A GEO-SPATIAL MODEL FOR THE ALLOCATION OF URBAN NATURE-BASED SOLUTIONS

Development of a spatial analysis method to quantitatively evaluate suitable NBS application for stormwater management and their co-benefits for socio-economic factors and urbanisation related pressures at a large scale

Rain Solutions Deliverable 3
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1. Introduction

In this report we present a prototype geo-spatial model to select and allocate nature-based solutions (NBS) in urban spaces. The model combines a geographical information system with multicriteria analysis to develop high resolution maps with options for NBS placement in urban areas.

The report is divided in several parts, first we describe the problem that we aim to solve through the use of this model, and the objective of this work. Afterwards, previous works on this topic and a theoretical framework is presented, it serves as an introduction for the methodology used in tis work. Then, the methodology to develop the model is presented. Finally, preliminary results obtained so far and next steps aimed to improve the model are presented.

1.1. Problem statement

Due to climate change, extreme weather events such as heatwaves, heavy precipitation, and droughts, have been observed to be more frequent than before 1950 across the planet (IPCC, 2021). Urban areas are especially vulnerable to the negative effects of climate change and this is expected to increase within the near future due to urbanisation (Rosenzweig et al., 2011). By 2050, the world population living in cities will increase from the current 55% to 68% (United Nations, 2019). One of the most common hazards to occur within cities are urban flooding which brings serious challenges to the safety of property and human lives (Jha et al., 2012; Li et al., 2020). As a results of urbanisation, impervious surface will be more abundant which in turn increases the risk of pluvial flooding. Therefore, measures need to be taken in order to reduce urban flood risk in the near future.

Nature-based solutions (NBS) have been seen as a sustainable solution for dealing with the urbanisation effects. NBS is an ecosystem-based type of ‘blue and green’ infrastructure and interconnected networks of natural and artificial landscape components, which are designed and managed to provide ecosystem services (Ghofrani et al., 2017; Liao et al., 2017). NBS include parks, green roofs, rain gardens, bio-swales, permeable pavements, constructed wetlands, etc. (Din Dar et al., 2021), which utilise biophysical processes, such as detention, storage, infiltration, and biological uptake of pollutants, to manage stormwater quantity and quality (Liao et al., 2017). In addition to stormwater-related ecosystem services, NBS are also capable of providing multiple co-benefits e.g. heat stress reduction, water saving, aesthetic qualities and health benefits (Alves et al., 2019; Haruna et al., 2018).

Within the urban planning sector there are two questions that need to be answered regarding NBS, namely ‘Where to allocate NBS’ and ‘What type of NBS’. Within the literature on NBS there are works that either try to answer the question *‘where to allocate NBSI’* or *‘what type of NBS’*. The literature that provide methods to answer the first question does so by identifying priority areas, highest in demand for NBS. The methods that answer the question ‘what type of NBS’ do so by using a multi criteria analysis to create a suitability ranking of measures based on a set of criteria. The methods that create a suitability ranking list fail to incorporate a spatial analysis for the precise allocation of NBS. While the methods that focus on the identification of priority areas are based on a spatial analysis, but fail to describe which measures would be most appropriate to be used in each place. Based on the above, there is a clear need for urban planners to be equipped with appropriate systematic method that allows to answer the question of *‘Where to allocate what type of NBS’*.

1.2. Objective

Therefore, the general objective of this work is to answer the question of 'Where to allocate what type of NBS' from the large scale to the microscale. This objective will be reached by developing a spatial analysis model that identifies priority areas in demand for NBS, based on local problems that could be solved through these measures. Afterwards, the model evaluates the possible allocation of NBS at the microscale according to local characteristics and constrains.

Several different steps are followed in order to achieve the general objective. First, we identify which socio-economic and urbanisation related pressures should be included to define the priority areas in demand for NBS. Secondly, we stablish which spatial characteristics should be used to determine the suitability of NBS for allocation in different urban surfaces. Third, we define what criteria should be used to rank the suitability of NBS in the priority areas previously determined. Finally, we analyse what is the impact of the allocated NBS on the stormwater management and urbanisation related pressures.

2. Background

Regarding literature that focusses on answering the question of 'What type of NBS', the works of Jia et al. and Alves et al. demonstrate that multi criteria ranking is an effective tool to help evaluate suitable NBS. However, these methods fail to take into account a spatial analysis of where these measures need to be allocated within the urban area.

Literature on the question 'Where to allocate NBS' or rather which areas are in most demand of NBS, is quite abundant (Fernández & Wu, 2018; Fletcher et al., 2021; Honeck et al., 2020; Kaykhosravi et al., 2019; Li et al., 2020; Martínez & Rodríguez Sánchez, 2017). All these works make use of a GIS-based model in which a spatial analysis is used to derive the prioritised areas in demand for NBS. However, the criteria used to determine the priority areas differ among the papers. The large limitation from this body of literature is that even though the methods indicate where there is a high demand for NBS, they fail to indicate precisely what type NBS should be allocated on a small scale.

There is also a small body of literature that introduce models that combine both the 'Where and What for the allocation of NBS'. Muñoz Triviño et al. and Torres et al. use a method combining geo-referencing data and an optimization model. The method produces a map indicating where a certain measure it most suitable. The main limitation is that the optimization model is quite complex. As a result, the set of NBS used is small and the application is only possible on small scale levels.

The work of Kuller et al. 2019 developed the SSANTO method which takes into account the limitation described on the previous works on allocation of NBS. However, the method choses a certain measure beforehand and the result is a map which indicates the suitability for the allocation of the chosen measure. What makes this method especially interesting compared to the earlier described methods is that is fairly simple and can be applied to a large scale level. However, a limitation is that it can only asses the suitability of allocation of a single NBS at a time.

Another paper that combines both 'Where and what' is van de Ven et al. (2016). They introduce a tool that is able to assess the suitability of a measure based on a set of criteria. After the set of NBS that fit the criteria are ranked, the measures can designed into the project area by the user. Afterwards, the tool calculates the potential benefits that those NBS provide based on the sizing of the drawing. The main limitation of this tool is that the user is able to draw any NBS in anyplace, this means that some measures that might not be suited for that terrain due to local constrains can still be design into the area by the tool. Moreover, the tool is also only suitable for smaller scales and its application on larger scale would be questionable considering the interconnections and flow capacities between adaptation measures (van De Ven et al., 2016).

A similar tool has been created by Bach et al., the UrbanBEATS tool is a spatial model which designs different layouts of NBS options within a given urban block. It uses the urban form as input to generate these different options to allocate the different technologies within the biophysical constraints of the area. This tool provides a rapid systematic method for NBS planning and the resulting design is intended to be used as input for urban planners. The main limitation is that it does not include co-benefits and focusses solely on stormwater management. Moreover, the inputs for the allocation of measures are derived only from biophysical constraints based on the urban form. No other criteria are involved like socio-economic factors which are important for implementing NBS.

An overview of the literature reviewed and the methodology used within these papers is presented in Table 1.

***Table 1** Literature review overview of methods on NBS planning*

Author	Title	Method/tool	Where or What	Description
(Alves et al., 2018)	Multi-criteria approach for selection of green and grey infrastructure to reduce flood risk and increase CO-benefits	Multi criteria decision analysis with weighted summation	What	Provides a ranked overview of the best fitted NBS, using screening based on flood type and site characteristics, and ranking based on flood reduction reliability, cost reduction and co-benefits.
(Bach et al., 2020)	A spatial planning-support system for generating decentralised urban stormwater management schemes	Biophysical environments and technologies simulator (UrbanBEATS)	Where & What	Provides alternative layouts for combining different NBS options. Uses spatial analysis based on the urban form to create different designs in small raster blocks. The layouts can be filtered and evaluated based on stakeholders input.
(Fernández & Wu, 2018)	A GIS-based framework to identify priority areas for urban environmental inequity mitigation and its application	GIS-based environmental improvement priority Index (EIPI)	Where	Uses variables to compute an environmental stress indicator and a social relevance indicator which are aggregated to EIPI to identify priority areas.
(Fletcher et al., 2021)	Using demand mapping to assess the benefits of urban green and blue space in cities	Urban green and blue infrastructure mapping	Where	Uses population, vulnerability and pressure to compute and map the weighted demand for ecosystem services.
(Honeck et al., 2020)	Implementing green infrastructure for the spatial planning of peri-urban areas	Hierarchical priority ranking using zonation	Where	Makes a hierarchical priority rank map by spatially prioritizing the weighted pillars, namely biodiversity, ecological & connectivity and ecosystem services.
(Hutchins et al., 2021)	Why scale is vital to plan optimal Nature-Based Solutions for resilient cities	Framework	Where	The framework quantifies the demand of NBS and links this to ecosystem services. It identifies the optimal location for NBS on a set of socio-economic indicators.

(Jia et al., 2013)	Development of a multi-criteria index ranking system for urban runoff best management practices (BMP) selection	BMPSELECT	What	Preliminary screening of suitable BMPs followed by a multicriteria ranking based on runoff quantity and quality, benefits and costs.
(Jiménez Ariza et al., 2019)	A multicriteria planning framework to locate and select sustainable urban drainage systems in consolidated urban areas	Multiscale methodology	Where & What	The method identifies priority areas in demand of NBS using spatial analysis on different scales. On the micro scale level a selection of suitable NBS is made for the area and a treatment train is designed
(Kaykhosravi et al., 2019)	The Low-Impact Development (LID) Demand Index: A New Approach to Identifying Locations for LID	Geospatial framework	Where	Identifies sites with the highest demand for LID. Three indices are developed to determine the demand: hydrological-hydraulic index, socioeconomic index, and environmental index.
(Kuller et al., 2019)	A planning-support tool for spatial suitability assessment of green urban stormwater infrastructure	Spatial analysis	Where	Provides a suitability map for the allocation of NBS. A measure is chosen beforehand and then allocated based on a set of opportunity and needs criteria.
(Li et al., 2020)	Planning green infrastructure to mitigate urban surface water flooding risk	GIS-based multi-criteria evaluation	Where	Indicates priority neighborhoods for flood risk management based on hazard mitigation, vulnerable flooding receptors protection and exposure reduction.
(Martínez & Rodríguez Sánchez, 2017)	A GIS-based methodology to assess the potential of sustainable urban drainage systems implementation in residential areas	GIS-Based Spatial analysis for Urban planning	Where	Illustrates the potential for implementation of 8 types of NBS and which plots in the city have major water management potential based on three indexes.
(Muñoz Triviño et al., 2017)	A methodology for optimal sitting of sustainable urban drainage system.	Runoff quantification, optimization model.	Where & What	Select and allocate different NBS typologies by using runoff and water consumption quantification, stakeholder input and an optimization model.
(Torres et al., 2019)	A participatory approach based on stochastic optimization for the spatial allocation of Sustainable Urban Drainage Systems for rainwater harvesting	Stochastic Optimization	Where & What	Minimizes the use of potable water for irrigation and reduces water runoff at minimal costs by coupling GIS data with a stochastic mixed integer linear program
(Van De Ven et al., 2016)	Adaptation Planning Support Toolbox: Measurable performance information based tools for co-creation of resilient, ecosystem-based urban plans with urban designers, decision-makers and stakeholders	Adaptation support tool	Where & What	Helps to select measures according to water quantity and quantity goals, cooling effect and costs.

3. Methodology

3.1. Theoretical framework and definitions

In this section we describe the theory behind the suitability analysis for allocation of NBS. Additionally, key concepts are defined and their importance to the method development is explained.

To explain the theoretical framework a simplification of the suitability framework used by Kuller et al. (2019) is used, see Figure 1. In this case, to measure the suitability for the allocation of a measure, the framework takes two sides on the term suitability:

- ‘Opportunities’ referred to as ‘What type of NBS’
- ‘Needs’ referred to as ‘Where to allocate NBS’

Opportunities describe the possibilities for the implementation of measures based on the biophysical context of the location. Whereas needs describe the locations need for the benefits provided by NBS based on stormwater runoff potential, socio-economic factors and urbanisation related pressures.

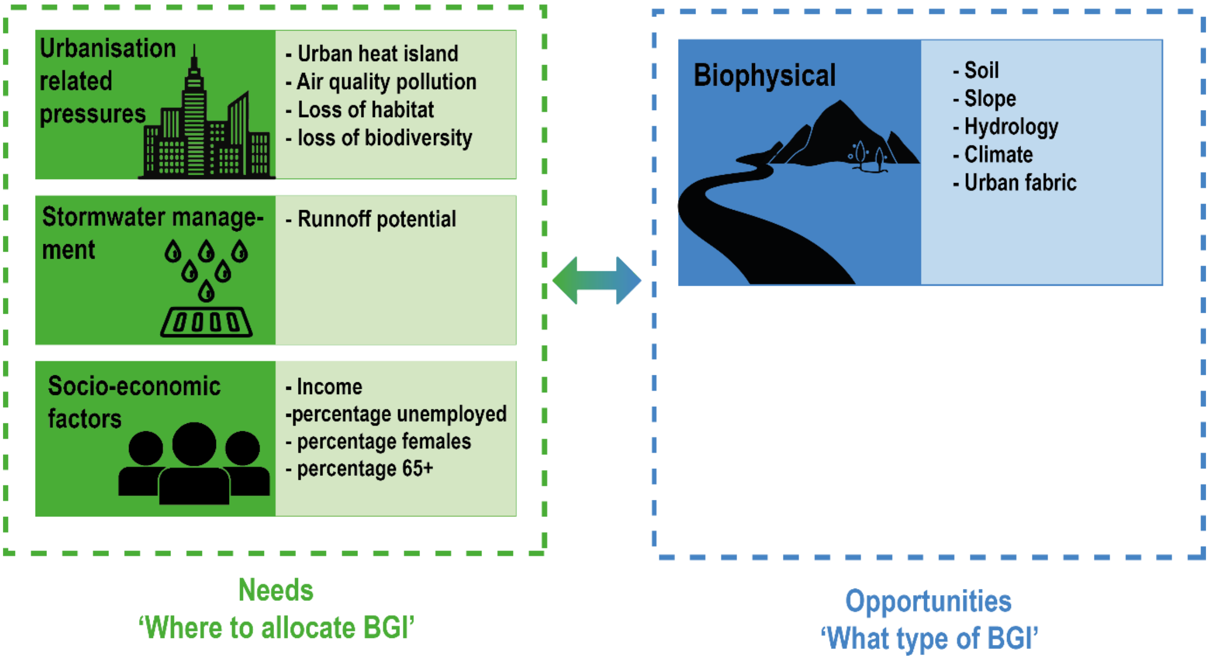


Figure 1 *Suitability framework adapted from Kuller et al. (2019). Both sides of the framework depict a half of the suitability described in categories and criteria*

3.1.1. Nature-base Solutions (NBS)

NBS are solutions based on nature, which use or mimic natural processes. It is an ecosystem-based type of infrastructure, also called ‘green’ infrastructure, which forms an interconnected network of natural and artificial landscape components. This network is designed and managed to provide stormwater-related ecosystem services but also provide other co-benefits (Ghofrani et al., 2017; Liao et al., 2017). NBS utilise biophysical processes, such as detention, storage, infiltration, and biological uptake of pollutants, to manage stormwater quantity and quality (Liao et al., 2017). In cities, these measures include parks, green roofs, rain gardens, bio-swales , bio retention cells, permeable pavements, constructed wetlands, etc. (Din Dar et al., 2021).

3.1.2. Co-benefits

NBS deliver multiple eco-system services (i.e. provisioning, regulating and cultural services) which in turn result in environmental, social and economic value (Hansen & Pauleit, 2014; Hoyer et al., 2011).

These benefits include, for example, improving water and air quality, reducing urban heat island effect (UHI), and providing health benefits (Alves et al., 2019; Haruna et al., 2018; Zölch et al., 2016).

3.1.3. Stormwater management

Stormwater management concerns itself with the understanding, control and utilisation of water in the hydrological cycle which originates from precipitation (Wanielista & Yousef, 1992). For centuries, stormwater management has been practised and multiple approaches have been developed which we now refer to as 'grey infrastructure'. These infrastructure approaches are artificially made and consist of pipes, pumps, ditches, and sewer systems (Li et al., 2020). However, even though grey infrastructure has been extensively implemented within urban environments, cities stay vulnerable to urban surface flooding (Dong et al., 2017). NBS provides a more sustainable solution to deal with urban runoff, while also providing additional co-benefits. Therefore, NBS approaches should be integrated within stormwater management in order to make urban areas more climate resilient.

3.1.4. Urbanisation related pressures

Urbanisation refers to the broad-based rural-to-urban transition involving population, land use, economic activity and culture (McGranahan & Satterthwaite, 2014). Urbanization has a large impact on the urban environment, due to urbanisation land use types tend to change resulting in an increase of impervious surfaces. This increase directly impacts urban pressures like urban flood risk, heat stress and habitat fragmentation (Jha et al., 2012; Liu et al., 2016). Besides, urbanisation has also contributed to other environmental pressures such as i.e. air and water quality degradation (Duh et al., 2008).

It is important to consider these urbanisation related pressures because NBS provide multiple benefits which can mitigate several of these problems. By incorporating these urbanisation related pressures in the methodology, NBS can be planned to tackle multiple of these problems simultaneously. Moreover, the consideration of these pressures allows to develop a ranking of the most suitable NBS in a location based on the benefits each NBS provides and on the most urgent problems in that particular location.

3.1.5. Socio-economic factors

NBS provide multiple ecosystem services which result in environmental, economic and social benefits. It would therefore be logical to include these socio-economic aspects as indicators for allocation of NBS. However, such indicators are in practise often overlooked which means that urban areas in demand for green infrastructure are excluded (Kuller et al., 2018). Moreover, spatial indicators, such as socio-economic indicators can influence the functioning of green infrastructure to a certain degree (Barbosa et al., 2012). It is therefore, important to include socio economic factors within this methodology to find areas in demand for green infrastructure (Li et al., 2020).

3.2. Software

In this work, GIS-software is used in order to develop the methodology for the allocation NBS. GIS is a system that allows to create, manage and analyse maps of all types of data. Because of this, GIS is an appropriate software to create this method in which spatial analysis is central and different spatial data sets will be used. The GIS-software used to create this method is QGIS.

3.3. Case study area

The case study area for this project is located in the capital city of the Netherlands, Amsterdam. Amsterdam has seen a vast increase in urbanisation and urban surface flooding in recent years during heavy rainfall events. The method to allocate NBS for stormwater management will be applied on a subregion of the study area (see Figure 2) supported by open spatial data for Amsterdam.

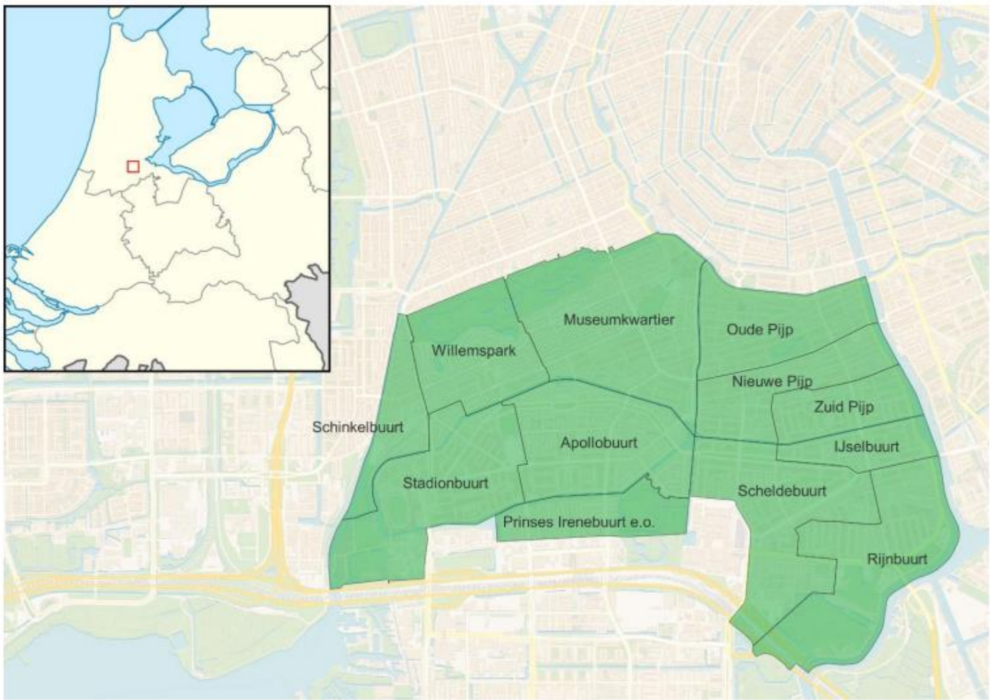


***Figure 2** Case study area*

3.4. Data collection

In order for the method to be applied, a large variety of spatial data had to be collected. The collection of this data was done through open data source points. Besides, data regarding the suitability for allocation of different NBS types was collected through literature review. Next Table shows this data.

***Table 2** Data collected*

Material	Category	Purpose	Source
DEM	Raster	Used as input of one of the spatial constraints for NBS	Open source
Runoff coefficients of land use	Values	Used to calculate stormwater runoff potential	Literature
Land use	Shape	Used to create stormwater runoff potential	Open source
Landcover	Image	Used to determine additional land uses (e.g. gardens, pavements)	PDOK services
Heat stress	Shape	Used as input for the urbanisation related pressures	Open source
NBS characteristics	Data	Used as input for NBS analysis	Literature

NBS benefits	Data	Used as input for NBS impact	Literature

3.5. Steps in developing the method

The following steps describe the development of the method for selection and allocation of NBS. The method consists of three major steps: preparation, creating priority areas in demand for NBS and allocation of NBS.

Preparation

0. By making use of an aerial image on a landcover map additional types of land uses are identified which are not present, or are not correct, within the available land use map. Once the additional land use types have been created, they are aggregated with the previous land use map to get a more accurate overview of land uses.

Priority areas in demand for NBS

1. Maps for the stormwater runoff potential, social economic factors and urbanisation related pressures are developed.
2. For the next step, the stormwater runoff, socio-economic factors and urbanisation related pressure are weighted and normalised before they can be aggregated.
3. The individual maps for the stormwater runoff potential, socio-economic factors and urban related pressures are aggregated to a single map indicating the highest priority areas for NBS allocation.

Allocation of NBS

4. Develop a table of NBS, collecting data about NBS constraints for implementation, such as soil type needed or maximum slope allowed.
5. Assign effectiveness factors for each NBS indicating its capacity to mitigate rain water runoff and urbanisation pressures.
6. For each priority area, a list of NBS is chosen according to local constraints and the main problems to solve there. Therefore, only NBS that can be applied under those local constraints (e.g. type of roofs) and that can solve the local problems identified are chosen.
7. A spatial analysis is performed to allocate the selected NBS, the result is a high resolution map with options of possible NBS to implement in each different surface, e.g. roofs, pavements, sidewalks, etc.
8. Create a suitability value. If the NBS cannot be allocated due to local constraint, the suitability value is set to 0. The suitability value will be based on the amount of benefits that each measure provides compared to the business as usual case. This value will allow to have a ranking to identify the most preferred measures.

4. Results

The outputs from the GIS-method have been divided into results for priority areas definition and results for suitable BGI allocation under different scenarios. Finally, an application of results from this tool for stormwater modelling is presented.

4.1. Priority areas

Within this major step of identifying the priority area in need for BGI, 3 intermediary results and a final results were obtained: 1. A stormwater management map: Pluvial flooding potential (Figure 6), 2. Urbanisation related pressure map: Heat stress (Figure 7), 3. Socio-economic factors map: need for greenery (Figure 8), 4. Priority area map (Figure 9).

The criteria for stormwater management consists of two indicators, areas prone to flood and the runoff coefficient. Firstly, a more detailed map was made which has been aggregated to the sub-neighbourhoods in Amsterdam-zuid of which Figure 6 is the result. From this figure it can be seen that the flood potential is highest in the neighbourhood which is called Nieuwe pijp. The flooding potential is a value between 0 and 100 which has not particular unit because it was created using the min-max normalisation method. The reason for why the Nieuwe pijp has the highest flooding potential is because a large portion of the area is indicated as an area that is prone to flood as well as having the highest average runoff coefficient of all the neighbourhoods.

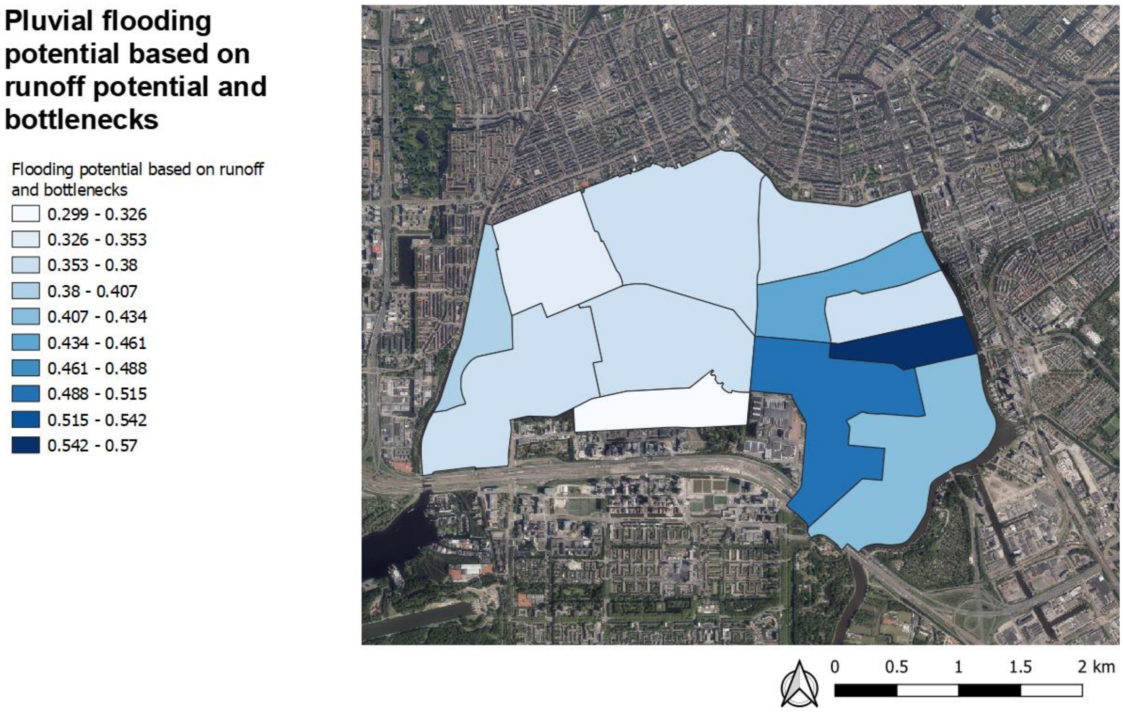


Figure 6 *Priority areas map according to runoff potential*

The heat stress criteria uses the indicator heat stress measured as Physiological Equivalent Temperature (PET). The heat stress data has been aggregated to the different sub-neighbourhoods in the case study area and Figure 7 indicates the average ambient heat stress temperature. What can be seen from this Figure is that there is one neighbourhood that score highest in on the average heat stress, the Schinkelbuurt. The presence of large amounts of pavement and low quantity of trees could explain the high average heat stress in this area.

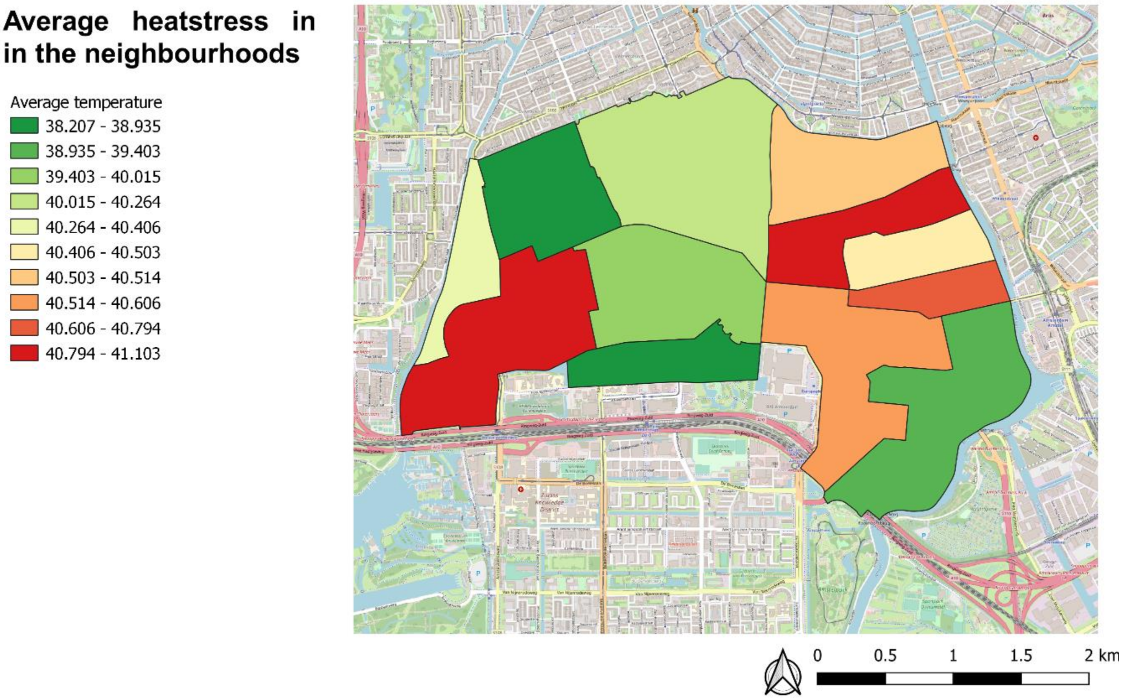


Figure 7 *Priority areas map according to heat stress*

The result shown in Figure 8 was created using four different indicators that are combined and called the need for greenery. The four different indicators used to create this map were the distance to 1 hectare of greenery, m^2 of greenery per inhabitant, privatization index and, fragmentation index. Based on Figure 8 it can be seen that the neighbourhoods Ijselbuurt, Zuid Pijp and Nieuwe Pijp scored the highest for the need of greenery.

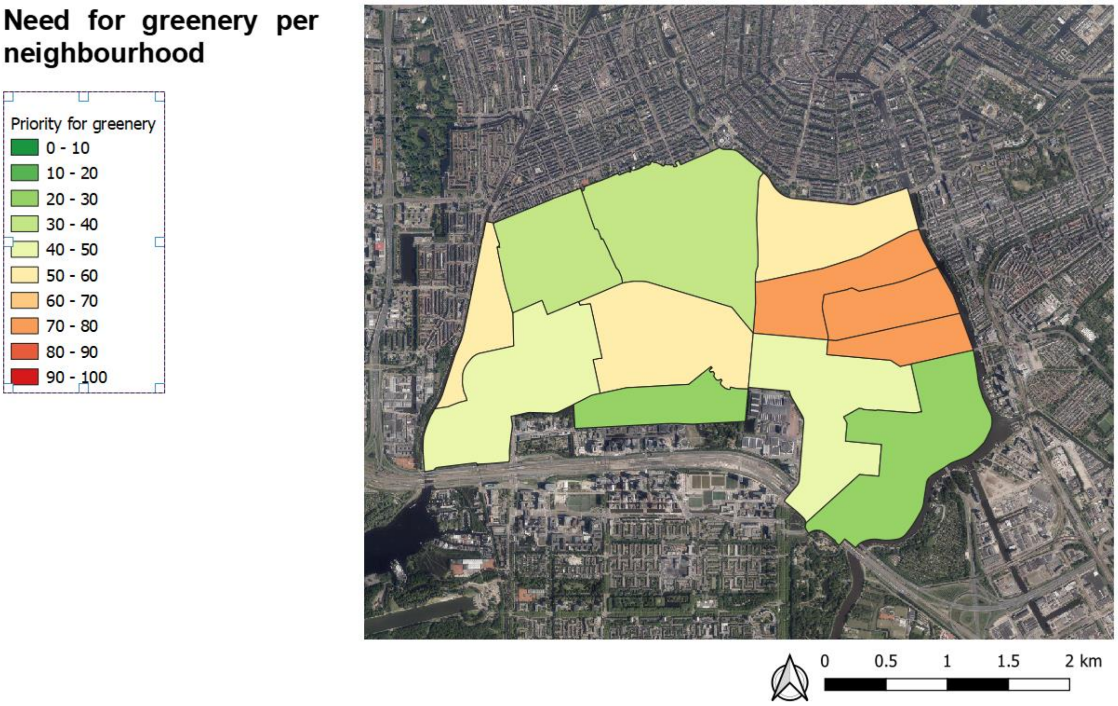


Figure 8 *Priority areas map according to greenery per neighbourhood*

After normalising and combining the previous three criteria maps, the result is the map of priority areas in need of BGI shown in Figure 9. From Figure 9 it can be seen that the area with the highest priority is the neighbourhood the Nieuwe Pijp. Based on this result, the Nieuwe pijp will be used as the priority area for the study of BGI allocation.

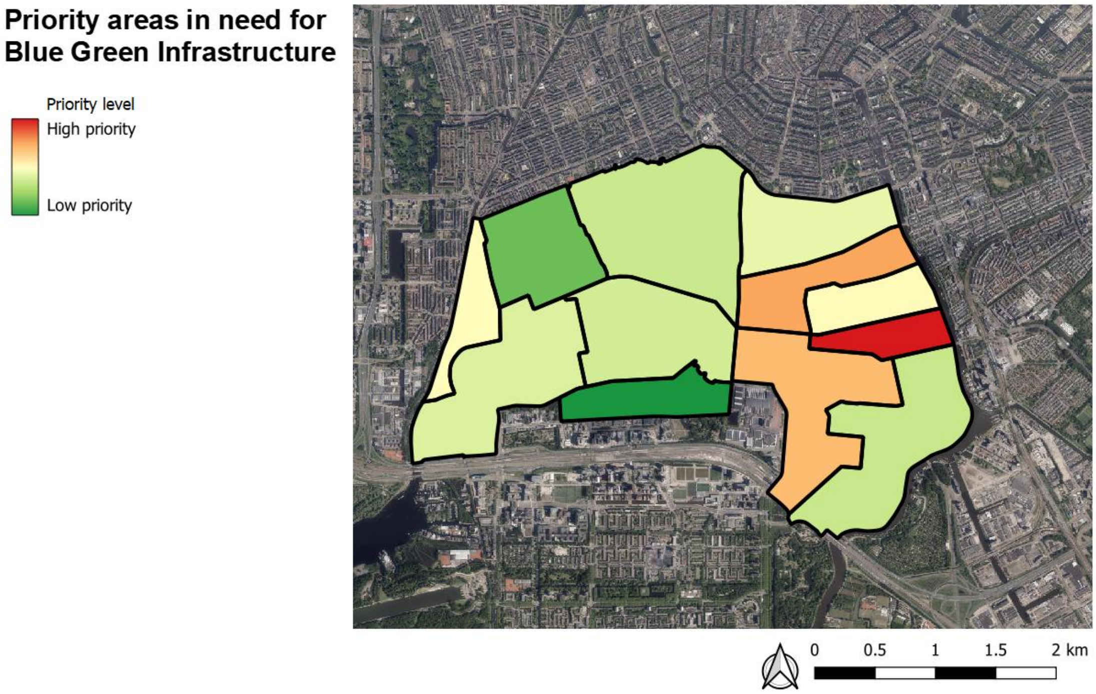


Figure 9 *Priority areas map according to runoff potential, heat stress and greenery per neighbourhood*

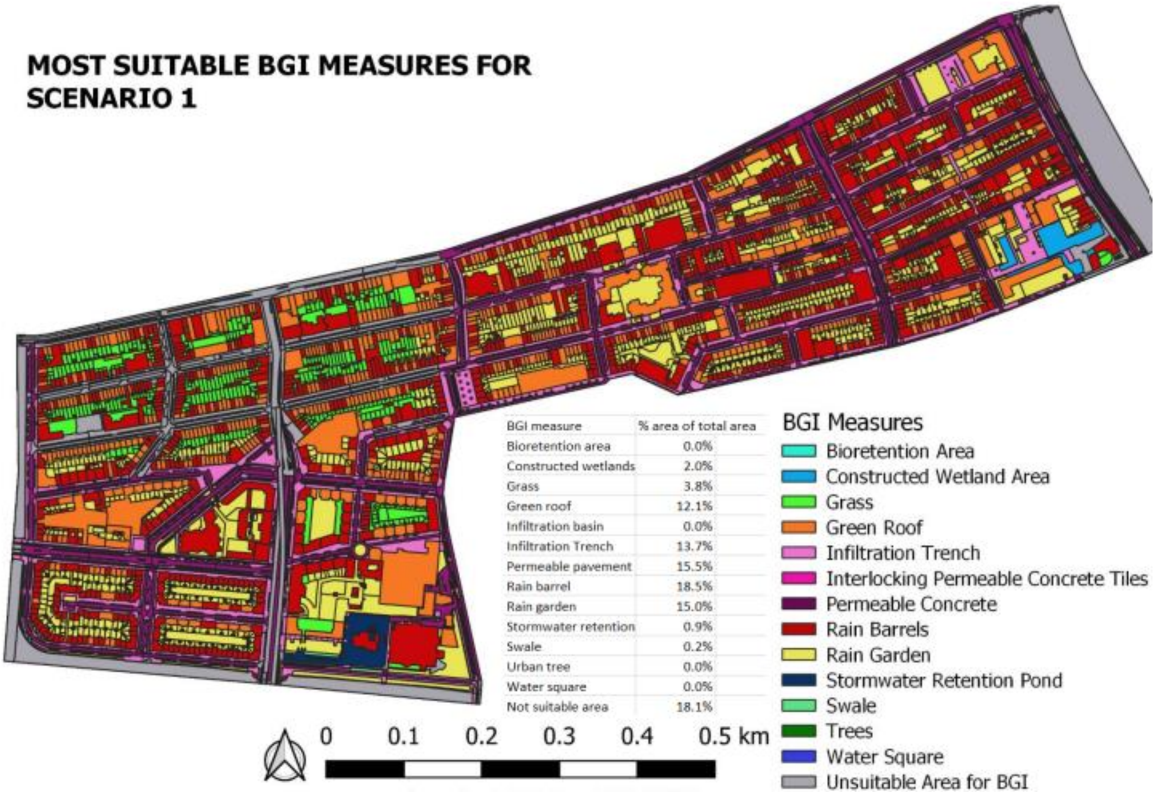
4.2. BGI allocation

For this case study 13 different BGI measures were chosen. The choice for these specific 13 BGI measures was mainly done based on the biophysical parameters. For this case study a diverse set of BGI measures was preferred to demonstrate the potential of this method on allocating different types of BGI measures. This means that the biophysical parameters should also not all be the same but instead differ between the BGI measures.

The results from the different scenarios will be discussed, different objectives are targeted in each scenario:

- Scenario 1: Stormwater management (SM)
- Scenario 2: Heat stress (HS)
- Scenario 3: Stormwater management + Heat stress (SM+HS)

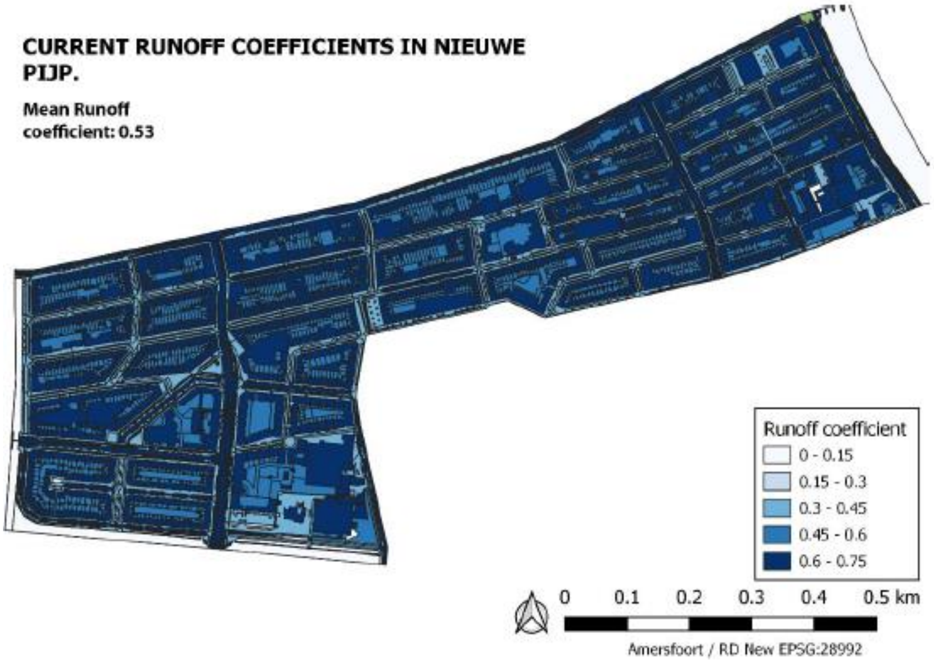
Figure 10 presents the results of the allocation of the BGI measures based on the single criteria stormwater management (Scenario 1). In this scenario 10 different BGI measures were allocated, in some areas no BGI measures could be allocated, this happens mainly in waterbodies and roads. The most applied BGI measures in this case are infiltration trench, permeable pavement, rain barrel, green roof and rain garden. Another BGI measure that is favoured in a particular area compared to the rest of the area is grass. Grass is favoured in the gardens of the Noord west part of the neighbourhood compared to the rain gardens being favour in the rest of the neighbourhood. The reason why rain gardens are not favoured in the total area is because the groundwater levels in some places are too high, as a result only grass can be fitted there based on the biophysical parameters.



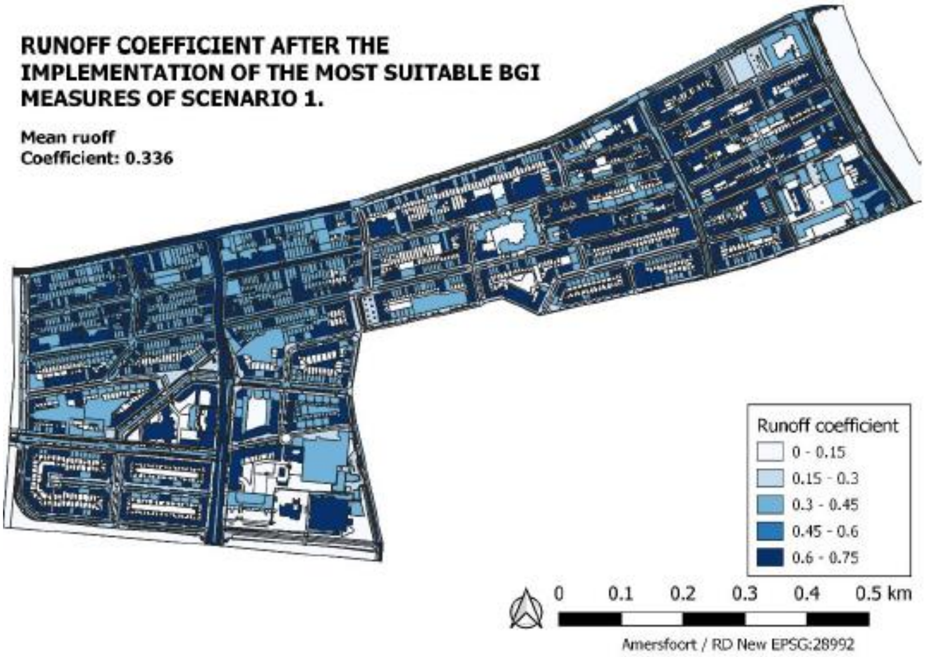
BGI measure	% area of total area
Bioretention area	0.0%
Constructed wetlands	2.0%
Grass	3.8%
Green roof	12.1%
Infiltration basin	0.0%
Infiltration Trench	13.7%
Permeable pavement	15.5%
Rain barrel	18.5%
Rain garden	15.0%
Stormwater retention	0.9%
Swale	0.2%
Urban tree	0.0%
Water square	0.0%
Not suitable area	18.1%

***Figure 10** Visualisation of the most suitable BGI measures of Scenario 1 including the land coverage percentage of the BGI measure of the total area*

Figure 11 shows the RC in the Nieuwe pijp before (a) and after (b) the implementation of the recommended BGI measures for this scenario. It can be seen that before implementation, the RC in most of the area is between 0.45 and 0.75. Figure 12(b) illustrates a large reduction in RC after measures are implemented. Several surfaces have turned from a dark blue to light blue, indicating a decrease in runoff coefficient. Moreover, the mean RC has gone down from 0.53 in the current situation to 0.34 after the implementation of BGI in this Scenario.



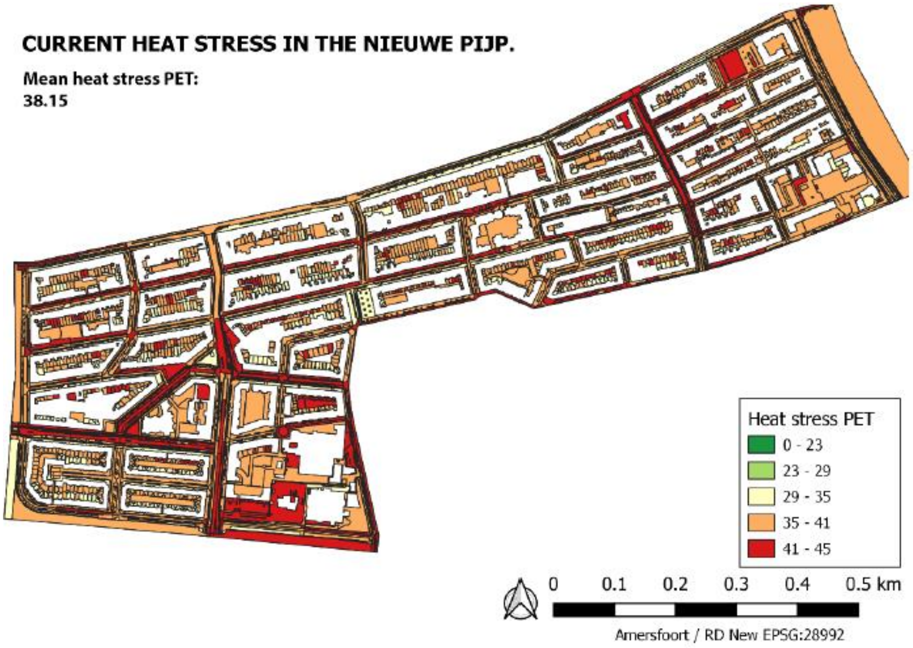
(a)



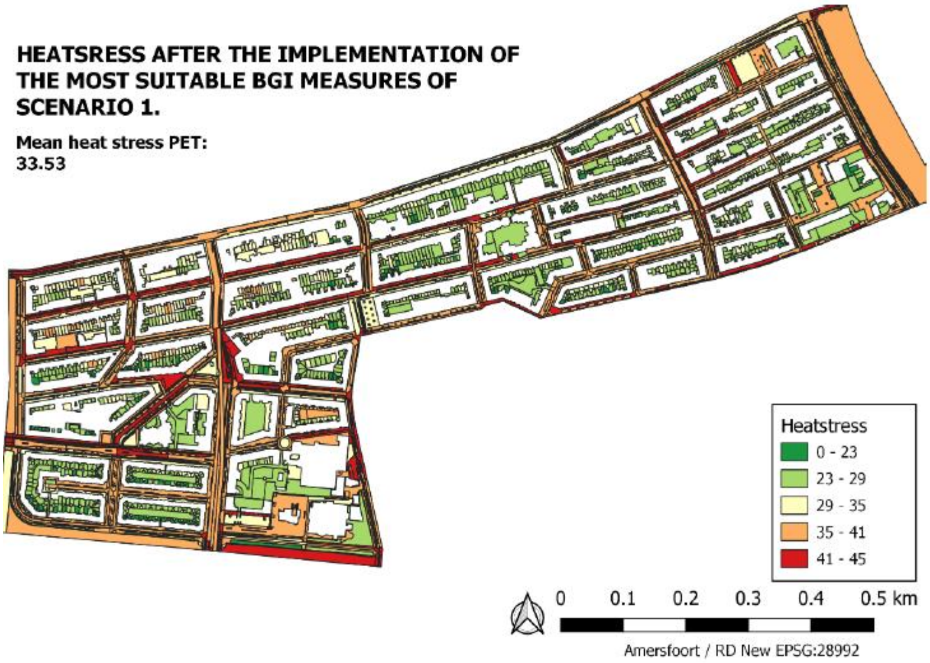
(b)

Figure 11 *Current runoff coefficient map of the neighbourhood Nieuwe pijp* ***(a),*** *Impact map on the runoff after the implementation of the most suitable BGI measures for Scenario 1* ***(b)****.*

Figure 12 illustrates heat stress levels before (a) and after (b) application of the recommended BGI in the case of Scenario 1. It can be seen that currently the entire neighbourhood has a risk of heat stress ranging between the 35 to 45 degrees, which can be experienced by inhabitants as hot to extremely hot. However, if we look at Figure 12(b) in which the most suitable BGI measures for Scenario 1 are introduced, the heat stress drops in multiple locations, mainly gardens and barren terrain. As a result, the mean heat stress is reduced from 38.15 in the current situation to 33.53 after the implementation of the BGI measures for Scenario 1.



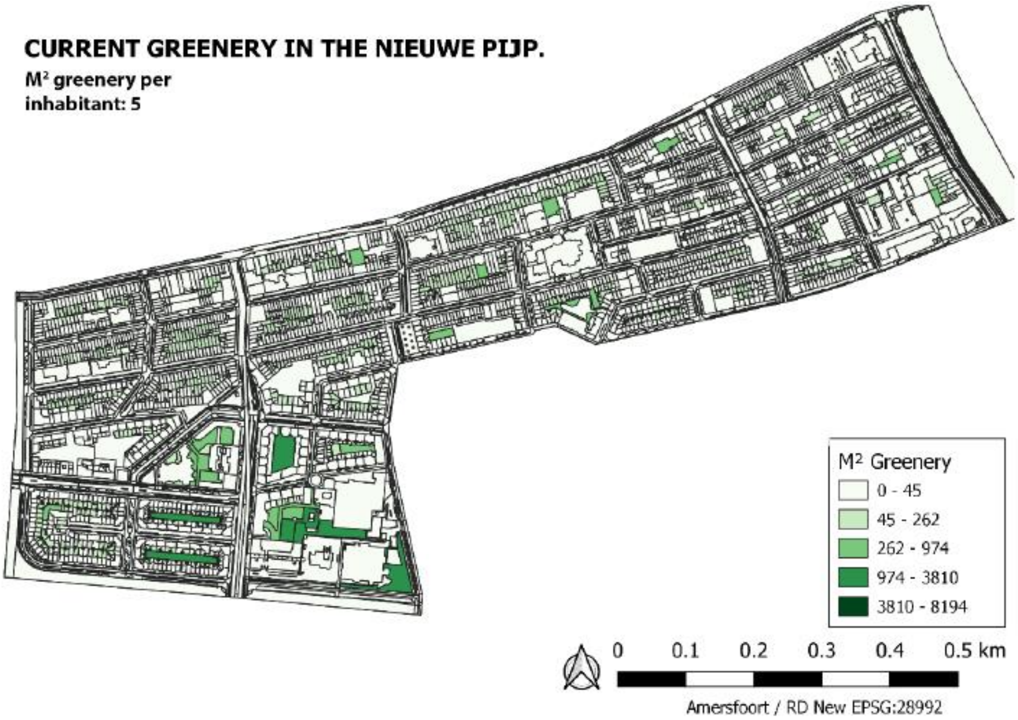
(a)



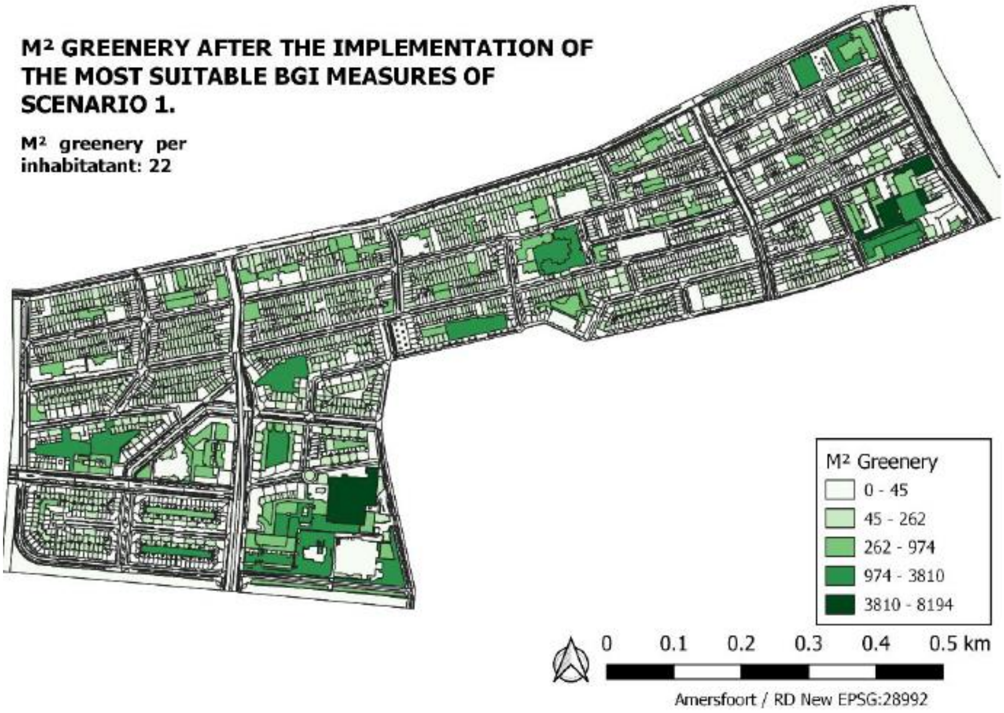
(b)

Figure 12 *Current heat stress map of the neighbourhood Nieuwe pijp* ***(a)****, and impact map of heat stress after the implementation of the most suitable BGI measures from Scenario 1* ***(b)****.*

Figure 13(a) illustrates the quantity if m^2 of greenery per inhabitant for the current situation in the Nieuwe pijp. As can be seen, there is not so much greenery in the area (most of the area is coloured white in indicating 0 to 45 m^2 of greenery). Figure 13(b) shows the situation when the BGI measures recommended have been implemented, it can be seen that the amount of greenery increases substantially. As a consequence, the m^2 of greenery per inhabitant in the area goes up from 5 m^2 to 22 m^2. This improvement in amount of greenery would allow the neighbourhood to reach the recommended minimum amount of greenery in the neighbourhood of 9 m^2 of greenery per inhabitant set by the WHO (2012).



(a)



(b)

Figure 13 *Current m^2 greenery map of the neighbourhood Nieuwe pijp* ***(a)*** *and impact map on the m^2 greenery after the implementation of the most suitable BGI measures for Scenario 1* ***(b)****.*

Next we compare results among different scenarios. In Table 5 the most suitable BGI for each scenario are presented, while Table 6 shows the impact on the different criteria from applying the measures recommended for each scenario.

Table 5 *Overview of application of preferred BGI measures for each scenario*

Scenario	***BGI***	***% app***	***BGI***	***% app***	***BGI***	***% app***
1: SM	*Rain Barrel*	*18.5*	*Permeable pav.*	*15.5*	*Rain Garden*	*15.0*
2: HS	*Permeable pav.*	*28.9*	*Urban tree*	*16.7*	*Green Roof*	*12.1*
3: SM+HS	*Permeable pav.*	*28.9*	*Rain Barrel*	*18.5*	*Rain Garden*	*15.0*

Table 6 *Impacts of BGI application for each scenario*

Scenario	***Runoff coeff.***	***Heat stress (PET)***
Base line	*0.53*	*38.15*
1: SM	*0.34*	*33.53*
2: HS	*0.43*	*31.35*
3: SM+HS	*0.34*	*33.25*

5. Planning

Validation of results with stakeholders and improvements to the prototype for the GIS model are expected by mid-2022. In June 2022, a conference session planned as a workshop with different stakeholders will be held to co-evaluate this tool. The aim is to obtain further feedback for improvement and input to maximize the applicability and usefulness of this tool in order to help decision making an planning processes for climate adaptation in cities. An open access scientific paper presenting this tool and its validation is under preparation to be submitted in the second half of 2022.

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