, often coming back to the younger age and smaller size of city trees, yet concluded that all in all, carbon density and sequestration rates in local urban street trees are comparable in orders of magnitude to those of rural trees.

Based on this conclusion, the same methodology for urban fabric areas as for green urban areas was employed, which involves attributing carbon storage capabilities to urban fabric and industrial areas as a fraction of the carbon storage capabilities of forest areas, based on their tree density in comparison to the local forest areas. For a table containing all carbon storage values per LULC class based on the previously mentioned methodologies for the current scenario, please refer to Appendix 9.4. As carbon storage capabilities per LULC class are linked to GI density, please refer to chapter 4.4 for elaboration on the creation of alternative scenario data.

In order for the amount of stored carbon to be put in relation to the yearly CO2 emissions of The Hague, the average carbon footprint of cities comparable in size and geographical location to The Hague was calculated (Moran et al., 2018), which amounted to around 5.5 Mt CO2 and was divided by the total amount of carbon storage of The Hague.

4.2.4 Coastal Vulnerability

The InVEST coastal vulnerability model distinguishes itself from the other InVEST models in a way that all 3 of the other models have a primarily quantitative output and are said to analyse final ES, whereas the coastal vulnerability model is described as a tool to facilitate ES analyses, giving primarily qualitative results, meant to support further final ES studies. The goal of the model is to analyse how modifications of coastal biological and physical infrastructures impact the coasts exposure to storm-induced erosion and inundation. The final exposure output is given in terms of a vulnerability index along the coast, hinting to different areas that are more or less affected by storm erosion and inundation. Exposure per shore point is calculated by up to seven bio-geophysical variables, such as topography, bathymetry or coastal forests and seagrass occurrences.

First, based on the model resolution chosen by the user, shore points are placed at every x meters along the coast. For this study, shore points were placed every 100 m, resulting in a total of 157 entries. Next, the model calculates the total exposure index (*EI*) for each of these shore points based on single exposure indexes for each bio-geophysical variable. The exposure ranks (*R*) vary from 1 (very low) to 5 (very high exposure). The rank of the bio-geophysical variables are either user defined (e.g. Natural habitats, Geomorphology) and inspired by literature or example rankings from table 4.1 in the InVEST user guide (Natural Capital Project, 2020b), or predefined by the model itself (e.g. Relief, Wave exposure, surge potential). For an exact account of the model defined as well as the user defined habitats and ranks, please refer to Appendix 9.5. Please note that this table refers to the current scenario. For instructions on how to manipulate the data for alternative scenarios, please refer to chapter 4.4.

$$EI = \left(R_{Geomorphology}\, R_{Relief}\, R_{Habitats}\, R_{SLR}\, R_{WindExposure}\, R_{WaveExposure}\, R_{Surge} \right)^{1/7}$$

In order for the model to plot exposure points along a coast line, landmass information needs to be provided to distinguish ‘dry’ land from the sea area. In this case, the landmass file was identical to the soil map file from the Urban Flood Risk Mitigation model (TU Delft, 2020b), as only the contour of above sea level soil occurrence is needed. Shore points will be created along the coastline within the AOI, which, in this case was again made up by the municipal boundary file of The Hague (CBS, 2019b).

Information about local geomorphology is meant to provide the model with a sense of ‘roughness’ concerning the coastal terrain. Rocky cliffs and sea walls provide a vastly superior ability in terms of erosion and wave resistance than for example sandy beaches. Concerning the geomorphology value, each shore point receives the average score of all geomorphology data situated in a radius of half the model resolution around the specific shore point. If geomorphology data is missing, a user defined fill value, here 5 due to the dominant occurrence of sand, will be taken instead. A geomorphology vector map for the Netherlands was provided by TU Delft (2020b). This geomorphology vector map was transformed to a polyline map, representing the exact shoreline, where each geomorphology type intersecting the shoreline (sand or seawall) needed to be assigned a user added exposure rank (Appendix 9.5).

As areas with a greater elevation above mean sea level are generally at a lower risk of inundation, a detailed relief file is important for exposure mapping. Relief in the model was provided by the AHN3 elevation map (PDOK, 2020b), from where on, each shore point receives the average elevation from a user defined radius around it. The radius was left at the default 5000 m. In order to increase model accuracy, the user is prompted to provide an elevation map expanding at least the same distance away from the AOI as the value of the search radius.

Natural habitats are the variable with the most user input needed as well as the variable that is easiest to manipulate, such as for alternative scenarios. Especially in terms of erosion and wave mitigation, natural habitats such as coastal forests, dunes, mangroves or seagrass play a major role. For each shore point, all-natural habitat occurrences that fall into a certain radius are taken into account. The model then creates an array (*R*) containing all the ranks associated with these habitats, and a final Natural Habitat (R_{Hab}) exposure rank is created.

$$R_{Hab} = 4.8 - 0.5\sqrt{(1.5 \max_{k=1}^{N}(5 - R_k))^2 + \sum_{k=1}^{N}(5 - R_k)^2 - (\max_{k=1}^{N}(5 - R_k))^2}$$

The habitat with the lowest rank is weighted 1.5 times higher than other habitats in order to assure that fronted segments as well as segments made up of a single natural habitat experience a higher exposure grade, as to mimic real-life conditions. Furthermore, every habitat has a maximum protection distance. As natural habitats analysed in this study were exclusively made up of dunes and coastal forests, which are both natural habitats being referenced in the InVEST user guide, the protection distance values have been taken from the provided example values given (Natural Capital Project, 2020b). Although seagrass fields do exist in the Netherlands, no current occurrences were recorded near the coastal area of The Hague (NGR, 2011; Rijkswaterstaat, 2019). Also, no further InVEST relevant natural habitats could be identified (e.g. Mangroves, corals, kelp). If at least 1 cell containing a specific natural habitat falls within distance of a specific shore point (depending on the protection distance of that specific habitat) the presence of the natural habitat for that specific shore point is assumed. The existence of coastal forest areas is documented by the same spatial data input map as used for urban GI occurrence, namely the tree cover density map by Copernicus (2018), serving as a direct spatial input map for the model.

Due to different exposure ranks, dunes needed to be divided into high (>5 m) and low (<5 m) dunes (Natural Capital Project, 2020b). In order to create such a file, in a first step, the geomorphology file was overlaid with a high-resolution aerial imagery file (ESRI, 2020), where manually, spatial data concerning dune areas were transferred to a new file. In a second step, the dune area file was overlaid with the elevation file and split into areas of less than 5 m height and areas of more than 5 m height, where each area was finally provided with a fitting exposure rank.

Concerning wind and wave exposure, wind in particular is known to be responsible for the creation of high storm surges as well as soil abrasion, whereas storm waves are an indicator for the potential of overall shoreline erosion. Wind exposure, provided by Wavewatch III data (NWS, 2009) is calculated by the Relative Exposure Index Methodology (Keddy, 1982) revolving around the analysis of the highest 10% wind speeds from a long record of measured wind speeds, combined with shore point fetch characteristics, of which the distance is the only user influenceable variable. This distance has been left at the default 12000 m. A minimum distance needs to be set as to not analyse much further than is important for the AOI. Wave exposure relies on the geographical location of the study area, as sheltered regions experience less storm oceanic waves than coastal areas connected to the open sea. Next to assigning weighted power values of oceanic waves per shore point, each shore point is assigned a fetch characteristic, similar as for wind exposure, in order to determine the total exposure to potential waves for each point. Next to wind direction and power, average depth of the region of interest influences the calculated power of waves as well. A spatial bathymetry file is the only wave power related data expected to be provided by the user, and was taken from Emodnet (2018). As long as the study area is within latitudes -65 degrees south and 77 degrees north, which is the case for the Netherlands, the InVEST model provides the complete wind and wave data required, with the exception of bathymetry data, as well as calculates exposure ranks relating to wind and wave exposure automatically. As the user is not expected to provide any more information to this, nor is he necessarily expected or even able to change any, it was decided to leave out further methodological descriptions concerning wind and wave exposure. If more detailed information is desired on these variables, please refer to the InVEST user guide (Natural Capital Project, 2020b).

Storm surge height is a function of wind speed and direction, again relating to wind and wave exposure data. Their height is generally expected to rise if the distance between the coastline and the edge of the nearest continental shelf increases. Based on the distance of each shore point to the continental shelf, for which a spatial map is likewise provided by InVEST, storm surge exposure increases.

Lastly, by assessing exposure of coastlines to inundation and erosion, the directly affected human population is an important factor to keep in mind when thinking about countermeasures for very exposed areas. It is for this reason, that each shore point will be attributed with an average number of people affected within a user defined radius. The population search radius was left at the default 5000 m for this study. The number of people affected is strictly for informational purposes and does not influence the final exposure rank of a shore point in any way.

Population density was based on spatial population information of the Urban Atlas 2012 (Copernicus, 2016). The current version of Urban Atlas (Copernicus, 2020) does not yet contain any population information. Data about Sea Level Rise (SLR) was ultimately not included in the study, as SLR changes between different shore points are only noticeable for a bigger AOI. For the entire coastline of The Hague, only 1 SLR measuring station can be taken into consideration (Hoek van Holland), resulting in the same SLR exposure rank for each shore point, thus making the inclusion of this variable ultimately trivial (PSMSL, 2020).

4.3 Natural Capital Modelling

The NC tool employed in this study is, to date, not accessible by the public. Although the model has already been successfully tested for a multitude of Dutch cities, resulting in at least 2 publications concerning ES assessment studies for the city of Amsterdam (Paulin et al., 2020a; Paulin et al. 2020b), access is restricted and there is no evident user interface, requiring at least basic coding skills to run the models. Access to the tool is currently managed by the National Institute for Public Health and the Environment (RIVM, 2020). All NC tool related documentation consulted for the purpose of this research was either taken out of the previously mentioned research papers and their supplementary materials (Paulin et al., 2020a; Paulin et al. 2020b), from documentation available on the RIVM server, or from private communication with NC affiliated entities (R. Koopman, personal communication, 2020). Data values for the NC tool that are not explicitly consisting of their own spatial data input files (e.g. tree coverage, wind speed map, …), are to be provided through lookup tables, assigning certain values (e.g. roughness factors, cooling factors, …) to a specific spatial data class, such as values from the LULC map.

4.3.1 Urban Cooling

The NC urban cooling model aims to capture the UHI reduction by green and blue infrastructure. Next to vegetation and water coverage, factors influencing the assessed heat reduction are functions of sealed surface areas, population density, wind speed and surface roughness. First, a spatial LULC map is needed, as much of the input data, with the exception of GI, is tied to a specific LULC type. As done previously for our InVEST model, the Copernicus Urban Atlas (UA) data (2018) served this purpose (Copernicus, 2020). Then, a population map is needed. Although it would have been possible to make use of the same population map as used in chapter 2.2.4, a more detailed population map was provided by the NC tool for the area of the Netherlands. The creation of the NC population map is based on the methodology applied by Remme et al. (2017), and involved the combination of the BAG3D (TU Delft, 2020a) and the Wijk- en buurtkaart (CBS, 2019b). Next, a vegetation map, being subdivided into trees, shrubs and grass, needs to be provided. As the Tree cover density map (Copernicus, 2018) does exclusively represent tree infrastructure, being unfair to the NC tools abilities into assessing cooling and water retention abilities of shrubs and grass infrastructure, an alternative spatial GI map was yet again provided by the NC tool. The creation of this map is based on the combination of AHN3 (PDOK, 2020b) height data, which subdivides vegetation into 3 different height categories (trees, shrubs, grass), and uses aerial photography to calculate a Normalized Difference Vegetation Index (NDVI) and differentiate GI from other objects. All vegetation above 2.5m is considered 'tree', between 2.5m and 1 m 'shrub' and less than 1m 'grass'. For more information on the meticulous creation of the NC GI map, please refer to the Supplementary Material document of Paulin et al. (2020a).

In order to calculate the maximum UHI effect, needed as an input map for further UHI calculations, spatial data about air speeds for 10m above ground is combined with population data for a 10 km radius around each cell. With the goal to create a spatial 10m above ground air speed map (WS_{10m}), the publicly available 100m above ground air speed map (WS_{100m}) (NGR, 2015) is multiplied by a roughness length for momentum ($z0m$) value that is connected to each land cover type within the LULC map. $Z0m$ values, representing the height at which wind speeds theoretically drop to 0, are taken out of De Ridder & Schayes (1997), and were assigned to UA LULC types (Appendix 9.6).

$$WS_{10m}=WS_{100m} \cdot \frac{ln\left(\frac{10}{z0m_{lc}}\right)}{ln\left(\frac{100}{z0m_{lc}}\right)}$$

Based on the methodology on how to assess the maximum UHI for the UrbClim model (De Ridder, Lauwaet & Maiheu, 2015), the maximum UHI effect (UHI_{max}) is calculated by combining population density in a 10 km radius with the average wind speeds for a height of 10 m above ground.

$$UHI_{max}= -1.605 + 1.062\, log(population_{10km}) - 0.356\, (WS_{10m})$$

As to create the potential UHI effect (UHI_{pot}), an additional map, representing local soil sealing needs to be provided. Here, soil sealing is defined as the area of urban fabric LULC classes which are not covered by GI, reflecting the inverse of the unified vegetation map. Soil sealing percentage ($fr_{soilsealing}$) emerges by deduction of GI coverage per LULC class within the AOI. Only land classes such as 'Continuous Urban Fabric' or 'Sport and Leisure Facilities' are considered in order to not falsely classify open spaces in forests or parks as sealed surfaces. For this, a lookup table was created, classifying green areas (0) and grey areas (1) into separate groups (Appendix 9.6). Furthermore, only LULC classes with at least 20% soil sealing were being considered, as in rural areas with less soil sealing, the UHI is less relevant. For each pixel, the area taken into account for this calculation has a radius of 1000 m around the cell.

$$UHI_{pot}=UHI_{max} \cdot fr_{soilsealing}$$

Now, for each pixel, the actual UHI (UHI_{actual}) is calculated. The actual UHI consists of the potential UHI multiplied with a reduction fraction ($fr_{reduction}$) specific to either the vegetation type, or if no vegetation type is defined, the LULC value. Reduction fraction values are based on Remme et al. (2018) (Appendix 9.6). The actual cooling radius for each cell is restricted to a conservative estimate of 30 m, as the actual distance to which an effect can be detected is still under discussion. As such, the mean of all vegetation or LULC reduction fractions in a 30 m radius around the cell are looked at. It might be interesting to note that in this step, given the specific LULC class, the cooling effect of BI is finally calculated.

$$UHI_{actual} = UHI_{pot} \cdot (1 - \sum fr_{reduction})$$

Lastly, the actual UHI reduction ($UHI_{reduction}$) by green and blue infrastructure emerges by subtracting the actual UHI off the maximum UHI.

$$UHI_{reduction} = UHI_{max} - UHI_{actual}$$

In order to transform the UHI reduction capabilities of green and blue infrastructure into actual air temperature values, the calculated UHI reduction values could be subtracted from the measured air temperature values for a specific day. Actual air temperatures for The Hague on the 27/08/2019 were taken from 5 urban weather stations, distributed around the city center (Appendix 9.2) and combined to an average temperature. If following this approach, it is best to choose values from weather stations situated in city centric, predominantly grey areas, in order to minimize direct influence of green and grey infrastructure before applying the UHI reduction.

4.3.2 Water Storage

The NC water storage model tries to showcase avoided amounts of rainwater going into local stormwater/sewage systems due to rainwater stored by vegetation. Furthermore, associated monetary savings in water treatment costs can be represented. As the water storage model attributes retention of stormwater runoff exclusively to the presence of vegetation (fr_{veg}), a GI map is needed. As for water storage capabilities, the model does not distinguish between different types of vegetation, spatial data about single types of vegetation could be joined into 1 single map. For more information on the creation and source of such maps, please refer to subchapter 2.4.1 as well as the Supplementary Material document of Paulin et al. (2020a).

Based on vegetation coverage, each cell receives a value between 0 and 1, expressing the extent to which the cell is covered by greenery. Based on expert judgment and past research about green roof water retention, the model assumes a mean yearly water storage capability (*SC*) of 55% by vegetation. Based on a design storm with a precipitation intensity of 70 mm/h (Den Haag, n.d.) and the local stormwater time of concentration, as calculated in subchapter 2.3.2, a design storm depth (*P*) of 62.3 mm/h was assumed. Finally, the water storage (*WS*) capacity of GI in The Hague is calculated by multiplying all 3 variables with each other:

$$WS = SC \cdot P \cdot fr_{veg}$$

To calculate avoided sewage treatment costs, sewage treatment itself is expected to amount to 0.3752 €/m^3. In order to find out about avoided costs (RC_{ws}), water stored in vegetation per m^3 (WS) will be simply multiplied with the treatment costs in € per m^3 (TC).

$$RC_{WS} = WS \cdot TC$$

4.4 Scenario work

The goal of this research was to analyse the role of green and blue infrastructure into mitigating negative climate effects by showcasing the effectiveness of NbS as well as to evaluate the performance of 2 different ES assessment tools. Based on these goals, for a total of 3 different scenarios, results have been calculated for, where each scenario is distinguished by a different amount of GI present in the AOI. Next to illustrating the importance of urban natural infrastructure by modifying its presence, the employment of different scenarios enabled a better analysis between models and tools, highlighting the sensitivity for each model into reacting towards a major variable change. Both tools define the presence and amount of GI by either a corresponding value connected to the specific LULC (e.g. shade) or by separate input data. Each scenario saw alterations in either the LULC input file and/or the GI input file, based on the specific tool. For each of the InVEST models, GI equals tree coverage and GI dominated LULC classes, whereas for the NC models, GI data contains next to green LULC classes and trees, shrubs and grass as well. The amount of BI was identical for each scenario, as not all of the employed models made use of the presence of BI. By influencing the amount of green area coverage, a very common NbS approach, the positive impacts of urban NbS could more effectively be concluded upon.

4.4.1 Current Scenario

The first scenario, labelled 'Current Scenario' (fig.1), represents the current state of affairs for GI distribution in The Hague. The 'Current Scenario' is the main focus of this research, and makes this study comparable to others like it. In this research, no future scenarios have been analysed. The main goal of showing the benefits of current NbS and the capabilities of urban ES assessment tools was expected to be possible by only analysing the nature that is already present as well as the effect of taking away already existing nature. Galt and Anderson (Naturvation, 2020b) talk about the importance of assessing urban nature that is already present today in order to showcase the importance of not losing already existing GI before being bothered with creating future green scenarios. As the 'Current Scenario' represents the current conditions regarding GI distribution, no additional modifications, next to model specific alterations as seen in the previous 2 subchapters, have been done to either the original LULC input dataset, or the original GI input dataset.

4.4.2 No Parks Scenario

The second scenario, labelled 'No Parks Scenario' (fig.2), represents the first alternative scenario in which the city does still value private and some public GI, but only in limited dimensions. For the InVEST tool, all parks, forests and green urban areas above a size of 2 ha, labelled in the LULC dataset as either 'Green Urban Area', 'Forest' or 'Pasture' have been replaced with the LULC 'Open spaces with little or no vegetation'. This was done as the LULCs 'Green Urban Area', 'Forest' and 'Pasture' are the 3 LULC that are consistently being used as public green spaces and NbS as well as being the biggest contributors to 'nature' in the city. As bigger green urban areas are said to have a significantly increased cooling effect on their surrounding (Aram et al. 2019), the cut-off size of 2 ha was specifically chosen based on research from Vaz Montairo et al. (2016) calculating green space cooling effects for the city of London, experiencing comparable climate conditions as the Netherlands. Furthermore, InVEST honors such research by accrediting green areas above 2 ha a significantly enhanced cooling effect.

The LULC 'Open spaces with little or no vegetation' has been chosen as a 'grey' replacement for former green land classes, as per definition and shade assessment, the GI value of this land class is near zero, while resembling a space in transformation, possibly becoming part of the urban fabric or other grey infrastructure in the future. As the NC tool does not calculate green area coverage exclusively as part of a LULC dataset accompanying lookup table, but further by integrating a separate GI spatial input map, the alternative 'No Parks' scenario for the NC tool was created by adapting the changed 'No Parks' scenario LULC map and by deleting GI spatial data for the same geographical areas as were altered for the creation of the 'No Parks' LULC map.

GI on dune areas has been left aside, because although it lies in the realms of possibilities to dismantle green urban areas to create space for further urban development, dunes generally do not present an attractive nor sensible area for construction projects (O'Leary, 2014). For the Coastal Vulnerability model of InVEST, no 'No Parks Scenario' was enforced due to the mechanism of how the Coastal Vulnerability model calculates 'presence' of natural habitats (Sub-chapter 4.2.4).

4.4.3 Grey Scenario

The third and last scenario, labelled 'Grey Scenario' (fig.3), represents the worst-case scenario in terms of GI. For this specific scenario, all GI, with the exception of dune areas, has been cut out of the appropriate LULC and GI maps. No typical NbS are present for the AOI in this scenario. Although this scenario represents a much more unrealistic approach then the 'No Parks Scenario', it is able to showcase the total effect of what GI already does for the urban area as of now and to truly investigate the mechanics behind both tools into reacting to the removal of a major input variable.

Concerning InVEST, the 'Grey Scenario' was forged through 2 steps. First, all remaining LULC classes of the land cover map defined as 'Green Urban Area', 'Forest' or 'Pasture' were changed into 'Open spaces with little or no vegetation'. Now, even after having transformed all formerly green urban areas, there was still green left in the city in the form of gardens or street trees, which can be a substantial amount depending on the LULC class. This type of GI could not be changed with a land class change, as this would have gotten rid of GI independent variables, such as soil sealing or building density, which are all essential factors for further model calculations. Instead, each model needed further specific adaptations in their accompanying biophysical tables. In the *Urban Cooling* model, we needed to alter the shade and the crop coefficient values for all urban land classes into representing the state of non-existent greenery based on the values for the LULC class 'open spaces with little or no vegetation'. In order to do so, in the Urban Cooling biophysical table, the shade values needed to be set to 0 and the KC value needed to be set to 0.28 for the following land classes : all '*xxx* urban fabric', all '*xxx* roads and associated land', 'Industrial, commercial, public, military and private units', 'Construction sites', 'Isolated structures', 'Mineral extraction and dump sites', 'Land without current use', 'Sports and leisure facilities', 'Port areas' and 'Airports'. The only exception was 'water', for which, due to the specific properties of water, the original KC value would remain, while the shade value would still be set to 0. It should be noted that this only applied for the 'Day' variant of the urban cooling model, as the 'Night-time' temperature model does not rely on the heat mitigation of GI and thus will see no changing results based on the alternative scenarios employed in this study.

Fig. 1: 'Current' Scenario based on tree coverage for InVEST (left) & NC (right)

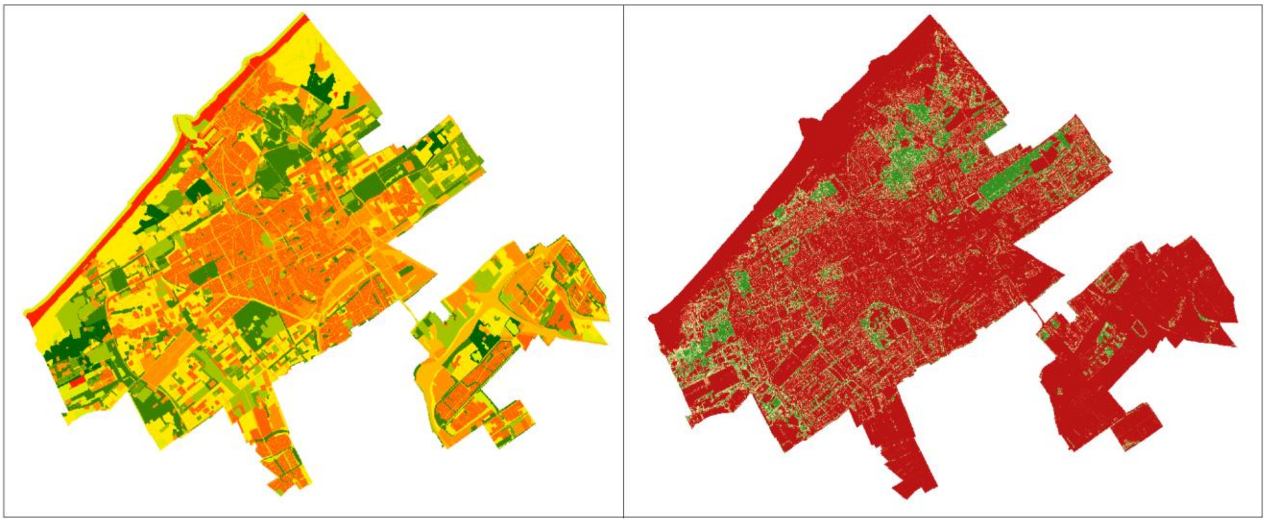


Fig. 2: 'No Parks' Scenario based on tree coverage for InVEST (left) & NC (right)

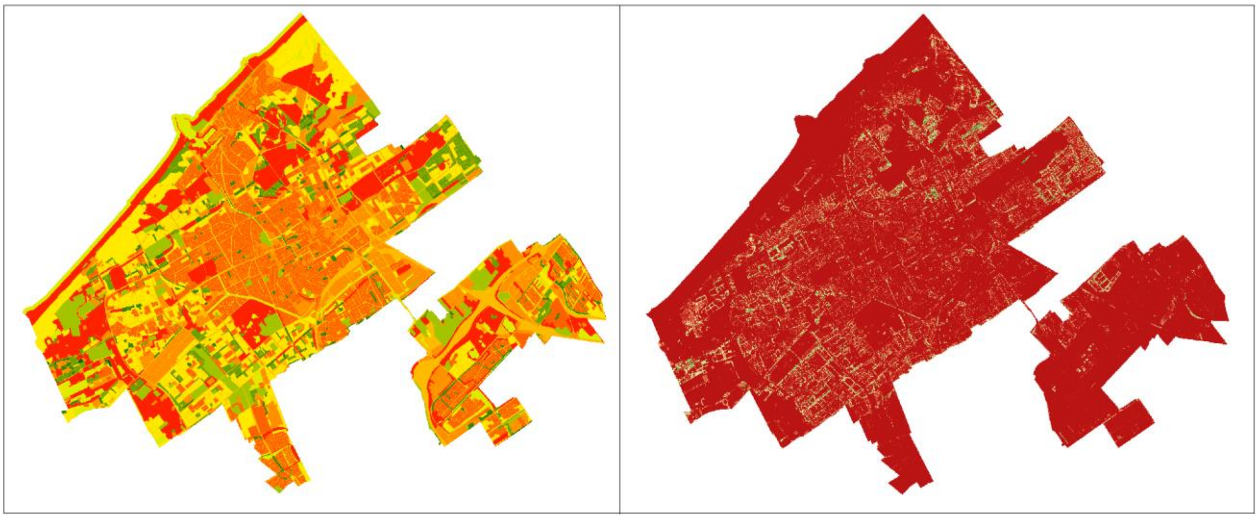


Fig. 3: 'Grey' Scenario based on tree coverage for InVEST (left) & NC (right)

The *Carbon Storage* model needed additional alterations in its ability to store carbon in the 4 major carbon pools. Considering that most natural carbon capture is directly and indirectly related to the presence of GI, which is absent in this alternative scenario, the biophysical table of the carbon storage model saw changes for the same LULC classes as the biophysical table of the urban cooling model. Again, orienting on the data for the land class 'open spaces with little or no vegetation', the carbon storage capabilities have been changed to 1, 1, 1 and 1 for the very same LULC classes as for the urban cooling intervention in the previous paragraph. For the *Urban Flood Mitigation* model, after changing all remaining 'Green Urban Area', 'Forest' or 'Pasture' LULC classes into 'Open spaces with little or no vegetation', no further alterations in the biophysical table needed to be done, as the physical presence of greenery is not a considered variable in the urban flood mitigation model. Lastly, the *Coastal Protection* model, which did not make use of a 'No Parks Scenario', was eligible for a 'Grey Scenario'. This was realized by, next to the modified LULC file, not providing a coastal forest shapefile to the model at all, effectively simulating the non-presence of coastal greenery. This was not strictly in line with the alternative scenario methodologies for other models, yet necessary due to the mechanism of the coastal protection model into detecting natural habitats (Sub-chapter 4.2.4).

For the NC tool, a grey scenario was designed in a similar way as a 'No Parks' scenario. First, the earlier created 'No Parks' scenario LULC map was adapted again, now by a complete deletion of GI spatial information for the entire urban area of The Hague. Such a modified LULC and GI map served as model inputs for both the *Urban Cooling* as well as the *Water storage* model and no further changes for any of the model inputs needed to be done. Once again, dune areas were left out of these GI alterations for both tools, with the exception of the *coastal protection* model

5. Results

In this chapter, final results are being presented. The first half of each subchapter treats the main analysis outputs, including co-benefits if applicable, whereas the second half analyses the results against the background of The Hague and it's neighborhoods. As for the Urban Heat Mitigation and Urban Flood Mitigation services, 2 different spatial assessment tools have been employed. At the end of both subchapters, main differences in results for each methodology will be expanded on.

5.1 Urban Heat Mitigation

In order for both the results of the InVEST and the NC urban heat mitigation models to be comparable to each other, as well as for simplified comparability to similar studies, output values of both tools are given in °C. The output values are either natively given in calculated air temperature in °C for the city (e.g. InVEST) or have been modified to represent the calculated air temperature in °C (e.g. NC). The main native output results for the urban cooling model of InVEST are given in CC (Chapter 4.2.1), representing the ability of specific LULC classes in cooling the surrounding air by a certain % relative to the reference air temperature. Additional output maps are provided, for which one represents the calculated air temperature, chosen to be the output map of choice for this study. Urban Cooling results for the NC tool are given in °C as the amount of degrees natural infrastructure is able to mitigate the UHI. In order for these results to be comparable to the values of InVEST, a modification in form of a subtraction of the 'mitigated' temperature value from the reference UHI effect has been performed, resulting in calculated air temperature output maps (see also Chapter 4.3.1).

5.1.1 InVEST results

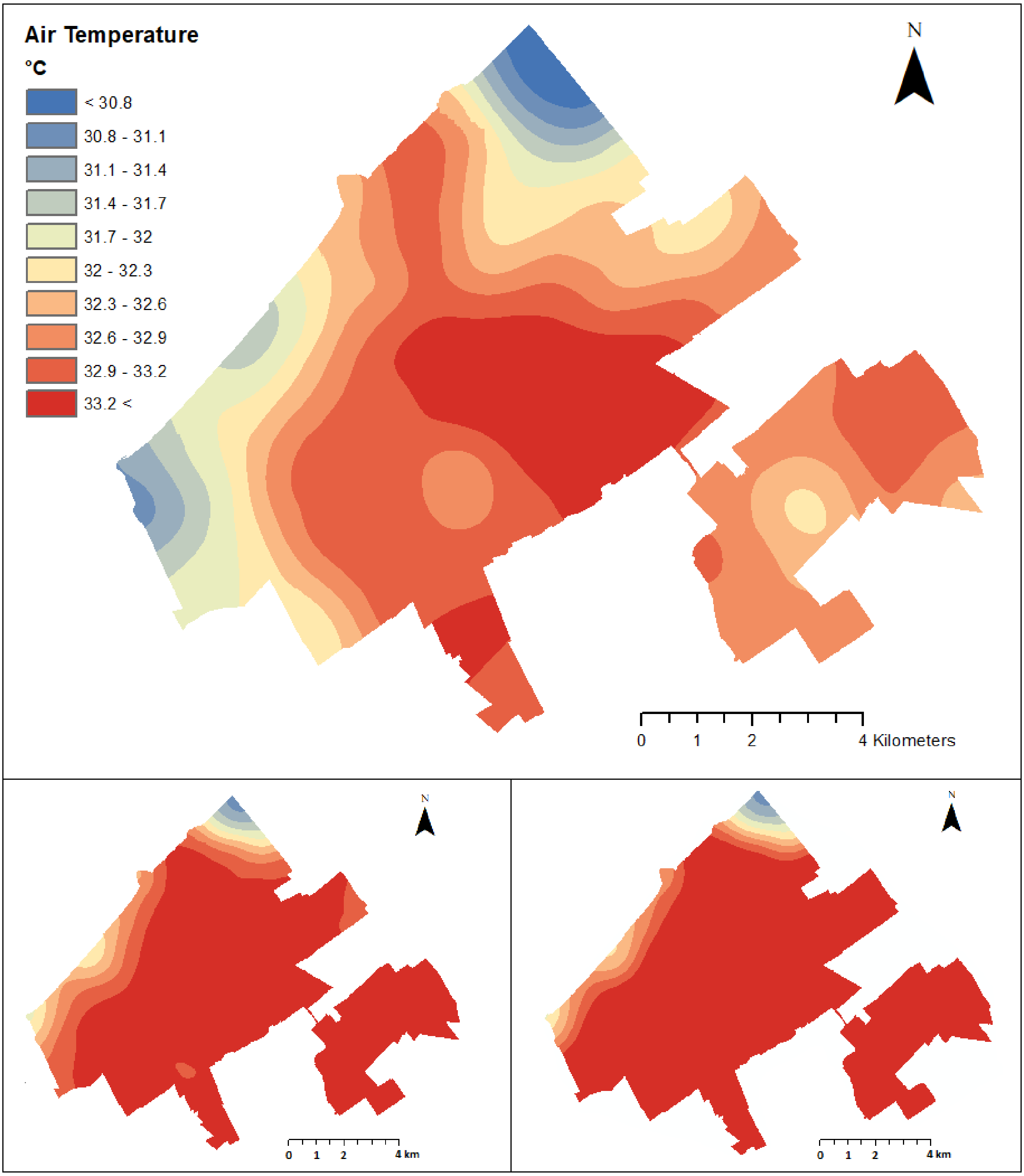
Figure 4 (*top*) represents the calculated InVEST daytime air temperature for the 27/08/2019 based on measured urban and rural reference temperatures, and has not been modified in any way. It is important to note the time of day, as InVEST is able to calculate estimated nighttime temperatures as well (fig.5). With a reference rural temperature of 29 °C and a measured UHI of 5.3 °C, the city wide **daytime air temperature** is estimated to be **32.65 °C**, representing a total cooling ability by vegetation of 1.65 °C and reducing the UHI effect from a former 5.3 °C to 3.75 °C. The hottest areas within the central city area reach a maximum of up to 33.5 °C, whereas the coldest areas on the outskirts of the city reach a minimum of 30.5 °C. In terms of co-benefits calculated, heat reduction services enable energy savings of 294.190 kWh. This equals a yearly energy usage of around 100 households (CBS, 2020) or daily monetary savings of around 53.800 € (European Commission, 2019). Furthermore, figure 4 shows the hottest areas to be situated in the dense urban core of The Hague, corresponding with the least shaded LULC classes (fig. 1). The positive cooling effects of major green urban areas, such as 'Haagse Bos' or 'Het Zuiderpark' (Annex 9.10) are well recognizable, with air temperatures of up to 0.5 °C less than their immediate surroundings.

For the 'No Parks' urban cooling scenario (fig.4, *bottom-left*), the heat distribution situation changes drastically from the 'Current' scenario (fig. 4). With major green urban areas gone, no outstanding cooling areas are left to observe in the urban areas in comparison to a 'current' scenario, and the majority of the city area experiences temperatures similar or higher to the ones formerly present in only the core urban area of The Hague. Average **daytime air temperature** for the AOI rises to **33.24 °C**. As such, the cooling effect of leftover GI is only able to diminish the UHI effect by 1.05 °C. This is a regression in cooling capability of GI between 'Current' and 'No Parks' scenarios of 0.6 °C or 36%. The same difference can be observed for the energy use as well, where saved energy in kWh per day is reduced to 197.568 kWh, and daily monetary savings to 36.170 €. The temperature of centrally located areas rose by only around 0.1 °C , yet urban areas experiencing sub 33 °C ambient air temperatures in the previous scenario now almost all reach temperatures of above 33 °C, up until 33.4 °C.

For the 'Grey' urban cooling scenario, (fig.4, *bottom-right*), visual differences in terms of heat distribution are hard to spot. With every GI in the urban areas gone, not a single outstanding 'cooling' hotspot is left. With elevated air temperatures spreading to the very edge of the city, only the vegetated dune areas are able to keep air temperatures under an average of 33.2 °C. The average **daytime air temperature** of the entire AOI reaches a peak of **33.6 °C**, only 0.36 °C hotter than a 'No Parks' scenario, yet 1.4 °C hotter than the 'Current' scenario. A raise of 0.36 °C from a 'No Parks' scenario represents a difference between scenarios of only 21 %. In case of a 'Grey' scenario, the average UHI can still be fought by 0.7 °C. In terms of energy use, energy savings in a 'Grey' scenario are still given with 119.952 kWh, or 21.950 € per day.

When it comes to nighttime air temperatures, only a 'Current' scenario run has been done, as nighttime temperature assessments do not give any value to GI, thus making employment of alternative GI scenarios ineffective. Average air temperature for the night of the 27/08/2019 is calculated to be around 29.9 °C (Annex 9.9). As this air temperature value is referenced to a daytime UHI, actual nighttime temperature can be expected to be lower. Temperature hotspots are situated in the city center of The Hague, where building density is the highest. Nighttime air temperature for the urban core area is up to 0.5 °C higher than for urban fabric areas on the outer edges of the city area, or up to over 1 °C higher than at the edge of the urban fabric altogether.

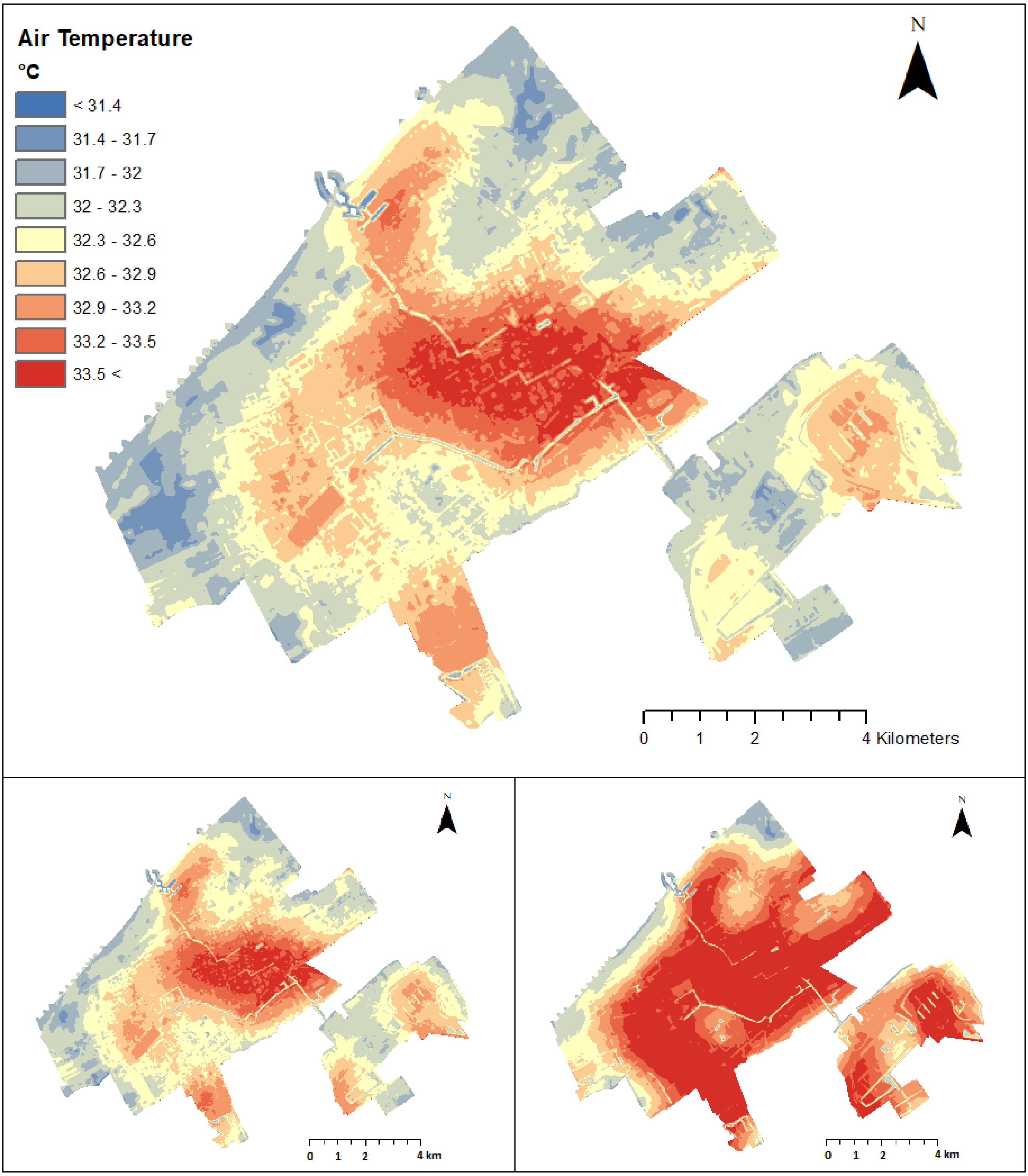
Fig. 4: InVEST Air Temperature - 'Current' Scenario (top), 'No Parks' scenario (left) & 'Grey' scenario (right)



5.1.2 Natural Capital Results

Figure 5 represents the calculated NC daytime air temperature for the 27/08/2019. The average **daytime air temperature** for the AOI is calculated to be **32.68 °C**, representing a cooling ability of GI & BI of 1.62 °C. The air temperature of centrally located areas reaches locally up to 33.65 °C, whereas the coolest areas on the

Fig. 5: NC Air Temperature - 'Current' Scenario (top), 'No Parks' scenario (left) & 'Grey' scenario (right)



northern and western outskirts of the city area reach temperatures of as low as 31.5 °C. The city center can once again be seen to harbor the most heat, matching GI coverage of figure 1. The cooling effect of BI is observable by canals meandering through the city or by local ponds, representing local cooling hotspots of up to 2 °C. The effect of large green spaces is observable by air temperature differences of up to 0.9 °C.

For the ‘No Parks’ urban cooling scenario (fig.5, *bottom-left*), heat mitigation and distribution are still very well observable and hardly change in comparison to a ‘current’ scenario. While former major urban green areas are performing only slightly worse, with up to a maximum of 0.5 °C cooler air temperatures from a former 0.9 °C, maximum and minimum temperatures inside of the AOI stay nearly unchanged. The cooling effect of BI stays completely unchanged, as scenario construction does not involve modification to BI. With an average d**aytime air temperature** for the AOI of **32.74 °C**, the ‘No Parks’ scenario is still able to mitigate the UHI effect by 1.56 °C, which only represents a 4 % difference in terms of cooling capabilities from a ‘Current’ scenario.

For the ‘Grey’ scenario (fig.5, *bottom-right*), major changes in urban cooling potential are observable. Heat mitigation can be seen to drop drastically, as air temperatures above 33.5 °C, formerly only present in the dense city center, are taking over all urban fabric areas. Next to BI, the only ‘cooler’ areas left in the urban areas are former green, now open spaces. Temperature differences between them and the surrounding areas are less than 0.5 °C. BI areas remain the only cool areas with local temperature differences of up to 2 °C. The average **daytime air temperature** for the AOI rises to **33.45 °C**, leaving the mitigation of the UHI effect overall by still **0.85 °C.** The hottest, centrally located areas reach up to 34.2 °, whereas the coolest areas within the AOI reach as low as 31.7 °C. The difference in cooling capabilities from a ‘No Parks’ scenario to a ’Grey’ scenario fell by nearly 60 %.

5.1.3 Neighborhood Analysis

By averaging the results to a neighborhood level, a clearer picture can be drawn towards high priority areas, enhancing the use of results for the municipality. For this model, high priority areas are defined as areas experiencing temperature values equaling or overpassing the highest measured temperature values as calculated in the ‘Current’ scenario and can be seen as areas where urban cooling focused urban NbS can potentially have the biggest impact. For the InVEST ‘Current’ scenario, the hottest neighborhoods (fig. 6, *left*) with above 33.2 °C (up to 33.4 °C) of average daytime air temperature are the dense centrally as well as south-east located neighborhoods of the city, namely from Koningsplein until Binckhorst (Appendix 9.10). Neighborhoods with major parks represent the coldest neighborhoods in the urban fabric areas of the city, notably Zuiderpark and Haagse Bos, with average air temperatures of 32.5 °C, whereas the coldest neighborhood outside of the urban fabric is at the north edge of the city, Oostduinen, with an average air temperature of 31.0 °C. For both the alternative scenarios (fig. 6 *top-right & bottom-right)*, all urban neighborhoods experience temperatures above 33.2 °C, with up to 33.8 °C for the ones in the urban core area. Although the most centrally located neighborhoods remain the highest priority areas in absolute terms, due to overall urban temperatures for both alternative scenarios of above the prior ‘maximum’ temperature, no single specific high priority areas are to be made out in comparison to the ‘Current’ scenario.

For the NC ‘Current’ scenario, the hottest neighborhoods (fig. 7, *left*) with above 33.4 °C (up to 33.6 °C) of average daytime air temperature are once again the dense centrally located neighborhoods, namely from Koningsplein until Huygenspark. neighborhoods with average air temperature of up 33.2 °C extend until Binckhorst. Temperatures continue to fall with greener or more outward lying areas with average air temperatures of 31.9 °C for the coolest neighborhoods. For a ‘No Parks’ scenario, priority areas do not change by much, as already hot neighborhoods only experience a rise of 0.2 - 0.4 °C while other neighborhoods do not experience a significant change. As for a ‘Grey’ scenario, most of the urban neighborhoods experience average temperatures of above 33.4 °C with a maximum of up to 34 °C for Transvaalkwartier-Noord and Schildersbuurt-West. Only formerly green, now open space neighborhoods average less than 33 °C.

Fig. 6: InVEST Air Temperature - Neighborhood analysis for 'Current' scenario (left), 'No Parks' scenario (top) & 'Grey' scenario (bottom)

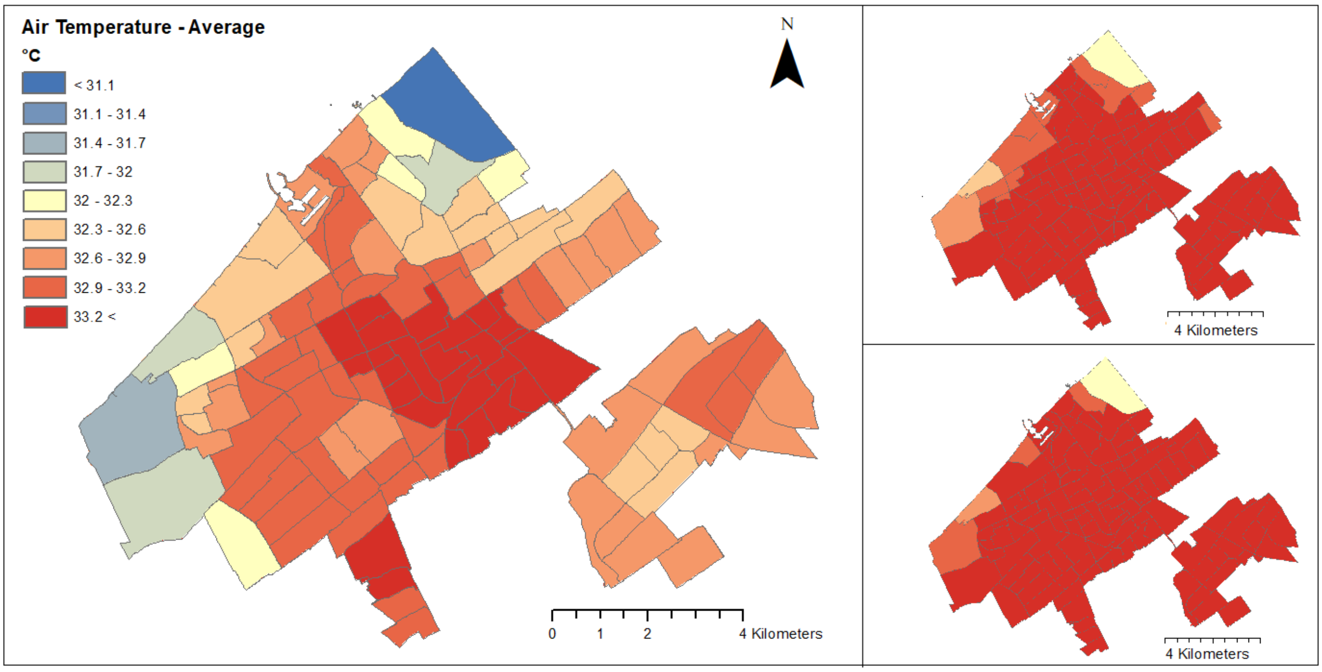
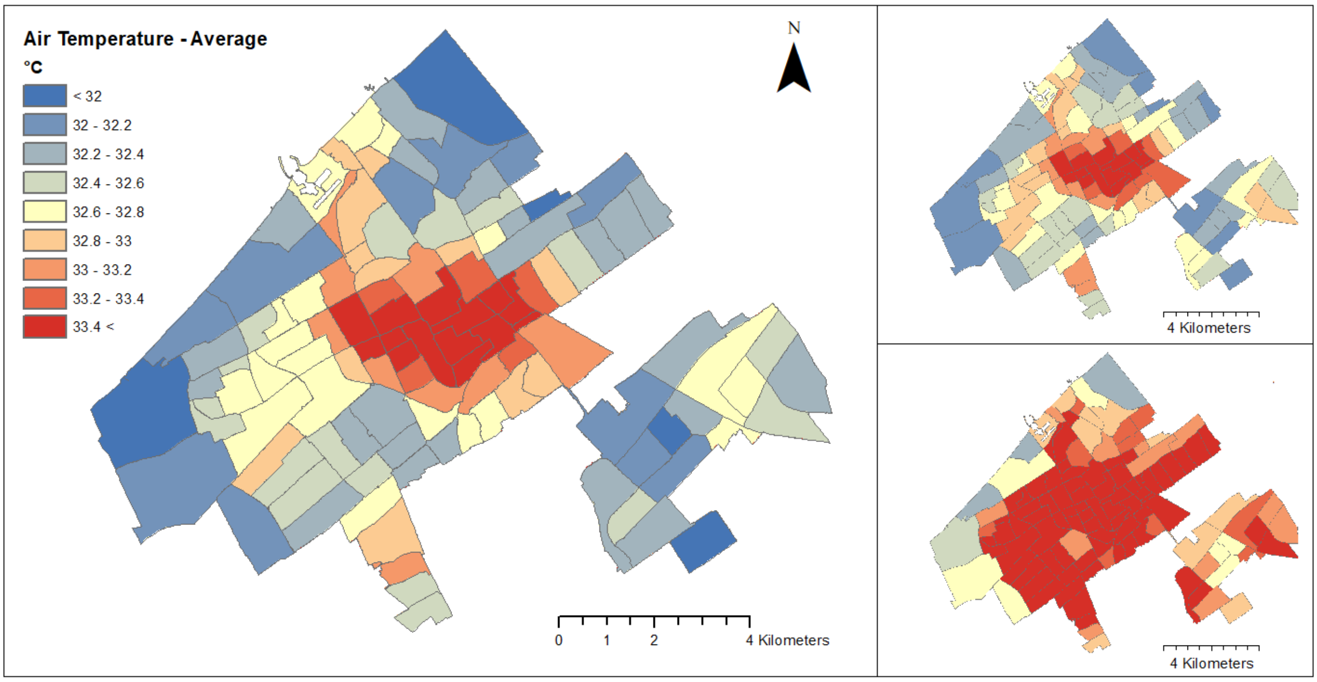


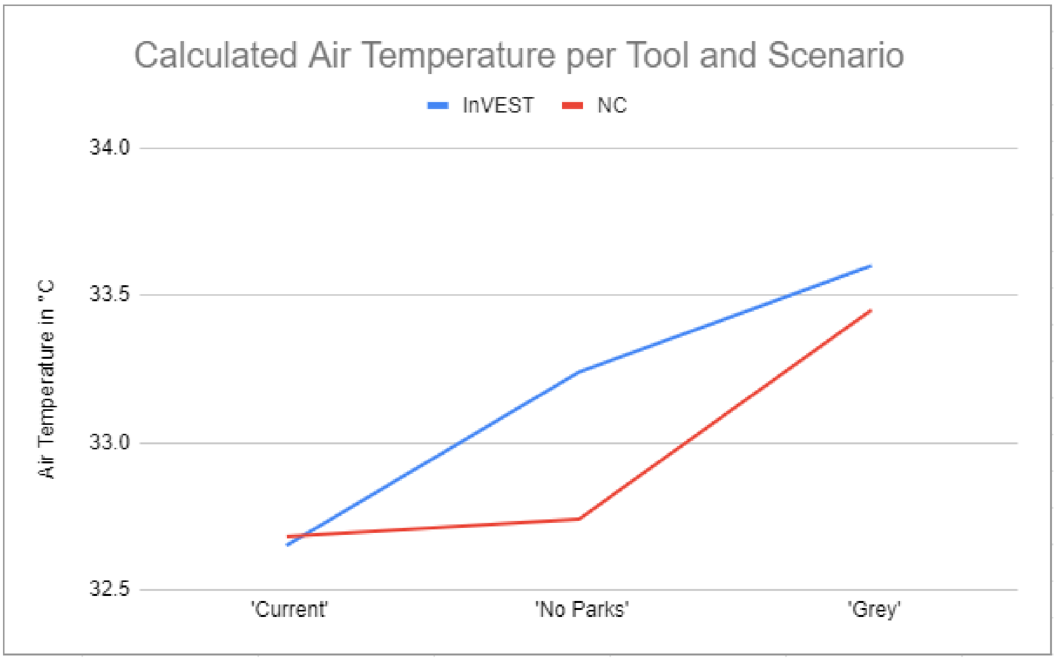
Fig. 7: NC Air Temperature - Neighborhood analysis for 'Current' scenario (left), 'No Parks' scenario (top) & 'Grey' scenario (bottom)



5.1.4 Output Comparison

Both the NC methodology as well as the InVEST methodology capture GI coverage as a main variable, but differ in terms of additional variables greatly. Despite their differences, the average city wide air temperatures as well as heat distribution (fig. 4, *left* & fig. 5, *left*) for the 'Current' scenario are nearly identical. With an average air temperature of 32.68 °C for InVEST and 32.65 °C for the NC tool (fig. 8), their calculated cooling capabilities of urban natural infrastructure differ by only 0.03 °C. Although the average calculated air temperatures differ slightly more per neighborhood, both tools identify similar neighborhoods as priority areas in terms of urban cooling oriented NbS. When it comes to the 'No Parks' scenario, results start to vary greatly. While the overall temperature situation for the NC tool barely changes, with less than 0.1 °C difference, results for InVEST change by over 0.5 °C, as does the representation of heat distribution in the city. Average air temperature results for NC and InVEST differ for a 'No Parks' scenario by over 0.5 °C. On a neighborhood level, high priority areas, in comparison to the 'Current' scenario, differ drastically depending on the methodology, where for the NC tool, only the very city center is still of utmost priority, high priority areas for InVEST shifted to the entire urban area. Finally, for a 'Grey' scenario, results for both tools are nearing each other again. While InVEST average air temperatures only marginally worsen by up to 0.3 °C from a ' No Parks' scenario, NC calculates a drastic loss in CC of 0.7 °C for the entire city. In terms of heat distribution as well as priority areas, both tools are overall accrediting the entire urban fabric as problematic, with only the NC tool giving some more cooling capabilities to major open spaces. The final average air temperatures for a 'Grey' scenario for both tools are only differentiated by 0.15 °C.

Fig. 8: Differences in Air Temperature between scenarios for InVEST and NC



5.2 Urban Flood Mitigation

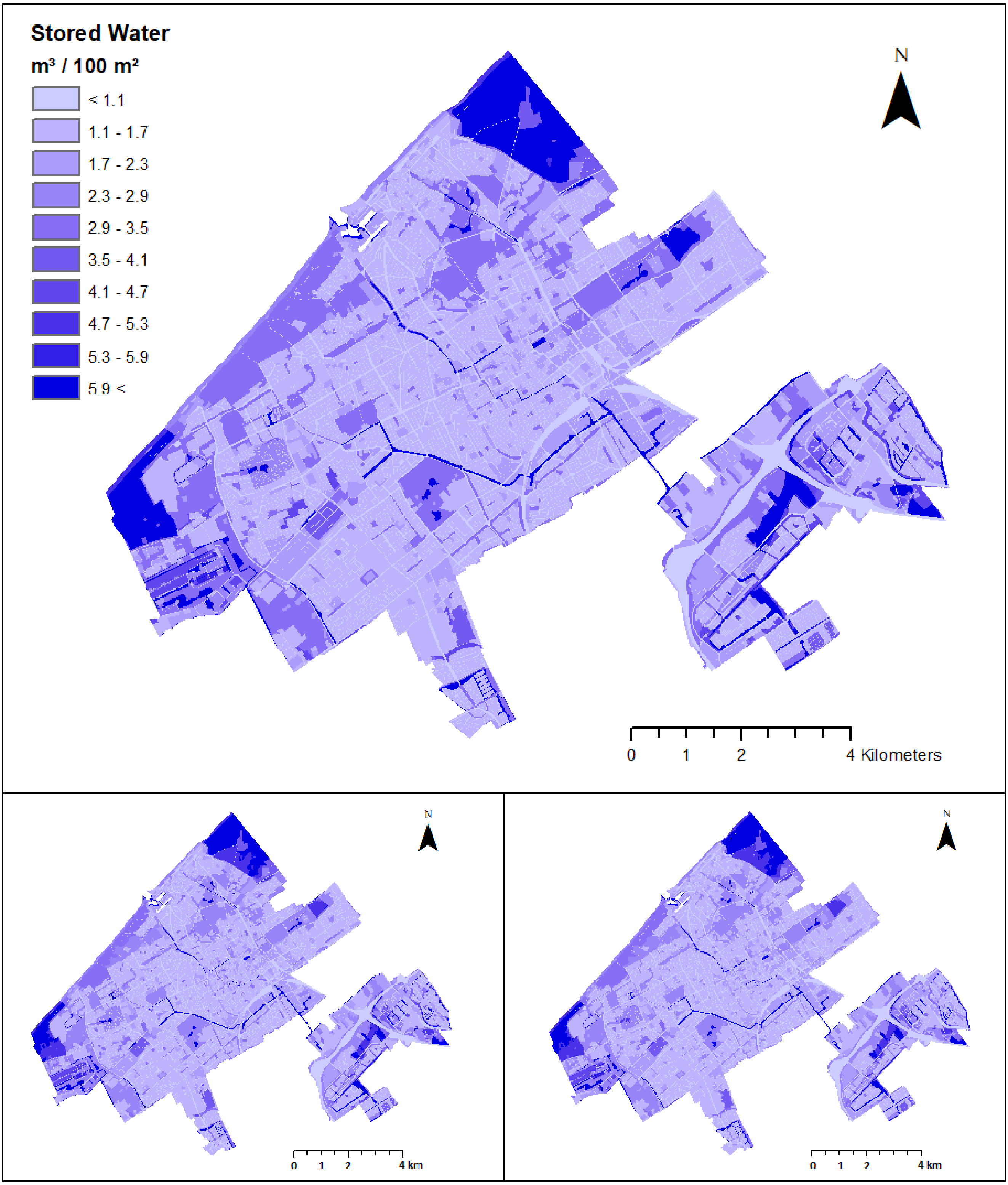
Results for the urban flood mitigation & water storage models are given in m^3 / 100 m^2, where 100 m^2 is the area of 1 single cell. Both models are able to output water storage natively in m^3. Differences in model descriptions come from InVEST explaining their model as calculating captured runoff by soil catchment, whereas NC explain their model as precipitation stored by vegetation. As a common ground, both tools can essentially be seen as calculating precipitation not going into the combined sewage system.

5.2.1 InVEST results

Figure 9 (*top)* represents the InVEST calculated runoff captured for the AOI in the case of a designed storm event with a precipitation of 70 mm/h. Total runoff captured for the entire AOI is amounting to 1**.893.258 m^3 of rainwater**. The dense urban area of the city can be seen to provide relatively little runoff retention, with the most sealed surface areas holding as little as 0.6 m^3 water per cell. Green urban areas can be seen capturing the most runoff inside of the urban fabric, with up to 3.5 m^3 per cell, equaling to above half the amount of precipitation. Water basins in between urban fabric, such as ponds, capture naturally 6.2 m^3 of runoff, equaling the entire amount of precipitation per cell. Maximum capacity for such basins is not calculated as part of the model. Natural areas outside of the urban fabric areas are expected to capture up to 99 % of runoff, with above 6.1 m^3 per cell. When it comes to calculated co-benefits, InVEST does calculate the 'worst case' flood damage possible in case of flooding of the watershed, which, as mentioned in chapter 4.2.2, has been simplified to the municipal boundaries for this study. Because of this reason, the expected 'worst case' flood damage for the Hague includes the flooding of every single building within the AOI (as calculated per building footprint, without taking into account multiple stories), equaling to calculated damage of around 8.077.200.000 €, or 8 billion euros. As the 'worst case' flood damage calculation does not change with scenarios, this calculation is equal for all 3 scenarios.

In case of the 'No Parks' and 'Grey' scenarios (fig. 9, *bottom*), former 'forest', 'green urban area' and 'pasture' areas, now 'open spaces', are still the urban areas with the biggest runoff retention values, averaging to around 2.6 m^3 per cell, or around 40% of the precipitation per cell. All other calculated runoff retentions stay the same as for the 'Current' scenario. The total runoff retention of the **'No Parks'** scenario comes to **1.763.640 m^3** of rainwater, amounting to 7 % less than for the 'Current' scenario. The total runoff retention of the **'Grey'** scenario comes to **1.742.040 m^3** of rainwater, amounting to 8 % less than for the 'Current' scenario.

Fig. 9: InVEST Stormwater runoff retention - 'Current' Scenario (top), 'No Parks' scenario (left) & 'Grey' scenario (right)

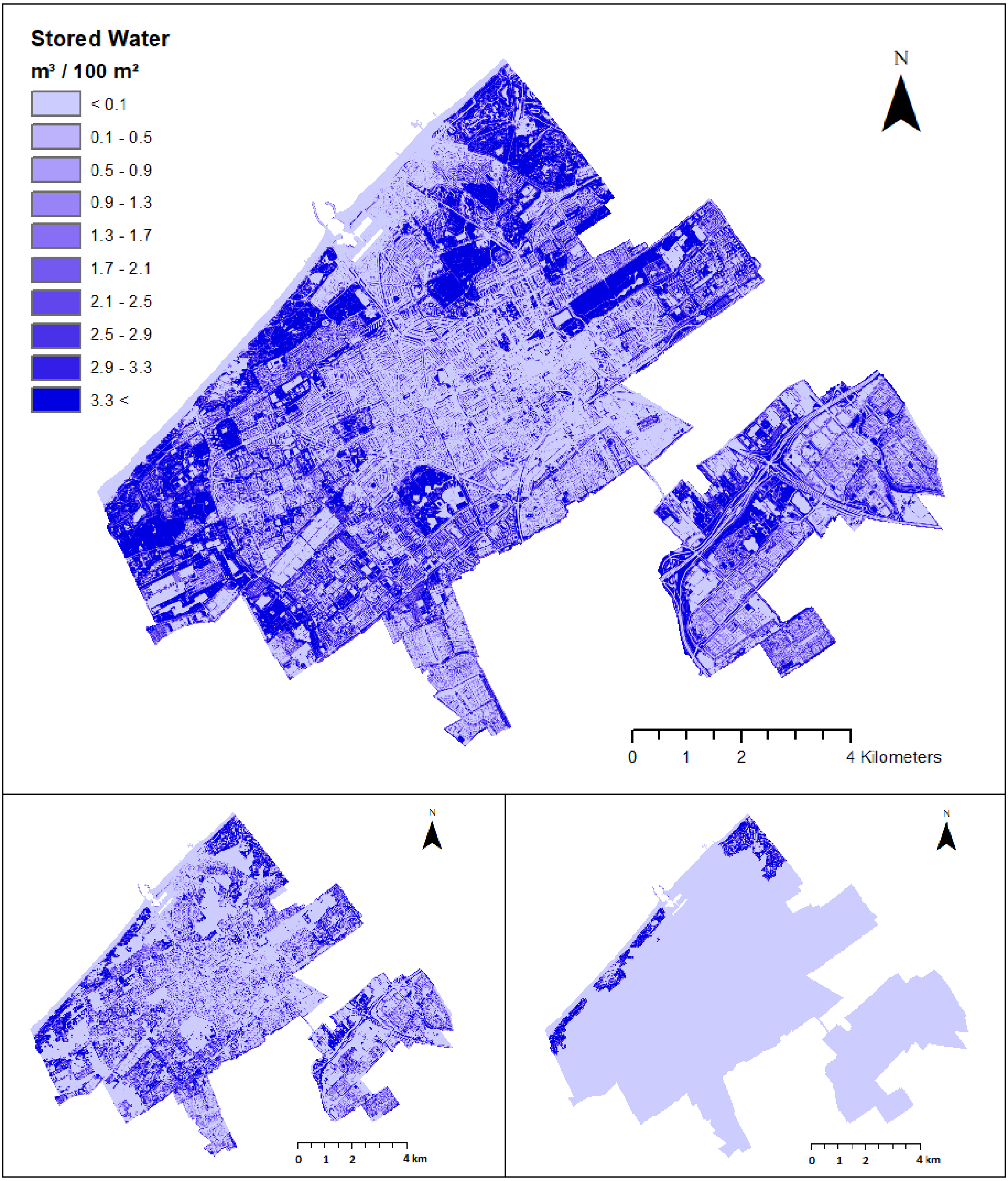


5.2.2 Natural Capital results

Figure 10 (*top)* represents the NC calculated water stored by GI for the same amount of precipitation as figure 9. As the NC tool calculates water storages solely by GI, water storage capabilities for the AOI for all 3 scenarios coincide 1:1 with the NC GI figures 1, 2 & 3, showing GI coverage for the Hague. The total amount of water storage for the current scenario comes to **1.228.814 m^3.** With an expected water storage ability of 55%, majorly urban and non-urban green areas are calculated to store up to 3.4 m^3 water per cell, representing exactly 55% of total precipitation per cell. With less dense GI, water storage drops towards 0 m^3 per cell, for areas without any GI at all. As far as additional metrics go, the NC Water Storage model calculates savings of around 958.476 € of wastewater treatment costs saved for a 'current' scenario.

As for the alternative scenarios of the NC model, with declining GI coverage, water storage values fall as well (fig. 10, *bottom*). As for all scenarios, areas with the highest amount of water storage equal areas with the densest greenery coverage, (e.g. dunes), while areas with no water storage equal areas without any vegetation coverage at all (e.g. open spaces, roads, …). For the case of a **'No Parks'** scenario, total water storage diminishes to **819.996 m^3** of rainwater, a loss of 34 % from the 'Current' scenario, equaling a reduced amount of saved water treatment costs of 639.597 €. For the case of a **'Grey'** scenario, total water storage falls to **120.473 m^3** of rainwater, a loss of 91 % from the 'Current' scenario or 85 % from the 'No Parks' scenario, equaling to 93.969 € of saved water treatment costs.

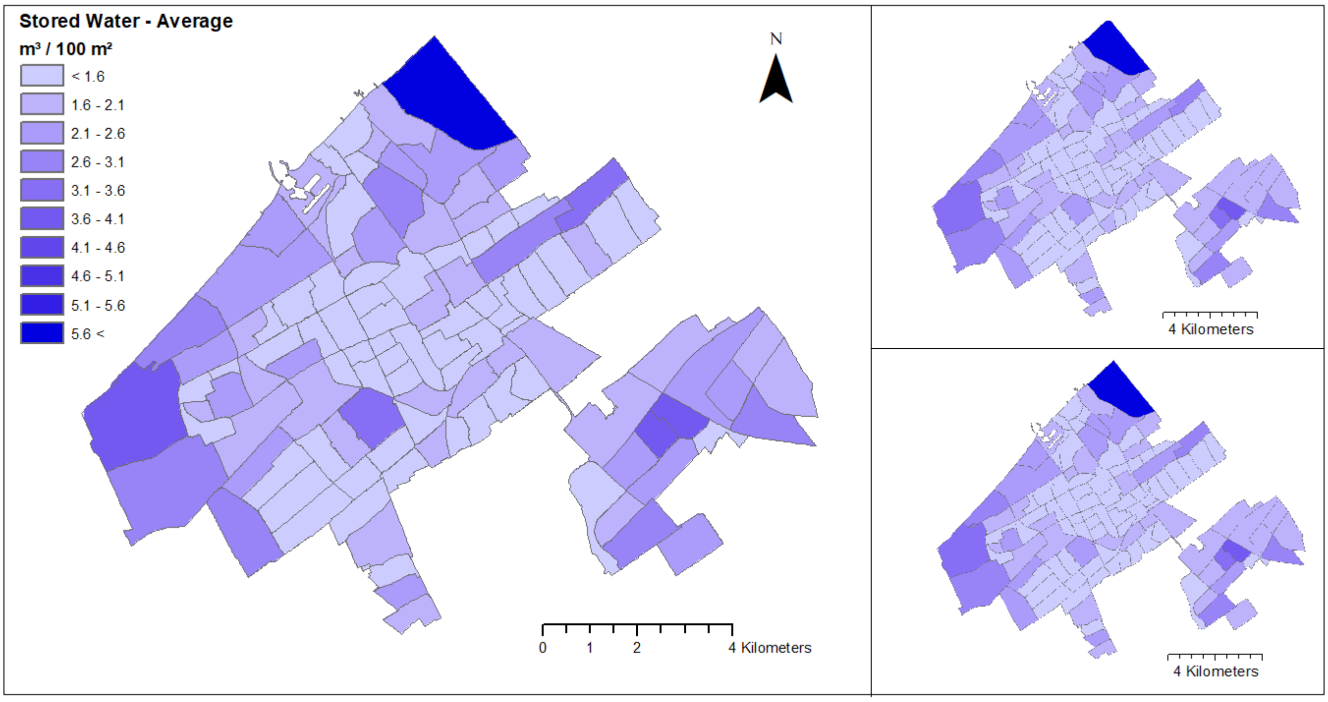
Fig. 10: NC Stormwater storage by greenery - 'Current' Scenario (top), 'No Parks' scenario (left) & 'Grey' scenario (right)



5.2.3 Neighborhood Analysis

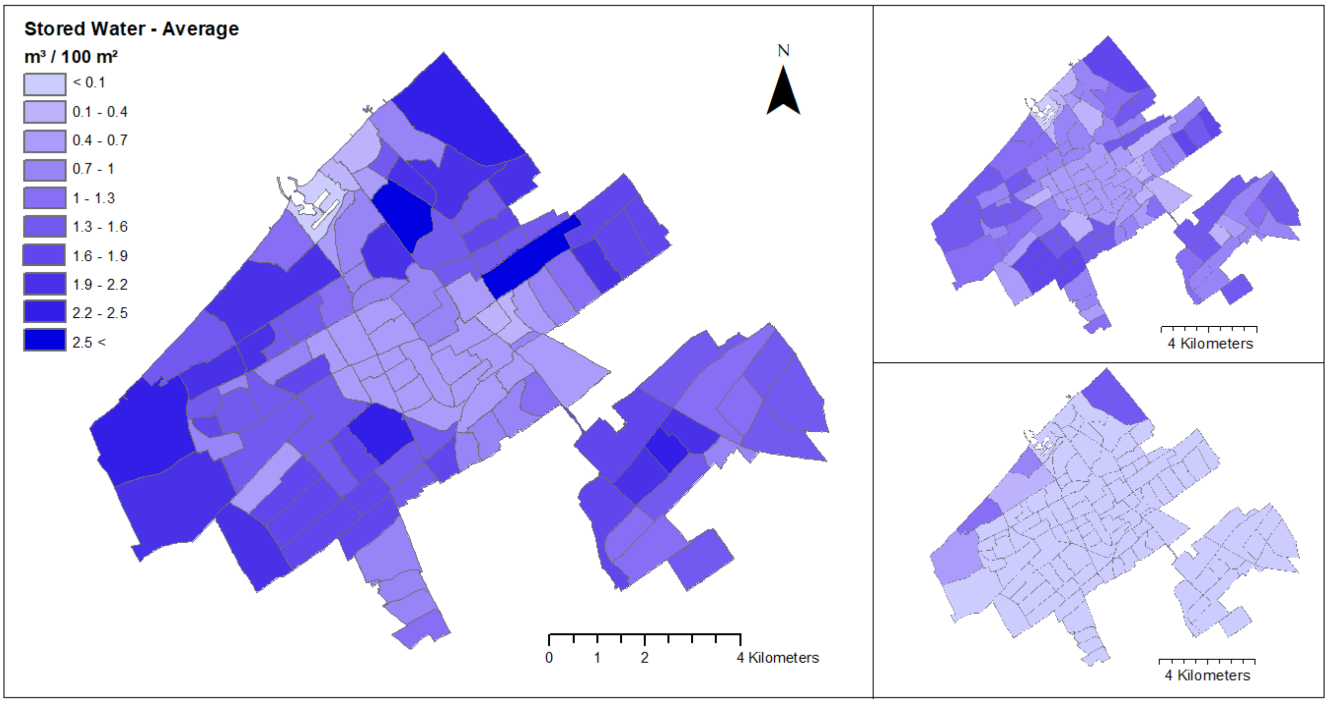
For this model, high priority areas are defined as areas experiencing runoff retention values equaling or overpassing the worst performing areas as calculated in the 'Current' scenario, and can be seen as areas where runoff catchment focused urban NbS have potentially the biggest impact. As far as the Neighborhood analysis goes, visual results for the InVEST stormwater runoff model (fig.9) look very similar to the neighborhood analysis (fig 11), in terms of runoff distribution as well as priority areas. For all scenarios, dense neighborhoods with foremost sealed surfaces, such as most of the centrally located neighborhoods catch an average of less than 1.6 m^3 of runoff per cell with a minimum of 1.2 m^3, (f.ex. Schildersbuurt-Oost, Oostbroek-Noord). Priority areas for runoff catchment oriented NbS are clearly all urban core neighborhoods, with the exception of Voorhout and Kortenbos. Neighborhoods with LULC classes relating to vegetation such as the non-urban Oostudinen or the urban Zuiderpark show the highest average amount of runoff catchment for the current scenario, with 5.8 respectively 3.1 m^3 per hour. For both alternative scenarios, former 'green' areas, now 'open' spaces still represent the urban areas with the highest amount of runoff catchment, with now open space dominant neighborhoods such as Zuiderpark averaging stormwater runoff catchment of 2.5 m^3. Priority areas remain the same for all 3 scenarios.

Fig. 11: InVEST Stormwater runoff retention - Neighborhood analysis for 'Current' scenario (left), 'No Parks' scenario (top) & 'Grey' scenario (bottom)



As for the NC water storage model, the neighborhood analysis coincides yet again very much with the GI coverage (fig. 1, 2 & 3). For the current scenario, high priority areas are very much all centrally located neighborhoods, with the most central neighborhoods, such as Uilebomen (harboring the Central Station of The Hague), storing as little as an average of 0.3 m^3 water per cell. Densely vegetated neighborhoods such as Zuiderpark or Oostduinen store an average of up to 2.4 respectively 2.3 m^3 per cell. For the 'No Parks' scenario, the averages for formerly green, now barren neighborhoods such as Zuiderpark drop to 0 m^3 per cell, while the averages for other neighborhoods stay the same. Priority areas expand from centrally located neighborhoods outwards to neighborhoods containing foremost open spaces. Finally, for a 'Grey' scenario, the very most part of the urban area shows an average water storage of 0 m^3 per cell, making it impossible to highlight any specific neighborhood as a priority area.

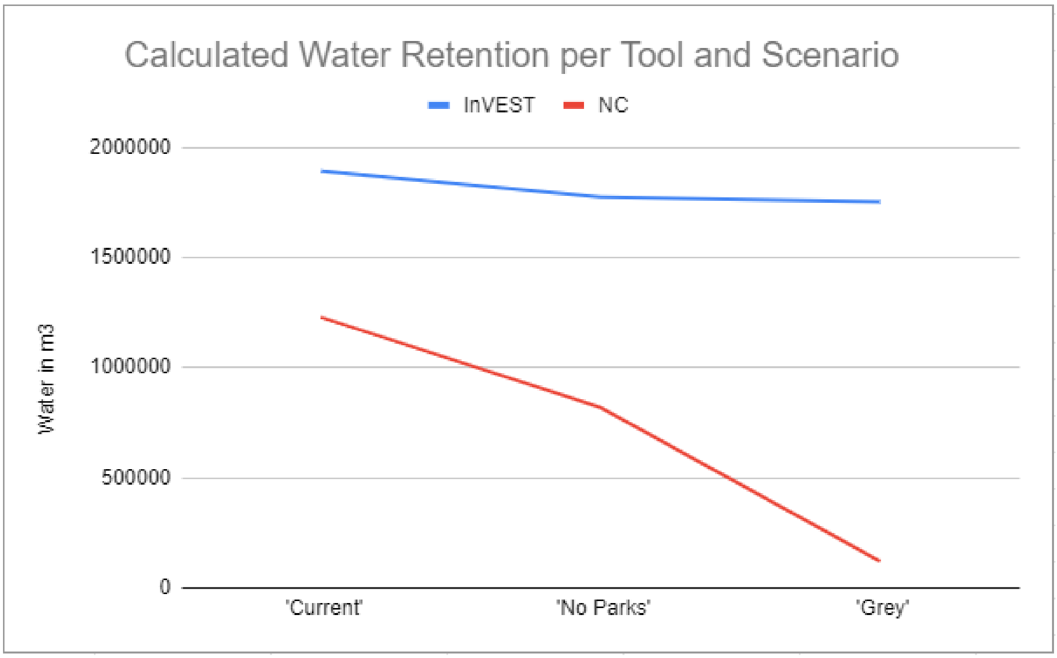
Fig. 12: NC Stormwater Storage by greenery - Neighborhood analysis for 'Current' scenario (left), 'No Parks' scenario (top) & 'Grey' scenario (bottom) scenario



5.2.4 Output Comparison

As the InVEST runoff retention model and the NC water storage model use vastly different variables when it comes to their specific calculations, their calculated water catchment values are quite different (fig. 13), yet in the same orders of magnitude at least for the 'Current' scenario. For the 'Current' scenario, the calculated water catchment of both tools varies from 1.228.814 m^3 to 1.763.640 m^3 respectively, a 35% difference. For the 'No Parks' scenario, both tools experience a drop in total water catchment, whereas the loss for the NC tool is several multitudes bigger than for InVEST. The difference comes to 73 % for the 'No Parks' scenario. Finally, for the 'Grey' scenario, the loss in total catchment volume for InVEST from a 'No Parks' scenario amounts to nearly insignificance, while for the NC tool, total catchment drops to almost 0, making the 'Grey' scenario outputs for both tools incomparable in orders of magnitude, as the difference calculates to over 1.622.040 m^3.

Fig. 13: Differences in Water Catchment between scenarios for InVEST and NC



5.3 Carbon Storage

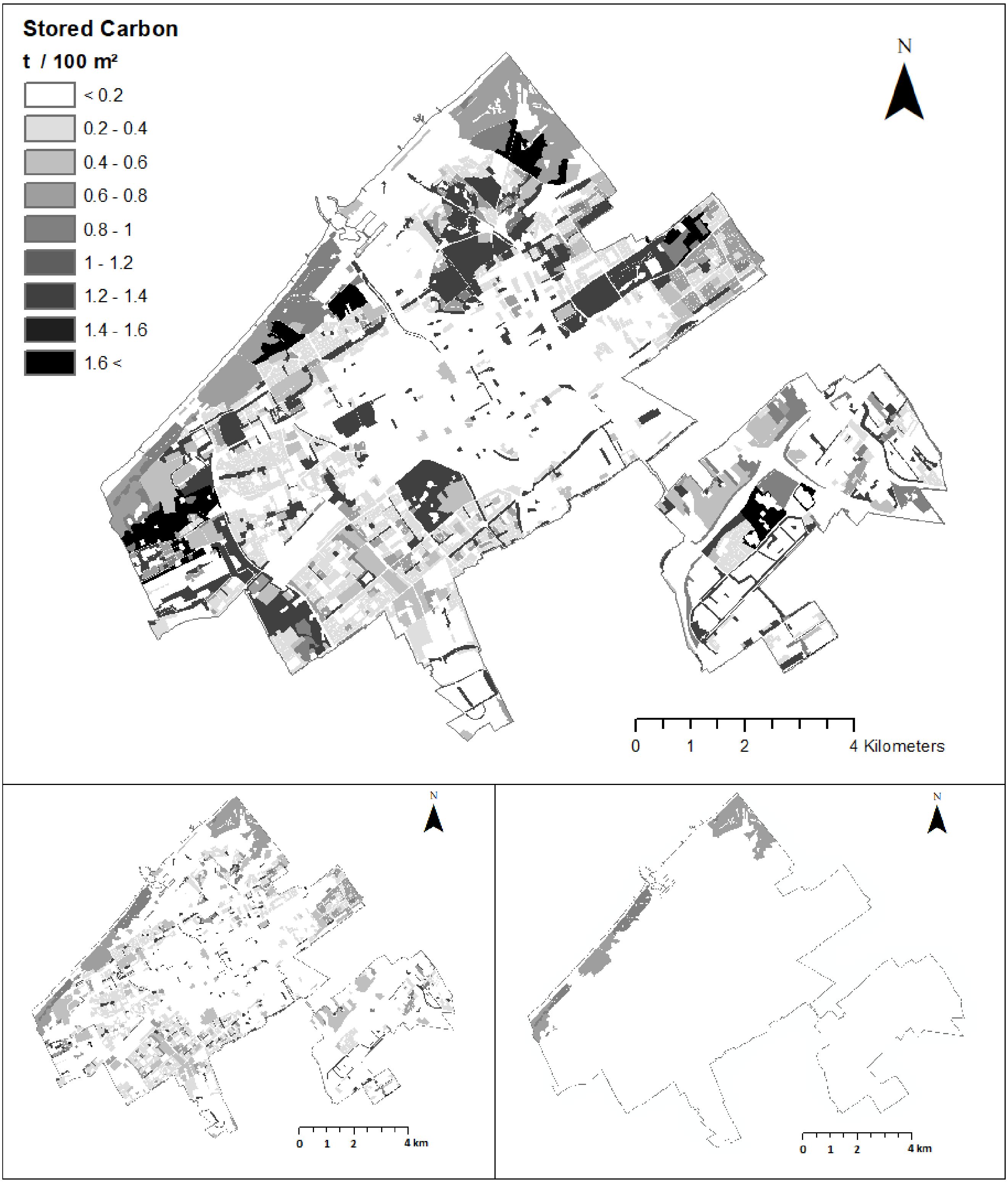
Results for the carbon storage model of InVEST are given in tons / 100 m^2, where 100 m^2 is the area of 1 single cell. The output data was not modified in any way, as tons / 100 m^2 is the native output format of the model. For urban carbon storage modelling, only the InVEST methodology was employed.

5.3.1 InVEST results

Figure 14 (*top*) represents the current scenario for the Carbon Storage model. As carbon storage is closely linked to the occurrence of GI as well as the presence of non-sealed surfaces, the output maps for all carbon storage scenarios resemble by a lot the InVEST GI scenario maps (fig. 1, 2 & 3). The dense urban core areas average less than 0.2 tons of carbon per cell, with up to no storage at all in the worst of cases. Areas with the highest amount of carbon storage for the urban fabric are green urban areas, averaging up to 1.35 t / cell, only being beaten by forest areas outside of the urban boundaries, with up to 1.7 t/cell. It can be seen that the presence of trees makes the biggest difference for carbon storage potential, as simple green remote areas, such as pastures in the north of the AOI (representing ideal areas for heat and runoff mitigation) show a relatively weak carbon storage potential of only 0.7 t/cell, representing only ½ of the storage potential of primarily wooded areas such as urban green areas.

The **total carbon storage** potential for the AOI is calculated to be **356.853 t** for all 4 carbon storage pools combined. Under the Dutch national intended policy (NEV) (CE Delft, 2018), the current CO2 footprint of The Hague should currently be around 1.700.000 t/yr. By setting these 2 numbers into relation, the current carbon storage potential of The Hague is able to store the equivalent of around 20% of a single year of CO2 emissions for the city.

Fig. 14: InVEST Carbon Storage - 'Current' Scenario (top), 'No Parks' scenario (left) & 'Grey' scenario (right)



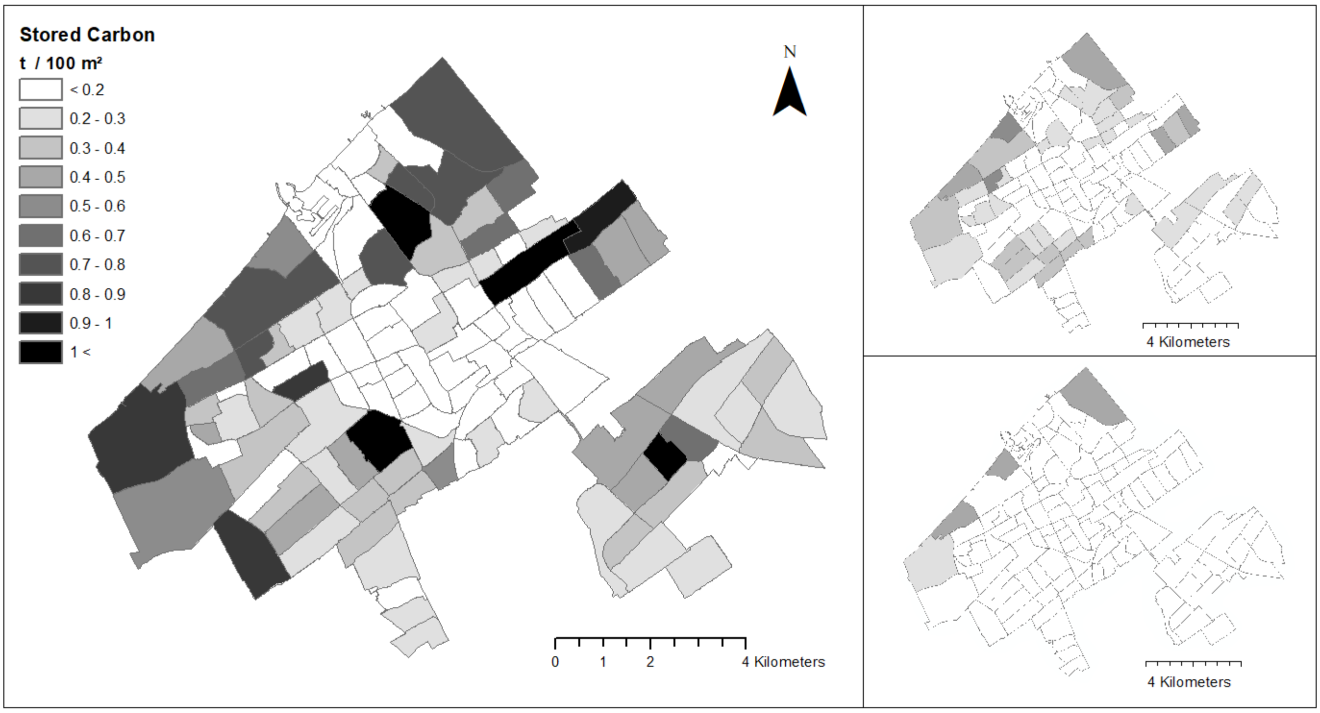
As of figure 14 (*bottom-left*), because of the already mentioned interconnectedness of trees and LULC classes towards carbon storage potential, the only differences between the 'Current' and a 'No Parks' scenario are diminished carbon storage values for former green, now open space areas. Forest and urban green areas, formerly able to store above 1.35 t / cells, are now at the bottom of the list, with an average carbon storage potential of only 0.04 t/cell. For all remaining areas, values stay the same. In terms of total storage, the '**No**

Parks' scenario amounts to **179.719 t**, a total carbon storage loss of over 50 %. Lastly, for the 'Grey' scenario (fig. 14, *bottom-right*), with the absence of GI and no urban green areas left, the average carbon storage ability of urban areas drops to an average of 0.04 t/cell or less. Only vegetated dune areas are able to still store carbon in more significant amounts, which have stayed unchanged in every scenario. Total carbon **storage** potential for The Hague in case of a **'Grey'** scenario is diminished to **60.098 t**, a loss of 83 % from the 'Current' scenario and 67 % from the 'No Parks' scenario.

5.3.2 Neighborhood Analysis

For this model, high priority areas are defined as areas experiencing less carbon storage potential than the best performing areas as calculated in the 'Current' scenario and can be seen as areas where carbon storage focused urban NbS show the biggest potential. For the InVEST 'Current' scenario neighborhood analysis (fig. 15, *left*), the output map, as already seen for the runoff retention model (chapter 5.2), contains, due to the interconnectedness to LULC classes, very much the same visual clues as the main output maps of the model (fig.14). Neighborhoods located in the urban core area, such as Zuidwal or Uilebomen, dominated by sealed surfaces and sparse tree coverage, show the worst average carbon storage potentials, with less than 0.08 t/cell. As a contrast, urban green areas dominated neighborhoods show an average carbon storage potential of above 1 t/cell. Generally, the further from the urban core, the greater carbon storage potential the neighborhoods possess. As such, high priority areas are exclusive to the urban core area. As for a 'No Parks' scenario (fig. 15, *top-right*), the only observable difference is the vastly diminished potential of former vegetation dominated, now barren neighborhoods, which fall from above 1 t/cell to an average of 0.15 t/cell, a loss of 85 %. High priority areas remain the urban core neighborhoods, but shift outwards to now barren neighborhoods as well.

Fig. 15: InVEST Carbon Storage - Neighborhood analysis for 'Current' scenario (left), 'No Parks' scenario (top) & 'Grey' scenario (bottom)



Lastly, for a 'Grey' scenario (fig. 15, *bottom-right*), carbon storage potential collapses for every urban neighborhood, with the very most part of them only able to store less than an average of 0.04 t/cell, while the green, but not densely wooded neighborhoods adjacent to the dunes reaching a maximum of 0.4 t/cell. In the grey scenario, carbon storage potential is basically non-existent and explicit priority areas are not identifiable.

5.4 Coastal Vulnerability

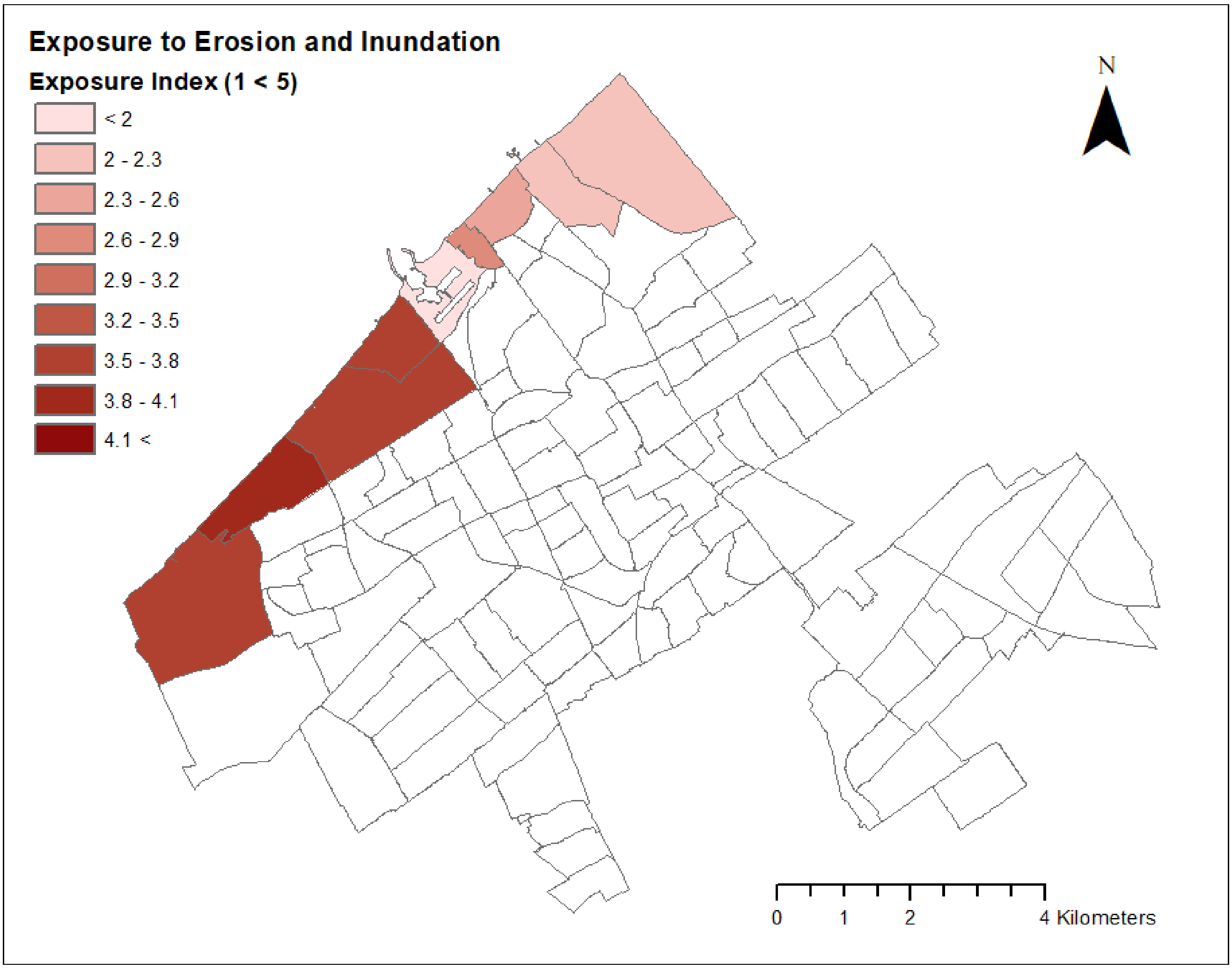
Results for the coastal vulnerability model are given in terms of an exposure index, ranging from a minimum of 1 (very low) to a maximum of 5 (very high). As the original output of the coastal vulnerability model is given as a multipoint shapefile, which is visually inexpressive, it was decided to average the rankings for a multitude of shore points to the adjacent neighborhoods. This allows for a better visual expression of exposure and facilitates communication. Another possibility would have been to create a polyline out of the multipoint file and to color the shoreline according to the exposure index, done so by Hopper & Meixler (2016), but it was ultimately decided against such a methodology, as for short coast sections, the differences in average exposure indexes did not show very clearly. Only the InVEST tool was employed to calculate coastal vulnerability. Furthermore, as already mentioned in chapter 4.4, the InVEST coastal vulnerability results are only made up of a current scenario as well as an adapted grey scenario, containing no GI whatsoever.

5.4.1 InVEST results

As for current exposure to erosion and inundation (fig. 16), the average exposure ranking for the entire coastal area comes to 2,8, expressing a below moderate exposure risk. Yet, as average exposure rankings do not necessarily represent adequate information for smaller coast sections, the average exposure index of different coastal neighborhoods is looked at. The least exposed coastal neighborhood, by a difference of 0,8 points above average, is the harbor area, Vissershaven, with an average exposure ranking of 2,0. Following are Oostduinen, with an average exposure ranking of 2,1. As all neighborhoods towards the right side of the harbor can be assumed to be relatively well protected against floods and erosion, with the top most exposed neighborhood ranking at 2,7, coastal neighborhoods to the left of the harbor are drastically less protected. With Ockenburgh expressing a calculated exposure ranking of 3.7 up to Kijkduin with 4,0, the leftmost situated coastal neighborhoods express more than 1 full point above average.

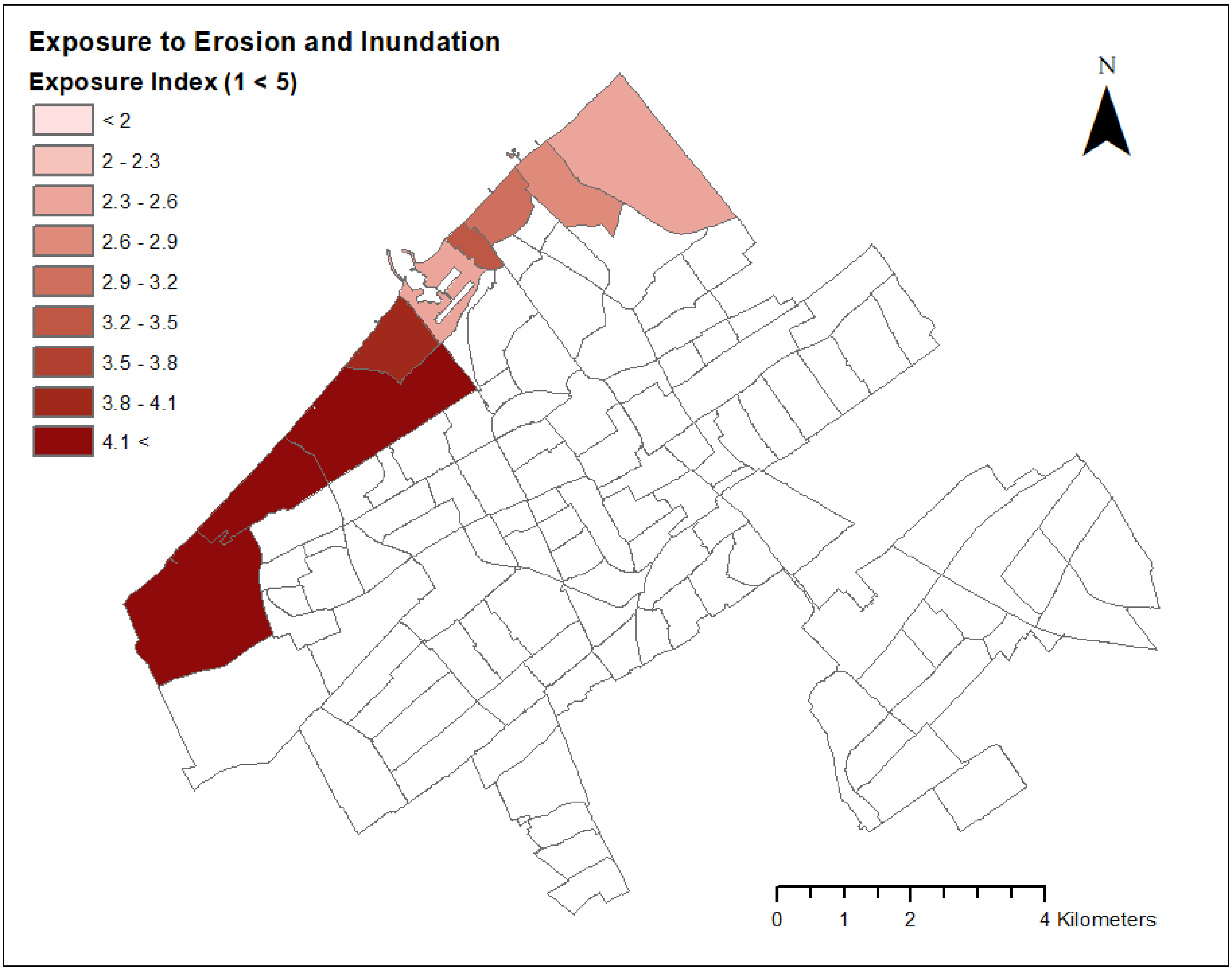
As for the alternative 'Grey' scenario (fig. 17), the overall average exposure ranking comes to 3,3, disclosing an above average exposure risk and a total rise of 0.5 points from the 'Current' scenario. As for single neighborhoods, the relative exposure rankings in relation to the average ranking stay similar as for the 'current' scenario, with the harbor area still being the least exposed neighborhood with an average exposure ranking of 2,4, a rise of 0,4 points, with all further rightmost coastal neighborhoods having elevated exposure rankings of between 0.3 and 0.5 points from a 'current' scenario. This trend equally continues to the left side of the harbor, where the exposure rankings for all coastal neighborhoods have risen between 0,4 and 0,5 points from a 'current' scenario. As for the 'Grey' scenario, only 1 single habitat is left (e.g. dunes) the role of dunes into mitigating exposure can be calculated by consulting additional information in the original multipoint output file. As for the leftmost part of the AOI, the Ockenburgh neighborhood, dunes are mitigating up to 0,5 points in terms of exposure to floods and erosion. This number progressively diminishes down to 0,3 points for the leftmost neighborhoods such as Duindrop, after dropping to 0 for the built-up neighborhoods of Vissershaven to Scheveningen. Only the right sided neighborhoods of Belgisch Park and Oostduinen experience some exposure mitigation by dunes, up to a maximum of 0,2 points. As for the affected population per shore point, they do not influence the final exposure ranking but are given as additional information. Due to the geographical shape of The Hague, coastal inundation in the leftmost areas affect the most people, with up to 7000 individuals, dropping to an average of 5000 people for the harbor area, reaching a minimum of 3000 affected people at the very rightmost edge of the coast.

Fig. 16: InVEST Coastal Vulnerability - 'Current' scenario



For this model, high priority areas are defined as areas experiencing exposure levels equaling or overpassing the worst performing areas as calculated in the 'Current' scenario, and can be seen as areas where coastal protection focused urban NbS have the biggest potential impact and priority. As in both scenarios the leftmost coastal regions show the biggest need for improvement, highest priority areas for NbS stay the same, as these areas furthermore rely the most on natural infrastructure to be present, such as coastal forests or dunes.

Fig. 17: InVEST Coastal Vulnerability - 'Grey' Scenario



6. Discussion

In this chapter, the results of the study as well personal experiences and future research recommendations will be discussed. First of all, results for each ES analysis will be critically analysed, followed up with an individual judgment of the performance of each tool. Then, a general opinion about the employment of urban ES assessment tools will be reflected upon, finishing up with thoughts about the here applied methodology and data sources as well as recommendations for future research on this topic.

6.1 Urban Ecosystem Services for The Hague

In this research, the benefits of 4 different urban ES have been analyzed for a total of 3 different scenarios. For 2 ES (e.g. Urban Heat Mitigation & Urban Flood Mitigation), 2 different quantitative ES assessment tools have been employed, while for the other 2 (Carbon Storage & Coastal Protection), only results from the InVEST methodology are provided.

6.1.1 Urban Heat Mitigation

The results for the 'Current' daytime urban heat mitigation analysis are overall synonyms. With the Hague experiencing an average cooling of 1.62 - 1.65 °C, both InVEST and NC agree upon a near identical cooling potential due to natural infrastructure. As expected, dense urban neighborhoods in the urban core of the city pose the biggest potential for amelioration, due to their general lack of natural infrastructure. Especially at night time, the dense building footprint without major open areas manifests in higher temperatures than neighboring areas. Positive effects of major green urban areas are recognizable on a city-wide scale, and have the biggest proven impact on localized, neighborhood level cooling. As for their importance for city wide cooling, results differ. While it can be attested that major green areas do attribute to city wide heat mitigation, their particulate proportion differs from over 0.5 °C to less than 0.1 °C depending on the ES assessment tool used. As unanimous as both tools attribute cooling capabilities to local natural infrastructure, as unanimous is the situation in case of no vegetation present. While it can be attested that not all urban cooling capability comes solely from GI (e.g. Albedo,...) their total absence delivers a major blow to UHI mitigation efforts. Although BI is attributed with some local cooling potential, and is as such even visually attestable, in its current state it seems to fail at making a major cooling impact for The Hague. Additionally, there is growing evidence for blue urban infrastructure to be a contributing reason for enhanced urban night time heating (Ampatzidis & Kershaw, 2020; Jacbos et al, 2020), yet cannot directly be tested for, as the NC Heat Mitigation model does not include a night time variant. With the urban core of the Hague emerging as the most affected area by trapped heat and the local urban green areas emerging as the 'coldest' hotspots, overall results line up with studies previously done on this topic as well as specifically for The Hague (Grilo et al., 2020; Veerkamp et al., 2020 ; Den Haag, n.d.; Oorschot, 2019). Considering NbS, without having incorporated any additional parks or green roofs, it can be attested that common, currently existing NbS, such as parks or canals do attribute a significant amount of cooling in comparison to alternative land cover classes, vouching for the effectiveness or their use. As such, without having modelled a 'Green' scenario, it can be assumed that the greater use of NbS will only enhance urban heat mitigation strategies. The results do however also showcase the limits of natural urban infrastructure into mitigating heat in a future climate change scenario, where a global temperature rise of 2 °C or more is very likely (UCAR, 2020), surpassing the current cooling capability of urban green and blue infrastructure altogether. For the nighttime temperature analysis, the negative implications of dense urban build infrastructure pictured represent the latest findings on this topic (EPA, 2014) and serve well for future planning exercises, yet could have been improved by incorporating a nighttime UHI.

As far as co-benefits of urban heat mitigation go, calculated energy savings are small and as such not very interesting for an entire AOI the size of a municipality (J. Schuurkamp, personal communication, 2020), leaving the inclusion of energy savings by less AC use a questionable decision for this study. Although low AC relevance for the Netherlands is a main contributing factor for this (IEA, 2018), a major drawback of the model is the process of calculating energy savings per building type based on footprint data alone, as this excludes calculations for multiple floors. A recent addition in the InVEST user guide (Natural Capital Project, 2020b) hints towards this problem as it advises the user to plan accordingly towards this limitation, but does not elaborate on how to do so.

Next to the issue with multiple floors, the inclusion of an energy use number per m^2 is problematic to begin with, as energy use for foremost industrial businesses tends to vary greatly with the size of their operations. A possible circumvention is to label building types much more detailed into specific business types and contribute fitting energy use numbers for each one, yet such a methodology is dependent on local data availability as well as time intensive. As an alternative to a heat stress neighborhood analysis, a 'Building

Footprint' heat stress analysis could have been performed as well (Appendix 9.9), enabling an even more precise problem location in terms of heat mitigation interventions. Yet as air temperatures are not limited to building footprints, as well as the presence of AC throwing off actual air temperature measurements in buildings, it was ultimately decided against the inclusion of such.

As for how much the difference in tree coverage data played a role in the different temperature calculations per methodology, tree coverage data used for the NC calculation was substituted in the InVEST calculation, resulting in a final average air temperature difference for the AOI of a maximum of 0.3 % or less than 0.1 C for each scenario. As such, the choice of GI data does influence the overall final results, but by a nearly insignificant amount. As the change in tree cover density between datasets is not limited to single cells or specific LULC classes, but can be observed universally for the entire AOI, no single region would especially be discriminated against. Ultimately, it was possible to quantitatively demonstrate the existence of benefits for heat mitigating urban NbS for The Hague with the here employed spatial assessment tools, yet overall inclusion of useful co-benefits was lacking and the definite impact of the removal of urban parks and forests remains uncertain.

6.1.2 Stormwater Runoff Mitigation

Results for stormwater stored vary greatly for each tool. Both tools credit the occurrence of GI, either directly or indirectly, with water retention potential, yet entirely different methodologies are employed to do so. As for the current state of affairs, stormwater runoff catchment is expectedly the worst for the dense urban core areas of The Hague, with neighborhoods adjacent to the central station coping the worst with stormwater runoff mitigation. In terms of the neighborhood analysis, priority areas remain for all 3 scenarios the most soil sealed areas. These results are in line with similar studies done for The Hague (Den Haag, n.d.; Oorschot, 2019). Less surface-sealed neighborhoods, such as major green urban areas, are found to help relieve some stress off the mixed sewage system, by storing up to over half of the precipitation of the design storm. This is as far as both analyses have in common. While, due to the limitation of vegetation, water uptake capability for the NC tool never exceeds 55%, InVEST calculates for green rural areas water retention values of over 99% for the design storm. With diminishing green area coverage, water retention values for the NC tool drop to nearly 0, while for InVEST, the change is nearly insignificant. Based on the straightforwardness of enhanced vegetation coverage and less soil sealing equaling enhanced water retention capabilities, common NbS for water runoff retention incorporating such interventions can be assumed to be an effective way in mitigating stormwater runoff. Although no scenario in which additional NbS have been introduced, it can be assumed that further greenification and the accompanying open soil areas will only enhance runoff catchment for the city. For co-benefits calculated with the InVEST Stormwater Runoff Mitigation model, possible monetary damages surpassing 8 billion € do not seem very helpful into realistically assessing flood damage calculations, as such a great overestimation of actual damage in case of stormwater flooding would hardly convince policy planners into taking action, as no specific priority area is highlightable. Such high damage calculations are ultimately expressed due to the methodology of employing a worst-case scenario, by assuming flooding of the complete AOI, instead of singling out actual areas in distress. If the watershed is divided into sub watersheds, which has not been done as part of this study, actual damage calculations could be limited to single sub watersheds yet still not necessarily represent areas that are in actual danger of flooding.

The NC models calculation of the value of water taken up by vegetation, subsequently not flowing into the wastewater treatment system, coming to over 900.000 € seems like a more conservative, yet still high estimation, as stormwater overflow discharges as well as the possibility of wastewater separation are not being taken into account. While for InVEST, it was tried to incorporate the existence of a sewage system by accordingly adapting the maximum flow length inside the AOI, the model does not natively incorporate runoff to the sewage system. As such, results of this study are not necessarily descriptive of the likeness of flooding, but are hinting towards minimum capabilities that a local sewage system needs to provide. As simplifications have been taken in this study, such as the assumption of a single watershed, final results are not to be taken granted, but aim to present a representation and estimation of possible urban runoff retention. Furthermore, the assumption of a fixed 55 % of water storage for vegetation by the NC model does exclude a lot of factors such as type and density of vegetation, intermittent droughts or soil porosity, all influencing water uptake capability of vegetation (Hacke et al., 2000; Kletter et al. 2009). Furthermore, as the 55 % precipitation uptake by vegetation of the NC tool is based on yearly averages, it is questionable if the same number can be assumed for shorter rain events.

To sum up, benefits of urban NbS in terms of stormwater runoff retention for The Hague could be demonstrated with the here employed tools, yet, due to a multitude of different variables and contrasting results, precise quantitative results for both the main benefits as well as co-benefits are hard to settle on. Depending on the aim of the study, the results of separate tools might be of interest. While the InVEST methodology conclusively represents an infiltration model, the NC results represent long term water storage inside of vegetation. Despite their common ground in being able to calculate reduced water load to the combined sewer system, their methodologies and results ultimately differ too greatly as to be seen as analogous models.

6.1.3 Carbon Storage

As already for both the previous models, carbon storage potential occurrence is generally greater for greener, less surface sealed areas and only diminishes for less vegetated scenarios. High priority areas match the ones of previous models, as the carbon storage model attributes centrally located urban core areas very little to none carbon storage potential, while the most densely wooded areas get attributed the most. This coincides with the fact that of all natural infrastructure, trees and associated soil and root systems are the superior long term carbon storage sinks, due to their woody stems as well as deeper reach into the soil system, as opposed to for example low vegetation areas alone (Boutton. T.W. et al. 1999; Mackey et al., 2008). Possible NbS capable of enhancing urban carbon storage are coinciding with possible interventions of both previous ES as well as concentrating on woody vegetation areas. It can be assumed that especially the creation of further urban forest areas, such as 'Haagse Bos' as well as street trees would further enhance urban carbon storage capabilities. This further manifests the multiple simultaneous benefits that NbS are capable of. Although the potential of natural infrastructure being able to store 20% of the yearly CO_2 emission of the Hague sounds promising, carbon storage should not be confused with carbon sequestration, as sequestration represents the long-term effect of storing additional carbon over a certain period of time, whereas carbon storage is a momentary extract in time, showing current storage capabilities only. In this case, if carbon storage is able to store 20 % of emitted CO_2 for the city, and no sequestration is taken into account, the possibility to store additional carbon for the following year drops to 0. Due to the unavailability of future land plans for the city of the Hague, and the preparation of future land plans being out of scope for this study, no carbon sequestration model could be applied. Furthermore, as not many studies have been done on the ability of urban vegetation to store carbon and the methodology of this research being inspired by the findings of a single study (Tang et al., 2016), results for the carbon storage model would profit from validation of additional research into this topic.

At last, the InVEST carbon storage model was able to reveal existing potential for urban NbS into enhancing urban carbon storage and mitigating urban CO_2 emissions, yet is limited in its ability to provide usable quantitative results for policy and planning exercises, both for a lack of research into this topic as well as an unfortunate study design.

6.1.4 Coastal Vulnerability

What differentiates the results of the coastal vulnerability model from other models in this research is the fact that, while all input values are of quantitative nature, the final outcome of the tool needs to be put in relation as to be helpful for further use. As the model showcases differentiations of the coastline towards inundation and soil erosion, it is not instantly clear as to how these results shall be further used. For this reason, it is indispensable to keep in mind that the InVEST coastal vulnerability model represents a tool to facilitate ES analysis and offers to better understand the relative contributions of different biological and physical variables towards their respective roles into securing the coast, without explicitly expressing quantitative results, such as for a carbon storage model. By providing exposure levels for each shore point, ranging from 1 (very low) to 5 (very high), the model tries to highlight high priority areas that either need further analysis into ameliorating their exposure ratings or at the very least try to nudge possible further research towards a specific high priority area. As such, the results of the Coastal Vulnerability model clearly show an elevated risk for the leftmost situated coastal area into being more vulnerable towards flooding and erosion than the centrally or right located areas. Furthermore, by taking out the presence of trees, their subsequent role in shielding the coast from floods and erosion becomes obvious by higher exposure values for the entire coastal area. The results also show that, although the left side of the coast is already the most vulnerable area to begin with, dunes play a bigger role in their protection than for the right sided areas, hinting at the indispensability of dunes and coastal forests into keeping the vulnerability levels for the leftmost areas from reaching high to very high. Aside from lower exposure to wind and wave induced hazards, lower exposure levels for the central and right sided shoreline can mostly be explained by the presence of a seawall and an overall higher relief.

For additional information, keeping in mind the presence of the sand motor project (Zandmotor, 2020) just outside the leftmost shoreline area in the AOI, the inclining exposure rankings towards the project area hint at an adequate position for such an automated sand replenishing strategy. In terms of NbS potential, the role of dunes and coastal forests are clearly graspable from this analysis. The result definitely vouches for their upkeep, yet, in comparison to NbS of preceding ES analyses, make it difficult to predict if the further expansion of them will have any additional positive effects for The Hague. The results further show the greatest effectiveness for NbS in combination with existing grey infrastructure, such as seawalls.

For the entire AOI, while the goal of this model is to calculate exposure levels for coastal areas, it is hard to draw a conclusion for the entire city, as geomorphology of further inland areas or building density is not taken into account, making an analysis for non-directly coastal adjacent neighborhoods impossible. The model does however provide insight of possibly affected population numbers, yet they do not play a role for the final scoring and represent only an addition to the output results. As such, they are not very telling, as higher exposure to population is not synonymous with the area being of higher priority. All in all, the InVEST coastal vulnerability model serves its purpose by highlighting the positive role that NbS play already now for the coast of The Hague, yet leaves it unclear if further building on NbS as coastal protection interventions is advisable.

6.2 Urban Ecosystem Service Assessment Tools

6.2.1 InVEST tool

With the Natural Capital project (2020a) describing the InVEST tool as a suite of models, able to "map and value the goods and services from nature that sustain and fulfill human life", the inclusion of currently 2 urban explicit models does certainly enhance the outreach of overall ES mapping and valuing, for which the urban environment has seen a lack of until now. For the future, a separate InVEST tool, called Urban InVEST (Natural Capital, 2020c) is currently being worked on, including many more urban explicit models (e.g. air quality, mental health, ...). For the models employed in this study, including 2 non-urban explicit models, overall performance for the urban environment can be attested as positive, as many urban relevant variables, such as population and building density, or societal co-benefits such as energy savings, find use in the specific methodologies. With free, constant updates to the software, a very well detailed user guide (Natural Capital Project, 2020b) active help on the official forum (Natural Capital Project, 2020d) and the inclusion of user feedback into help guides and software builds, the user experience of InVEST is reasonably pleasant. Due to the user interface of InVEST as well as explications for many of the needed variables, InVEST as a spatial modelling tool has promising potential as being used by a wide variety of stakeholders, as long as basic to intermediate GIS knowledge is present. Before the employment of the tool, extensive literature research as well as precise preparation of input variables and maps is required, as many of the required input values are case specific or need to be prepared with a certain methodology to be usable.

While the exact methodology and results of the InVEST models have been explained in earlier chapters, main perks include the wide variety of user influenceable input variables, the calculation of optional, not strictly ES limited co-benefits (e.g. nighttime temperature by building density) and the inclusion of recent scientific findings. Drawbacks of the InVEST tool include a certain obscurity towards certain results as well as unfortunate methodological limitations. As an example, while the inclusion of a nighttime model for Urban Cooling is of great interest, and a formula has been provided, the exact methodology of the model is still obscure, and the final temperature results are hard to put in context. Furthermore, although the occurrence of inundation and erosion goes hand in hand, sudden storm induced flooding can have instant effects, whereas erosion for the most part takes place over a certain amount of time, yet results for the Coastal vulnerability model do not allow for a different exposure ranking based on one or the other. Moreover, simplifications such as the assumption of the presence of a complete coastal forest while only 1 single cell within the radius of a shore point is dedicated as such, might be misleading as for the role that natural infrastructure actually plays. Lastly, in the context of a European study, some design choices for InVEST feel very USA centered, such as the inclusion of an energy saving metric depending on prevalent AC use, making little sense for the EU, or the inclusion of predominantly American specific classifications, such as for the geomorphology values.

Inspiration from a comparison with the NC tool can be taken from the inclusion of actual airspeed values as well as roughness coefficients for LULC classes, as to further personalise actual air mixing values in an urban context. Also the inclusion of different types of vegetation for urban heat and flood mitigation calculations might enhance final accuracy as would the incorporation of a separate spatial vegetation input file, instead of averaging shade values per LULC.

6.2.2 Natural Capital tool

As the NC tool aims to map and quantify ES for the Netherlands, with the goal of integrating ES further into policy and planning exercises, the current overall choice of available models fits well into current environmental policy agendas. Although only 2 models have been chosen for this study, further models such as Urban Health or Air Regulation are available. With the explicit aim of developing urban centric models, the urban variant of the NC tool tries to fill a void in the current urban ES analysis cosmos. As the NC tool is not publicly available as of yet, and has so far been developed with explicitly the Netherlands in mind, a comparison with a more major tool such as InVEST is not necessarily fair, yet helps to highlight flaws in both methodologies. As in order to run the tool, basic coding skills are required, in its current state, the NC tool would not directly be usable by a wide variety of users. Analysis results for a multitude of Dutch cities might be available from RIVM (R. Koopman, personal communication, 2020). As for the urban suitability of the tool, urban planning relevant variables such as a water treatment cost analysis, the calculation of sealed surface prevalence or the ability of urban infrastructure influencing wind speeds, speaks for a very urban centric application area and the use for an urban case study analysis can be described as satisfactory. As for explanations on the methodology on the tools as well as input values needed, information can be taken from past research (Remme et al., 2017; Paulin et al., 2020), and is mostly sufficient, but not very extensive. Due to the referral towards 'expert knowledge' in some of the methodological explanations, it is furthermore not always possible to completely follow the argumentation for certain methodological choices. As already for the InVEST model, the same care into creating an extensive literature research as well as precise preparation of input variables and maps is required, as again many of the input variables needed are case specific, such as LULC specific values or need to be prepared in a certain way as to be able to be used, an extraordinary important step for the proper functioning of the NC tool.

As the methodology and results of the NC models have been discussed in earlier chapters, main perks of the tool are the possibility of a bigger variety of urban specific models (only 2 of 6 + models have been employed in this study) than for similar tools, as well as the inclusion of more case specific variables (e.g. different kind of vegetation, population data influencing the UHI, ...). Drawbacks of the tool incorporate possibly overdone simplifications and unclear use cases. The 2 models tested do rely on many calculations based on Dutch yearly averages, such as for example rainfall intensity or the magnitude of the average UHI effect, ultimately diminishing case specific usability and results by not easily letting the user modify such values. Furthermore, by oversimplifying certain research, such as by assuming a strict 55% water storage rate for yearly precipitation by all forms of vegetation, actual results are to be taken skeptical and can hardly be assumed to depict actual storage rates. In addition, although a model such as the water storage model appears in the first instance to be able to calculate stormwater runoff retention fairly well, it is not until the actual employment of the model and peek behind the methodology, that the intended use case of the model becomes evident.

Inspiration from the comparison with InVEST can be taken from enhancing the documentation of the models as to better prepare potential users into what exactly they represent as well as documenting and allowing for interchangeable variables, in order to allow for better case specific analyses. Furthermore, the NC water storage model is very simplistic and could be further developed into a water storage & infiltration model.

6.2.3 Bottom line of quantitative urban ES assessment tools

Although results and usability vary, ultimately both here employed tools delivered on their promise of quantitatively assessing the benefits of urban ES, and therefore stand as valuable advancements into filling urban ES knowledge gaps. Not only do the ES analysis results of this study stand in line with what the tools were designed to do (R. Remme, personal communication, 2020) but further represent an important input for municipal planning exercises (J. Schuurkamp, personal communication, 2020). While many similarities between the tools could be found, such as the quantitative nature of input and output values or the monetization of co-benefits, foremost the importance of the case design as well as understanding the methodology behind the models stand out. While by description alone, models for different tools seem to pursue equal outputs, they might end up prioritizing entirely different variables. While this does not necessarily elevate one model above another, it does mean that models need to be truly understood before a final decision on either their employment or their results should be taken. Furthermore, case design seems to play an important role. While for one scenario, (e.g. 'Current' scenario), results for equal models (e.g. InVEST & NC Urban Cooling models) might be expressing near perfectly matching outputs, their results could not differ further from each other for a subsequent scenario (e.g. 'No Parks' scenario). As such, results from ES models should not be taken as granted and need to be questioned with both the case study design as well as the methodology of the specific model in mind. As far as differences between models go, the actual combination of similar models from different tools could even be beneficial, yet actual implementation in studies remains unheard of. For the water retention models, both methodologies would be profiting from a combination, as on one hand, the NC GI water storage model would profit from InVEST data about water retained in soil, while on the other hand, the overall stormwater runoff mitigation analysis could be improved by combining calculations for overall reduced stormwater runoff to the sewage system from both analyses.

Although the theoretical benefits of ES assessment studies are evident, their limitations have to be kept in mind as well. Especially urban ES assessment tools are still in the early stages of their development. As such, not only is much of the science behind variables influencing urban ES assessment still in active discussion (e.g. Cooling distance of green areas, carbon storage potential of urban vegetation, ...), the urban environment is furthermore much more heterogeneous than its rural counterpart, further complicating adequate predictions of current ES benefits as well as actual impacts of urban NbS. While studies relying on ES mapping and valuing are able to showcase potential ES gains as well as high priority areas concerning NbS interventions, their abilities in delivering precise impact assessments for a multitude of stakeholders are often limited by the precision, type and amount of data being put in, their amount of calculated co-benefits as well as the very diverse environment of the city. Especially the greater inclusion of co-benefits as well as a greater emphasis on supporting grey infrastructure into mitigating climate challenges together with natural infrastructure (as opposed to only replacing them) has potential to achieve the biggest gains in terms of impact as well as stakeholder adaption (Alves et al. 2019). Furthermore, although the models try to include relevant scientific findings as far as possible, certain scientific disagreements, such as the specific design and shape of blue and green spaces potentially having major impacts into affecting cooling potential (Gunawardena et al., 2017) are near impossible to take care of as part of a spatial ES assessment tool. While certain values are user adjustable, the core methodology of each model is mostly predefined.

Lastly, the very nature of these employed tools can also be questioned as part of a demand vs supply issue. Although in recent years, the valuation and mapping of ES for smart urban planning has become more and more standardized, especially the mismatch between the native tool based prioritization of ES & NbS intervention potential and the identification of residential stakeholders profiting from interventions, remains largely unaddressed (Hazell, E. 2020). While the analysis of either entire urban areas or on a neighborhood level might showcase high priority areas in terms of heat reduction or runoff catchment, as done in this study, it is not clear if, based on demand types other than direct risk reduction such as society specific values, direct usability or consumption of goods and services, the same areas would be favored as well (Wolff et al. 2015). At last, it needs a clear distinction between ES capacity, flow and demand as to not overly provide ES benefits and NbS in areas where they are used unsustainably, while falling short into meeting societal demand where they are needed the most (Baro et al. 2016). While specific models, such as the InVEST Coastal Vulnerability model include calculations for affected people per area, they do not allow such data to influence the final vulnerability score, and as such have no native role into addressing the specified problem as of yet.

6.3 Data and Methodological Approach

Most of the data used in this study, either spatial or non-spatial, comes from open access sources or has been adapted from past research. Many inaccuracies come from the fact that much of the past mapping and assessment of ES studies was done for the non-urban environment, and are as such often missing urban specific information, such as for example carbon storage potential for urban land use classes. On the topic of data, it should be noted that verified, precise urban vegetation data is hard to come by, yet essential for an accurate assessment of urban ES. Available data is often either not in the right form, such as consisting only of locations of trees, without containing information about size or extent (Geo Informatie Portaal, 2020) or relatively coarse (Copernicus, 2018). Also, neither dataset used for urban vegetation incorporated the existence of green roofs, leaving out the possibility of addressing a valuable type of NbS entirely.

As all models heavily rely on the provision of a LULC map by attributing much of the calculations and non-spatial data to a specific LULC class, absolute confidence needs to be put in the provision of this map. Although available information for data used in this research often fits well for the classes specified in the Urban Atlas LULC map (Copernicus, 2020), alternative land cover data, such as the LCEU maps (CBS, 2017), might have been a more precise fit for the Netherlands specifically.

As far as for the methodology, although in an earlier chapter the non-employment of a calibration method for the InVEST Urban Cooling model was argued for, the employment of one would certainly have been a plus. Afterall, a calibration of the InVEST urban cooling model in terms of comparability towards the equal NC model might even have been of benefit, as much of the methodology behind the NC tool is standardized to Dutch averages.

Furthermore, the choice of tools and models might not have been ideal. Although the purpose of the research was to compare 2 different urban ES assessment tools, which has ultimately been delivered on, a different combination of tools and urban ES models to compare might have delivered different results. The choice of scenarios can be questioned as well. Instead of 2 scenarios incorporating less green urban infrastructure, the ‘Grey’ or ‘No Parks’ scenario could have been followed up by one ‘Green’ scenario, being made up of more green and blue infrastructure than the ‘Current’ scenario. This could have further promoted the inclusion of urban NbS, as common NbS such as parks or green channels could have artificially been created and serve as an example for future planning exercises.

Lastly, although it was taken care of including as many necessary variable changes per scenario as necessary (e.g. changing shade values, LULC classes, crop coefficients, …) some variables that would changed with more or less vegetation coverage, such as evapotranspiration or roughness coefficients, were not altered between scenarios. Reasons included the incompatibility between resolutions as well as missing knowledge about the exact nature of the modification.

6.4 Future Research

Although some of the ES employed in this study, such as urban heat or flood mitigation, are essential for the urban environment, many more urban ES could have been employed. Especially socioeconomically influenced NbS such as urban health or mental wellbeing are of special interest for municipalities, as they are often left untouched to date (Schuurkamp. Personnel Communication. 2020).

As for ES employed in this study, more research is needed for many of their variables. Especially the carbon capture potential of urban vegetation, cooling capabilities of urban BI or runoff retention for urban vegetation belong among debated topics in the scientific community, yet ultimately had to be settled. Especially as, to a certain extent, experimental approaches had to be followed, further research will only enhance overall accuracy of results.

Considering accurate spatial data for certain necessary inputs was limited, the inclusion of more precise data might be of benefit in further modelling exercises, as accurate spatial data really can make a difference. Although specifically for the Netherlands, rather precise building data was available, possible alternative sources in the future might help to enhance accuracy even more (Microsoft, 2020). Furthermore, the possibility of mapping individual trees might be an option in the near future, possibly representing a leap forward into precise ES modelling (Hanan & Anchang, 2020).

Lastly, the overall lack of studies comparing different (urban) ES assessment tools to each other is concerning and should be further built upon. As the comparison and combination of tools and models highlights shortcomings as well as enhances usability and credibility of results, more research concerning the comparison and combination of different tools should be done by researchers and city planners alike.

6.5 Policy & Planning Recommendations

Due to the combination of uncertain science as well as occasionally vast differences between results, the design of urban NbS based solely on the outputs of the presently employed tools is debatable. While the possibility for planning and policy makers to fall back on commonly available spatial ES assessment tools certainly helps the overall use case of urban NbS, and the increased use of green and blue infrastructure in the urban environment displays many advantages, the decision for priority areas based on tools such as InVEST or NC alone is unwise. As long as different assessment methodologies for the same ES attribute drastically different values to specific NbS such as major parks, ranging from utmost importance to near indifference when it comes for example to urban heat mitigation, tool-based decision taking is troublesome. As for now, more studies need to be done employing such tools, followed up with real world NbS interventions, ending with a final comparison between calculated and measured benefits. As such, in parallel with an ES assessment tool-based study, local municipalities and governments should actively start employing the use of NbS in future planning exercises, as this research, among others, showed them to definitely harbor positive effects towards urban resilience, yet the exact extent remains unclear. In a first step, this should be done in combination with grey infrastructure, as actual impact assessment beforehand remains uncertain and combination of natural and grey infrastructure is not only attributed a high efficiency in literature, but could be proven in this research as well. Only if a common consent on the real-world consonance between theoretical modelling and actual implementation is established, the outlining of NbS as sole alternatives to existing grey infrastructure in city planning exercises, based on urban ES assessment tools, can be recommended for.

6.6 Modelling Recommendations

While ES assessment tools like InVEST are not exactly a novelty for environmentally focused study disciplines, which actively helped to develop such tools over the last decades, they only recently started to gain significance for urban planning exercises. Although urban ES mapping and valuation tools do increase access towards urban NbS evaluation, it is clear that the development of specific urban assessment methodologies is still lacking. This does not only show in the relatively low number of urban specific ES models to choose from, but as well in the overall rare employment in scientific studies. As for increasing the use of urban ES assessment tools, modelers should actively seek the employment of their models in current urban planning projects. Future spatial urban ES assessment studies should ideally be backed up with the possibility of implementing urban NbS in the priority areas found to be most in need of them, as this helps further validating the accuracy, and as such the trust of users into the results. Furthermore, transparency of the methodological background as well as shortcomings of the models should further be enhanced. Although efforts are being made towards full transparency, the composition of key outputs of some models is not always clear as aren't certain assumptions the tools take when it comes to current research.

7. Conclusion

In the face of climate change and anthropogenic pollution, cities' abilities into being resilient towards environmental changes has never been more important. In this research, the benefits of natural urban infrastructure into delivering such resilience has first been attested as part of a theoretical framework, followed up with a tool based case study analysis. As different scenarios, tools and models have been employed, uncertainties in current urban ES modelling could additionally be addressed.

In a first step, urban ES and NbS have been found to benefit the city and its citizens in a multitude of ways, such as by stormwater runoff reduction, active cooling of city wide air temperatures, the abrading of urban carbon dioxide domes or the protection from coastal erosion. As far as benefits go, mapping and valuation exercises confirmed what the literature research suspected. With direct risk reduction as the main demand type, the employed spatial ES assessment tools successfully highlighted known high risk areas of The Hague, such as predominantly surface sealed urban core neighborhoods, to be the most vulnerable to heat and flooding issues. The analysis further revealed the benefits of already present natural infrastructure, by promoting green and blue infrastructure dominated urban areas as the most admirable land use classes in terms of NbS for all ES tested. While the potential benefits of urban NbS have been demonstrated in multiple ways, uncertainties persist. Although carbon storage potential for the city has been proven as compelling, due to uncertainties in current research, further validation would be admirable. For key variables of model methodologies, such as the definite cooling ability of green and blue infrastructure, scientific opinions differ. Coastal vulnerability mitigation meanwhile is shown to profit from the presence of NbS, yet the results merely serve as an indication to further investigate high priority areas, as the potential positive impacts of additional NbS remain unclear.

The employment of 2 distinct tools for the assessment of 4 different ES models in this study proved successful in emphasizing the importance of universally questioning results of tool based urban ES analyses. Depending on the tool and the scenario, vastly different results have been obtained by seemingly similar models. Without being able to proclaim one methodological background superior to another, utmost care needs to be taken both by researchers employing the tools as well as stakeholders studying the results into understanding precisely the specific ambitions of each model as well as how alternative input variables influence the outputs. While it is unjust to universally write off resulting outputs as wrong, as long as many of the here addressed issues remain unclear, the quantitative results of tool based urban ES mapping and valuation studies should be taken with a grain of salt before being validated by further research on the topic.

This study ultimately demonstrated the probable positive effects of urban NbS in enhancing urban resilience, and highlights the shortcomings of current urban ES assessment tools. However, while this paper further vouches for the importance of spatially explicit urban ES assessment tools, it clearly showed the need for additional development and research within this field.

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9. Appendix

9.1 Data Sources and Resolution

Table 9.1.1: Modelling data, resolution & sources

Dataset name	**Resolution**	**Source**
Spatial Data		
Municipality & Neighborhood	10 x 10 m	CBS (2019b)
Land Use & Land Cover [1,2,3,4,5]	10 x 10 m	Copernicus (2020)
Elevation - AHN3 [2,4,5,6]	0.5 x 0.5 m	PDOK (2020b)
Building Footprints [1,2,5]	10 x 10 m	TU Delft (2020a)
Building Intensity [1]	10 x 10 m	Copernicus (2020)
Reference Pot. Evapotranspiration [1]	1 x 1 km	Trabucco & Zomer (2019)
Tree cover [1,3,4]	20 x 20 m	Copernicus (2018)
Dunes [4]	0.5 x 0.5 m	PDOK (2020a), PDOK (2020b)
Sewage System [2]	*	Geo Informatie Portaal (2020)
Soil Types & Landmass [2,4]	10 x 10 m	TU Delft (2020b)
Wavewatch III [4]	*	NWS (2009)
Bathymetry [4]	115 x 115 m	Emodnet (2018)
Geomorphology [4]	*	TU Delft (2020b)
Population density [5]	10 x 10 m	Copernicus (2016); Remme et al. (2017)
Wind Speed 100m [5]	2.5 x 2.5 km	NGR (2015)
Aerial Imagery [5,6]	0.5 x 0.5 m	ESRI (2020)
Continental Shelf Contour [4]	*	*- Provided with InVEST model -*
Non-spatial Data		
Crop Coefficient (Kc) [1]	/	Doorenbos et al. (1992); Allan et al. (1998); Bosch et al. (2020)
Albedo [1]	/	Stewart & Oke (2012)

Green Area Cooling Distance [1]	/	Aram et al. (2019)
Air Temperature Max. Blending Distance [1]	/	Schatz & Kucharik (2014)
Energy Consumption [1]	/	CBS (2019a); CBS (2020)
Energy Price [1]	/	European Commission (2019)
Curve Numbers (CN) [2]	/	HydoCAD (2020)
Flood Damage Loss [2]	/	European Commission (2017)
Carbon Pools [3]	/	Bouwer et al. (2018); Tang et al. (2016)
Temperature & Humidity [1,5]	/	Wunderground (2020)
Rainfall [2,6]	/	Den Haag (n.d.)
Surface Roughness [5]	/	De Ridder & Schayes (1997)
Carbon emissions per city [3]	/	Moran et al. (2018)
Soil Group Classification	/	Abraham et al. (2019); Purdue Univ., (2015a); Purdue Univ., (2015b); ESF, (n.d.)
Wastewater Treatment Costs [6]	/	*- Provided with NC model -*

1 = InVEST Urban Cooling
2 = InVEST Urban Flood Risk Mitigation
3 = InVEST Carbon Storage
4 = InVEST Coastal Vulnerability
5 = NC Urban Cooling
6 = NC Urban Water Storage
* shapefiles do not possess a specific resolution

9.2 InVEST Urban Cooling Data

Table 9.2.1: InVEST Urban Cooling (Current Scenario) - Shade, Albedo, KC and green area values

Urban Atlas LULC class	**Shade**	**KC**	**Albedo**	**Green Area**	**Building Intensity**
Continuous urban fabric (S.L. : > 80%)	0.1	0.38	0.15	0	0.44
Discontinuous dense urban fabric (S.L. : 50% - 80%)	0.1	0.42	0.15	0	0.26
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	0.26	0.5	0.19	0	0.17
Discontinuous low density urban fabric (S.L. : 10% - 30%)	0.33	0.54	0.19	0	0.07
Discontinuous very low density urban fabric (S.L. : < 10%)	0.04	0.38	0.19	0	0.19
Industrial, commercial, public, military and private units	0.06	0.4	0.18	0	0.28
Sports and leisure facilities	0.21	0.75	0.2	0	0.04
Airports	0	0.4	0.22	0	0
Port areas	0	0.31	0.18	0	0.16
Isolated structures	0.11	0.81	0.19	0	0.02
Construction sites	0.07	0.28	0.28	0	0.12
Land without current use	0.13	0.75	0.23	0	0.07

Open spaces with little or no vegetation	0	0.28	0.28	0	0
Mineral extraction and dump sites	0	0.28	0.28	0	0
Fast transit roads and associated land	0.07	0.35	0.23	0	0
Other roads and associated land	0.08	0.35	0.23	0	0.01
Railways and associated land	0.08	0.35	0.16	0	0.01
Green urban areas	0.48	0.92	0.23	1	0.01
Pastures	0.1	0.75	0.2	1	0
Forests	0.61	1	0.2	1	0
Arable land (annual crops)	0.25	0.75	0.2	0	0
Herbaceous vegetation associations (natural grassland, moors...)	0.09	0.75	0.2	1	0
Wetlands	0	0.65	0.06	1	0
Water	0.11	0.65	0.06	1	0

Table 9.2.2: InVEST Urban Cooling - Weather station measurements for the 27/08/2019

Weather Station description	**Maximum Temperature (°C)**
Urban	
ITHEHAGU24	31.6
ITHEHAGU53	35.9
ITHEHAGU19	33.9
ITHEHA8	34.2

ITHEHAGU67	35.9
Rural	
IWASSENA60	27.1
IZUIDHOL169	26.3
IMONSTER14	30
ITHEHA11	32.5

9.3 InVEST Flood Risk Mitigation Data

Table 9.3.1: InVEST Urban Flood Risk Mitigation - Soil map values to hydrologic soil group

Soil description as in soil map	**Specific hydrologic soil group**
Bebouwing	D
Opgehoogd & opgespoten	D
Warmoezerij	C
Bovenlandstrook	C
Moerige eerdgronden met een moerige bovengrond of moerige tussenlaag op niet-gerijpte zavel of klei	D
Tuineerdgronden	C
Zeekleigronden	D
Kalkhoudende zandgronden	A
Veengronden	A
Zeekleigronden	D
Moerige gronden	C
Enkeerdgronden	C

Table 9.3.2: InVEST Urban Flood Risk Mitigation - Curve numbers per LULC class per soil group

Urban Atlas LULC class	**CN_A**	**CN_B**	**CN_C**	**CN_D**
Continuous urban fabric (S.L. : > 80%)	89	92	94	95
Discontinuous dense urban fabric (S.L. : 50% - 80%)	89	92	94	95
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	89	92	94	95
Discontinuous low density urban fabric (S.L. : 10% - 30%)	89	92	94	95
Discontinuous very	63	75	83	87

low density urban fabric (S.L. : < 10%)				
Industrial, commercial, public, military and private units	81	88	91	93
Sports and leisure facilities	89	92	94	95
Airports	81	88	91	93
Port areas	81	88	91	93
Isolated structures	89	92	94	95
Construction sites	77	86	91	94
Land without current use	77	86	91	94
Open spaces with little/no veg.	68	79	86	89
Mineral extraction and dump sites	77	86	91	94
Fast transit roads and associated land	98	98	98	98
Other roads and associated land	98	98	98	98
Railways and associated land	98	98	98	98
Green urban areas	49	69	79	84
Pastures	49	69	79	84
Forests	49	69	79	84
Arable land (annual crops)	49	69	79	84
Herbaceous vegetation associations (natural grassland, moors...)	49	69	79	84
Wetlands	1	1	1	1
Water	1	1	1	1

9.4 InVEST Carbon Storage Data

Table 9.4.1: InVEST Carbon Storage - Carbon storage values (Mg/ha) per LULC class per pool

Urban Atlas LULC class	Above	Below	Soil	Dead
Continuous urban fabric (S.L. : > 80%)	1	0.26	1.8	0.3
Discontinuous dense urban fabric (S.L. : 50% - 80%)	8	2.1	14.4	2.4
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	20	5.2	36	6
Discontinuous low density urban fabric (S.L. : 10% - 30%)	27	7	48.6	8.1
Discontinuous very low density urban fabric (S.L. : < 10%)	3.5	0.9	6.3	1.05
Industrial, commercial, public, military and private units	5	1.3	9	1.5
Sports and leisure facilities	17	4.42	30.6	5.1
Airports	0	0	0	0
Port areas	0	0	0	0
Isolated structures	1	1	2	0
Construction sites	1	1	2	0
Land without current use	1	1	2	0
Open spaces with little/no veg.	1	1	2	0
Mineral extraction and dump sites	0	0	0	0
Fast transit roads and associated land	0	0	0	0

Other roads and associated land	0	0	0	0
Railways and associated land	0	0	0	0
Green urban areas	40	10.4	72	12
Pastures	2	4	90	1
Forests	50	13	90	15
Arable land (annual crops)	20	10	70	0
Herbaceous vegetation associations (natural grassland, moors...)	8	15	50	1
Wetlands	10	5	87	0
Water	0	0	0	0

9.5 InVEST Coastal Vulnerability Data

Table 9.5.1: InVEST Coastal Vulnerability - Model defined exposure ranks based on calculated exposure percentiles

Rank	1 (very low)	2 (low)	3 (moderate)	4 (high)	5 (very high)
Relief	81 to 100 Percentile	61 to 80 Percentile	41 to 60 Percentile	21 to 40 Percentile	0 to 20 Percentile
Wave Exposure	81 to 100 Percentile	61 to 80 Percentile	41 to 60 Percentile	21 to 40 Percentile	0 to 20 Percentile
Surge Potential	81 to 100 Percentile	61 to 80 Percentile	41 to 60 Percentile	21 to 40 Percentile	0 to 20 Percentile

Table 9.5.2: InVEST Coastal Vulnerability - User added habitats and exposure rankings

Bio-geophysical variable	Exposure Rank	Protection distance (m)
High Dunes	2	300
Low Dunes	3	300
Coastal Forest	1	1000
Sand	5	/
Seawall	2	/

9.6 NC Urban Cooling Data

Table 9.6.1: NC Urban Cooling - Land cover types with roughness, surface and UHI reduction values

Type	**Roughness length for momentum**	**Sealed Surface**	**UHI Reduction Value**
Urban Atlas LULC class			
Continuous urban fabric (S.L. : > 80%)	1.5	1	0
Discontinuous dense urban fabric (S.L. : 50% - 80%)	1.5	1	0
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	1.5	1	0
Discontinuous low density urban fabric (S.L. : 10% - 30%)	1.5	1	0
Discontinuous very low density urban fabric (S.L. : < 10%)	1.5	1	0
Industrial, commercial, public, military and private units	0.5	1	0
Sports and leisure facilities	0.5	1	0
Airports	0.3	1	0
Port areas	0.3	1	0
Isolated structures	0.5	1	0
Construction sites	0.1	0	0.2
Land without current use	0.1	0	0.2
Open spaces with little/no veg.	0.1	0	0.2
Mineral extraction and dump sites	0.1	0	0.2
Fast transit roads and associated land	0.3	1	0
Other roads and associated land	0.3	1	0
Railways and associated land	0.3	1	0
Green urban areas	0.3	0	0.2
Pastures	0.05	0	0.2

Forests	1.2	0	0.2
Arable land (annual crops)	0.05	0	0.2
Herbaceous vegetation associations (natural grassland, moors...)	0.1	0	0.2
Wetlands	0.1	0	0.3
Water	0.0001	0	1
Vegetation			
Trees	/	/	0.5
Shrubs and bushes	/	/	0.3
Low vegetation	/	/	0.2

9.7 Building Functions

Figure 9.7.1: Number of residential (green) vs. non-residential (red) dwellings per source

BAG data + Urban Atlas data	**Only Urban atlas data**
Residential: 149161	Residential: 148017
Non-Residential: 19133	Non-Residential: 20277

9.8 GIS Workflow Charts

Figure 9.8.1: InVEST Urban Cooling and Urban Flood Risk Mitigation GIS flowchart

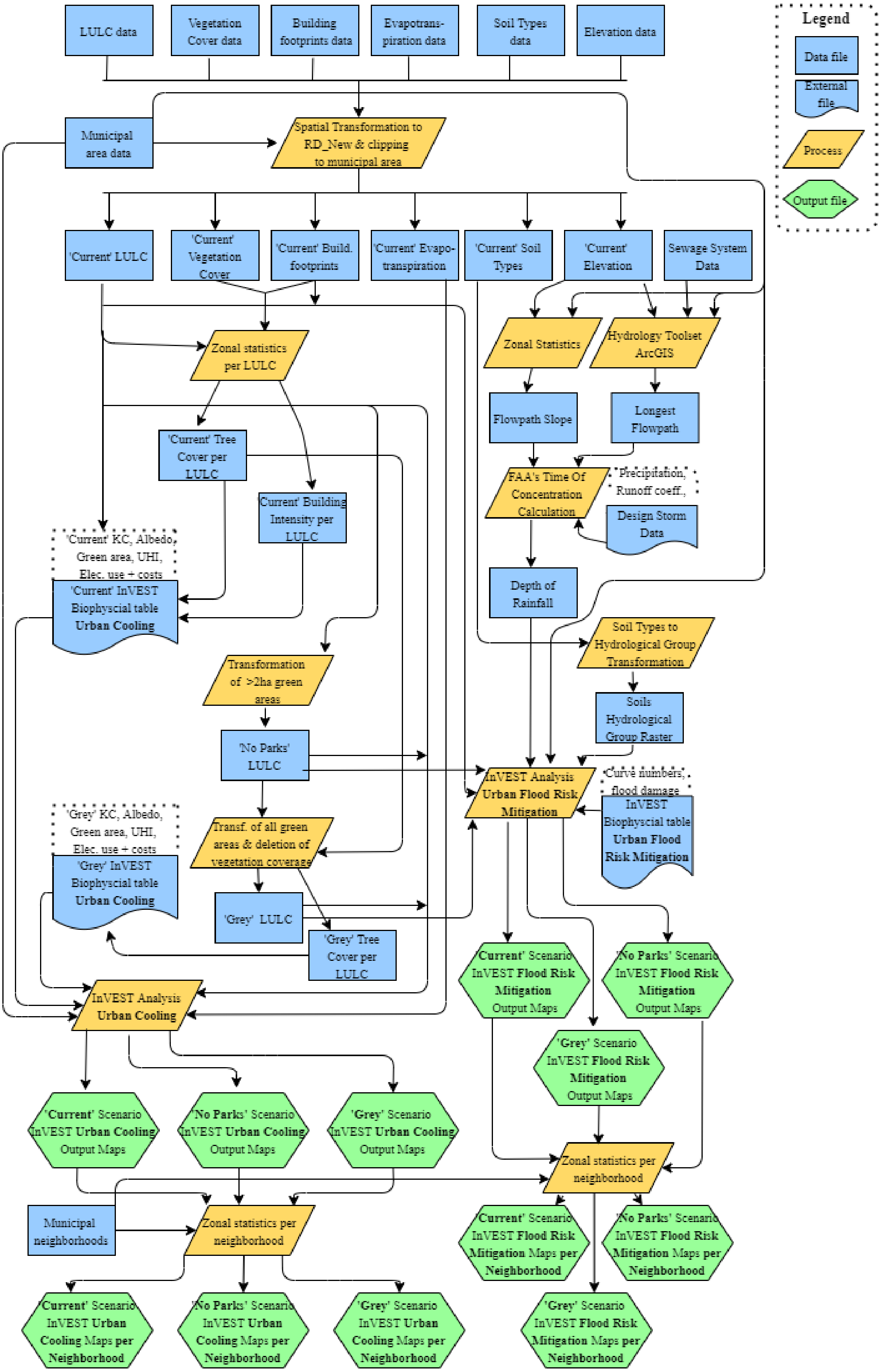


Figure 9.8.2: InVEST Carbon Storage and Coastal Vulnerability GIS flowchart

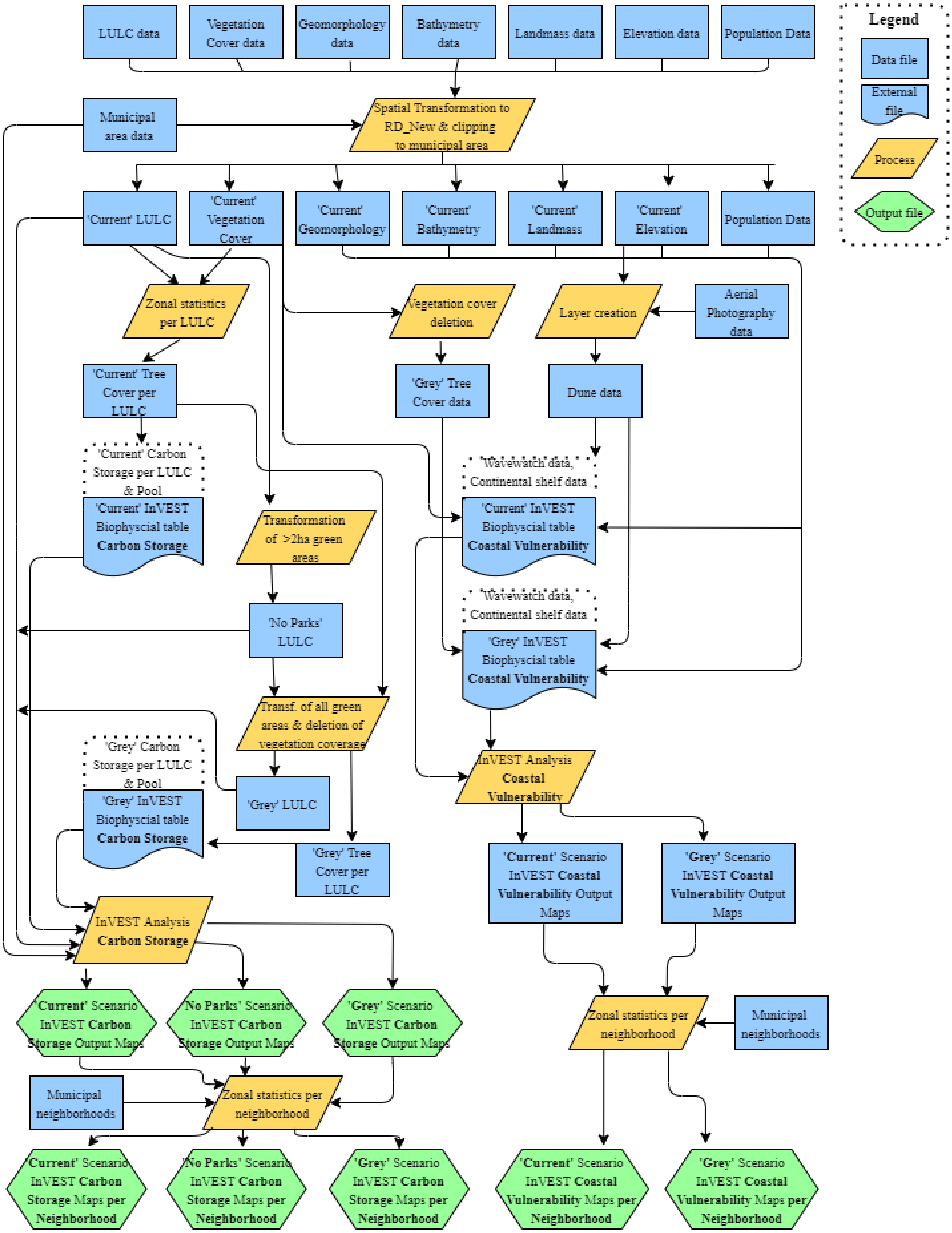
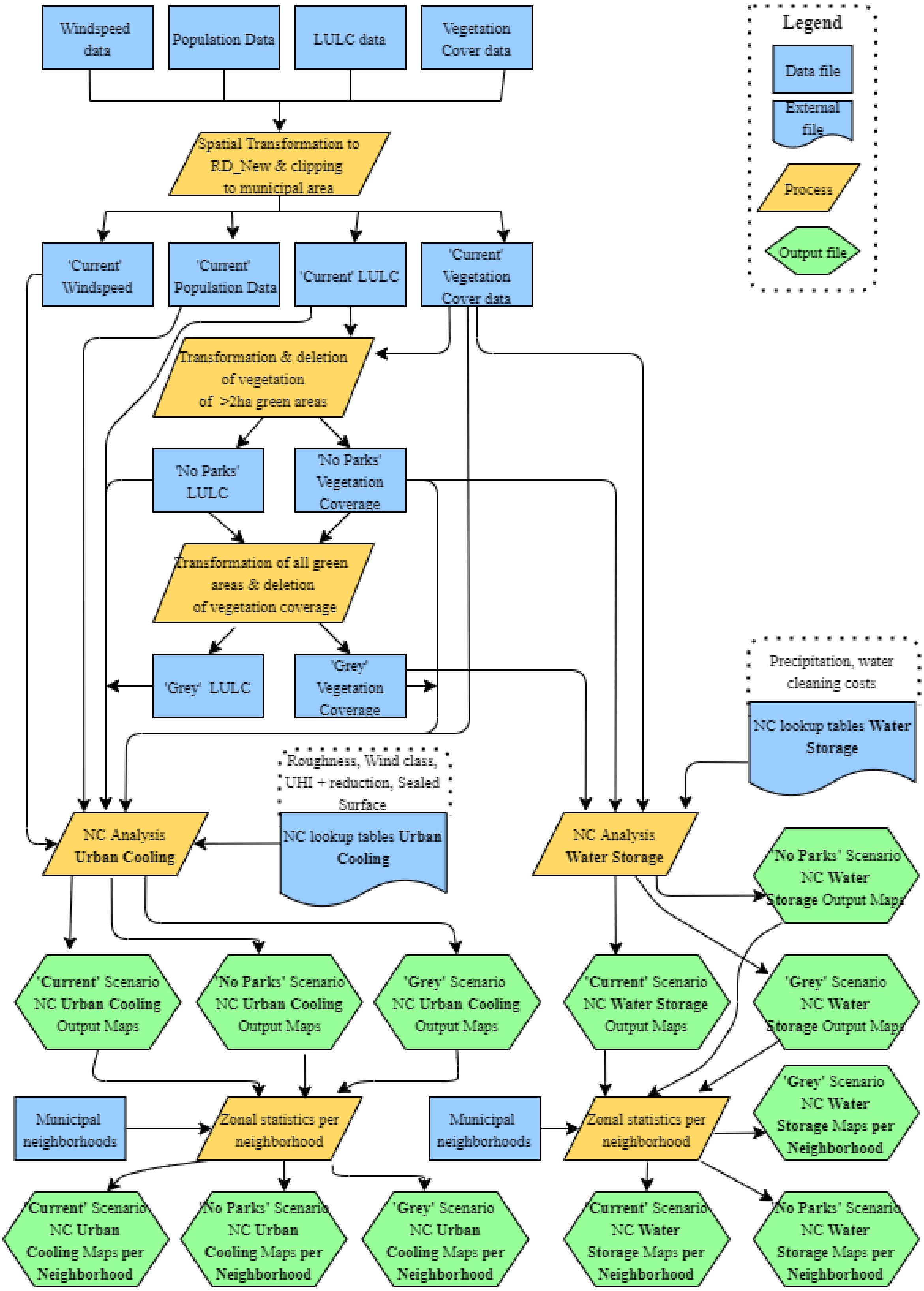


Figure 9.8.3: NC Urban Cooling & Water Storage GIS flowchart



9.9 InVEST Urban Cooling Additional Maps

Figure 9.9.1: InVEST Nighttime Air Temperature - Current Scenario

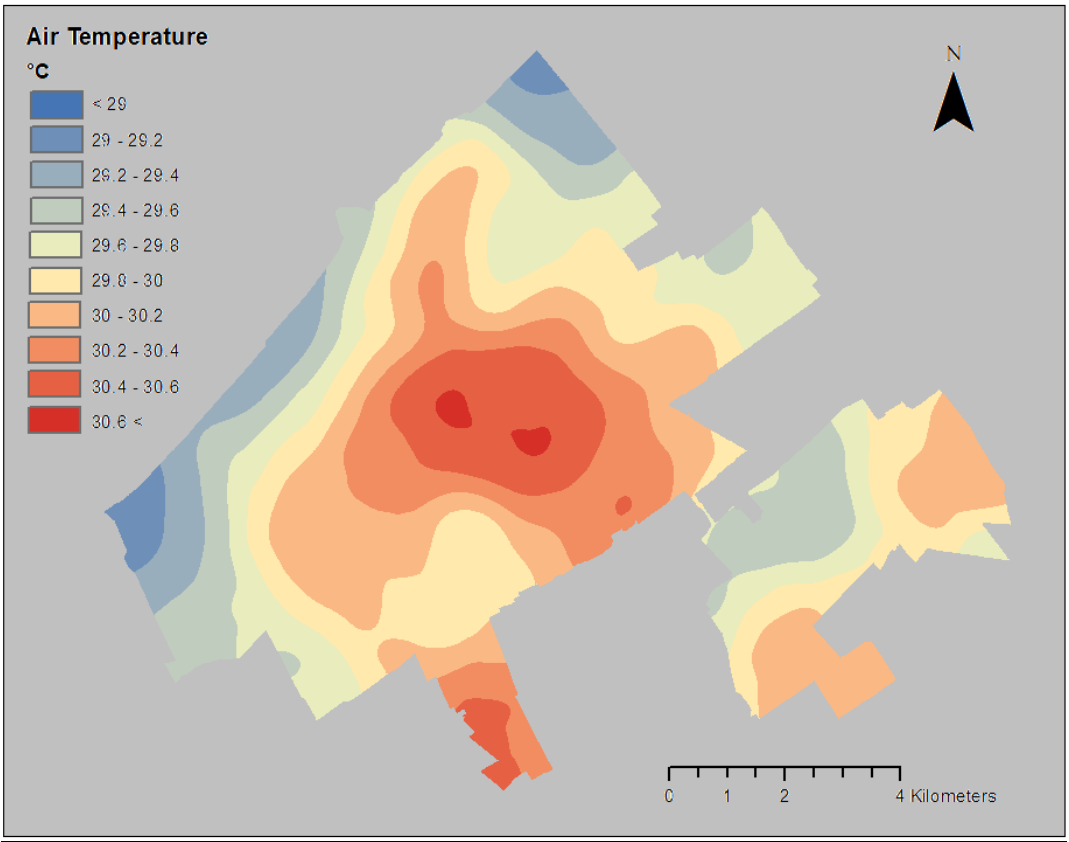
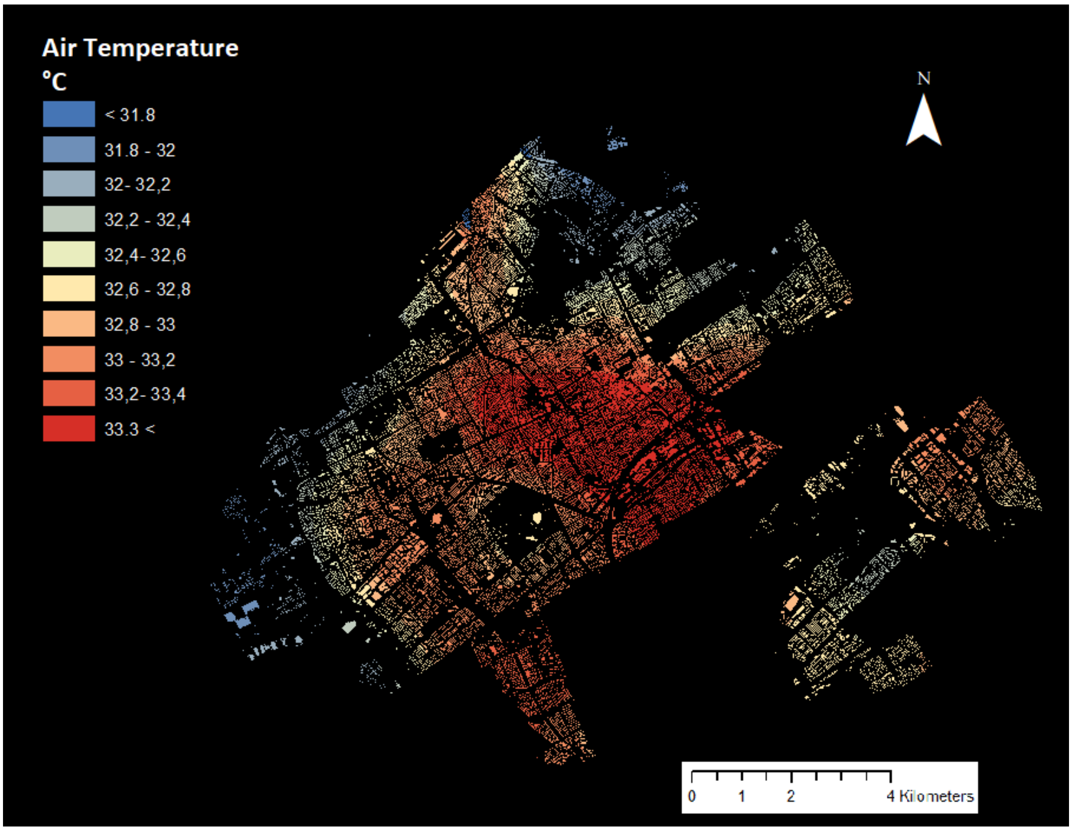


Figure 9.9.2: InVEST Daytime Air Temperature per Building - Current Scenario



9.10 The Hague Neighborhoods & major green urban areas

Figure 9.10.1: Neighborhoods & major green urban areas of The Hague