Modelling the additional costs for the risks of climate change effects in the Netherlands

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Preface

This thesis is written for the master program Geo-Information Science at the Wageningen University. I did this thesis in cooperation with foundation Climate Adaptation Services, who provided a large portion of the interesting datasets and the possibility for working together.

My bachelor program was in Environmental Sciences and this thesis was the perfect combination of both my study interests. The overwhelming amount of datasets and the creation of the spatial model was a challenge. Nevertheless the final results are worth the work.

Finally I would like to thank a few people, firstly Menno for all the hours discussing the assumptions and the framework of the spatial model. I would also like to thank my supervisor Arend Ligtenberg for being patient and helpful. I would like to thank Sanne for checking large portions of text and finally my parents for their love and support!

Tim Heerema

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Abstract

Anthropogenic climate change is likely to increase the human exposure to flooding, drought and changes in temperature. This increase of flooding is also present in the Netherlands and the damage and costs per incidence of flooding have increased. To develop successful adaptation strategies against the different effects of climate change it needs to be investigated which effects are happening at what location.

In order to determine the importance and the location of the effects of climate change it is needed to translate the large scale effects of climate change into local effects. With the use of a spatial model based on the methodology of different models, such as the HIS-SSM model and the STOWA model, it is possible to translate the effects of climate change into costs for society. The difference between the costs of climate change in the future, compared with the costs in the present are called the 'additional costs' of climate change.

These additional costs of climate change are calculated for the entire Netherlands and investigated per climate change effect per municipality for different damaged sectors, such as houses, infrastructure and agriculture. The additional costs to replace pile foundation as a result of drought are the most costly for the Netherlands. The additional costs of flooding because of a dike breach are mostly present around the main rivers of the Netherlands. The additional costs of pluvial flooding for a return period of 25 years are higher than for a return period of 100 years. These floodings are present in the main cities of the Netherlands, similar as the effects of heat stress which are both related to the density of people in urban areas.

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1. Introduction

1.1 Background

Nowadays more than fifty percent of the world's population lives in cities and this number is still increasing. Of the people living in these cities, two thirds will be vulnerable to flooding within the next thirty years due to sea level rise from climate change, land subsidence and extreme rainfall (Pathirana et al., 2014). The last decades this increase of flooding is also present in the Netherlands, furthermore, the damage and costs per incidence of flooding has increased.

To decrease this damage caused by climate change, lowering the amount of emitted greenhouse gases is not enough and the focus should not be on mitigation strategies only. Although greenhouse gases are accepted as the main reason for climate change, climate change is happening right now and the impacts of climate change on Dutch society need immediate adaptation strategies as well (Goosen et al., 2013). However it is only recently that European countries are starting to adapt to these consequences of climate change (Raes and Swart, 2007). To develop successful adaptation strategies against the effects of climate change it needs to be investigated which effects are happening at what location. This means that large scale effects of climate change, need to be translated to local effects, for the Dutch society to become more resilient to climate change (Lu and Stead, 2013). To achieve this resilience to the effects of climate change, different scientific disciplines need to work with similar goals in mind.

Approximately 20% of the Dutch land is covered with urban areas, which are vulnerable areas to climate change effects (Ven et al., 2010). In the context of climate change, this means that there is a lot of potential in the spatial planning community to work together with the Dutch water boards and water management. Normally these communities are separate streams in Dutch policy-making, but through the spatial configuration of cities, new alliances can be made, especially within new build-up areas (Lu and Stead, 2013)(Ward et al., 2013).

1.2 Problem definition

One way to investigate the effects of climate change on a local scale for the Netherlands, is with the use of already free available Dutch (spatial) information, together with future climate scenario's which are investigated by the Dutch Royal Meteorological Institute (KNMI). This data combined can give new insights how different climate change effects can affect municipalities in the future and the present.

This approach is already used by the Climate Adaptation Services (KAS) foundation, with the use of a specialized tool (Clico Tool, see Figure 1), which is made in Excel (Bijsterveldt and Scherpenisse, 2013). In combination with maps from the 'Klimaateffectatlas' this tool can be used to estimate the costs of the effects of climate change for flooding, dike breaches because of sea level rise, drought and heat stress.

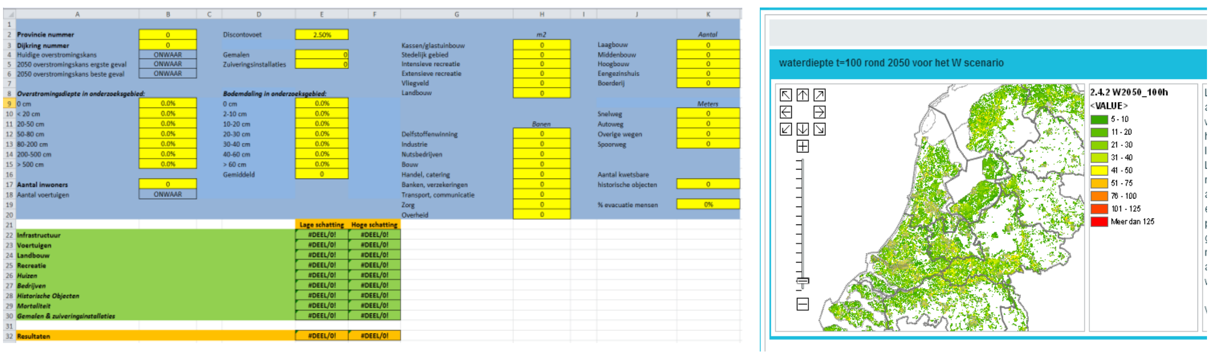


Figure 1: On the left an example of the Clico Tool. On the right an example of a flood map from the Klimaateffectatlas.

However, this tool is not explicitly spatial based nor is it automated, which lowers the usability of the tool drastically. Developing a spatial explicit model would increase the usefulness to local and regional planners and policy makers.

Therefore the idea of this research is to develop a spatially explicit model, which uses the maps of the 'klimaateffectatlas' to help create measures and decision-making at a municipality level. Such a model can produce maps and cost tables, which can express the costs of the effects of climate change for municipalities on different sectors (including labor, agriculture and different kinds of property). These maps can be used as a first indicator about the risks and costs of climate change in accordance to the different climate scenarios, which can support decision making about future land use and other climate change measures (Vis et al., 2003).

1.3 Research questions and objectives

1.3.1 Research objectives

The overall goal for this research is to develop a spatial explicit model for the exploration and assessment of the damage caused by local effects of climate change and to assess how different municipalities in the Netherlands are influenced by different scenarios of the effects of climate change in 2050.

- To model the costs and effects of climate change in 2050 compared to the present, for the individual municipalities in the Netherlands.
- To investigate which effects of climate change are relevant for different municipalities in the Netherlands.

1.3.2 Research questions

1. What are the modelling steps required to calculate the costs for the effects of climate change on a local level for the Netherlands?
    - What are the necessary steps for the model and what does the model's flow chart look like?
    - What are the necessary assumptions made to calculate the costs on a local scale and how can future investigations improve the model?
2. Which of the previously mentioned climate change effects (drought, flooding or heat stress) are relevant for the Dutch municipalities, and what is the order of importance?
    - Which municipalities have heat stress, and what are the specific costs of this effect?
    - Which municipalities have an increase chance of flooding and what are the costs of damage for flooding?
    - What are the damage and costs of drought and which municipalities are involved?
3. What is the sensitivity of the effects of climate change for the model?
    - Which climate change effects are most sensitive to input changes in the parameters and what is the order of sensitivity?

2. Review

To get a more general understanding how the Clico tool works and how to translate this Excel based tool to a spatial model, you have to know more about the Clico tool itself and the relationship between climate change effects, which in turn damaged sectors within municipalities. Furthermore you need a basic understanding of the different climate scenarios which are investigated by the KNMI and how these scenarios subsequently influence the effects of climate change.

2.1 Climate change effects used in the Clico tool

The effects of climate change are very diverse in nature, this is why it's important to define them thoroughly and to differentiate between primary effects (e.g. large scale climatological changes such as an increase of precipitation or temperature), secondary effects resulted from primary effects (e.g. drought or flooding) and sometimes tertiary climate change effects, which are based on the secondary effects, such as a decrease in biodiversity (Butler and Harley, 2010). For the Clico tool there are only secondary climate change effects integrated, because these effects mainly induce damage and costs for society. The four main secondary climate change effects used in the tool are:

- An increase of flooding, caused by an increase in precipitation;
- An increased chance of flooding, caused by sea level rise;
- An increase of drought;
- An increase of heat stress;

These four climate change effects influence the Dutch society in different ways, sometimes in a positive way, but mostly negatively, in which the latter can cause serious damages to society.

2.1.1 Flooding caused by extreme precipitation

Flooding because of extreme rainfall is common in the Netherlands, but although the occurrence of extreme rainfall is very high, the damage normally has a low impact on society (Koks et al., 2012). There are in recent history only a small number of events of serious inundation in the Netherlands due to extreme precipitation, because normally these events of inundation are very locally. However in 1998 for example, a large area of the southwestern part of the Netherlands suffered substantial damage, of around half a billion euro (Smits et al., 2004). But even after this event more policy measures are taken to prevent or to minimize large scale flooding than to prevent flooding because of extreme rainfall (Klopstra and Kok, 2009).

Flooding because of an increase of precipitation is a form of flooding due to more rainfall than a system in a specific area can handle. This can happen due to a lack of storage capacity in the ground, the infiltration speed is not high enough, lack of pumping capacity, or there is simply no other way for precipitation to flow to bigger streams (Koks et al., 2012). The height of inundation in an area is next to the capacity of the ground also determined by the duration of precipitation, the soil type and the type of build-up in the area (Smits et al., 2004).

2.1.2 Flooding caused by breaching of primary flood defenses

Flooding because of a primary dike breach is one of the most costly natural incidents for the Netherlands. A breach of primary flood defenses can result into large flood areas, large inundation depths and even mortality (Koks et al., 2012). To protect the Netherlands against a flooding, the Netherlands is divided into so called protection rings. These dike rings consists out of dikes with their own safety norms, which ranges from one incident every 250 years to one incident every 10.000 years per dike. However, due to climate change these safety norms of these dike rings are declining, because of an increase of precipitation for the rivers and an increase in the sea water height, although the costs per incident are increasing. (Bruin et al., 2013) Climate change also affects soil subsidence in the Netherlands, which adds to the relative water height when flooding caused by a dike breach occurs.

Instead of focusing on flood prevention, the Dutch water management tends to focus on a more integrated approach to take measures against the risk of flooding, by reducing economic damage and casualties (de Moel et al., 2012). This is shown by a paradigm shift from 'keeping your feet dry' to a 'living with water' approach and by measures to increase the resilience against flooding, such as 'ruimte voor de rivier' and the test facility 'IJkdijk' where experiments and tests are done on artificial dikes. (Lu and Stead, 2013)

2.1.3 Drought

Climate change is known to increase the daily temperature for the Netherlands with about 2 °C in 2050 during summer. In combination with a deficit of precipitation, an increase of drought is predicted for 2050 (Albert et al., 2014)(Ven et al., 2010). This increase in drought has a significant effect in urban areas where vegetation is maintained, and where groundwater determines the state of pile foundation and infrastructure below surface level. Hoogvliet et al. state that in high groundwater urban areas such as Rotterdam and Amsterdam, an increase in drought because of climate change can increase the damage to pile foundations with 60% in 2050. Furthermore, climate change is known to increases drought which can damage crops and increases the damage to infrastructure, especially in combination with an increase in rainfall (Pathirana et al., 2014). One of the biggest expenses of drought is the damage done to historical buildings. Over 600.000 buildings (about 30%) are sensitive to drought, because they are built on wooden foundations (Ven et al., 2010).

2.1.4 Heat stress

It's predicted that climate change can increase the periods of heat stress in urban areas, which can lead to an increase in the urban heat island effect (UHI). These so called 'hotspots' are mainly caused by industrial and dense urban areas and are increased by climate change because of an increase of average daily temperature (Ven et al., 2010). But this is effect is further increased because of the absorption of radiation and a lack of vegetation and water in large urban areas (Ven et al., 2010) as you can see in Figure 2. The UHI can lower the productivity of labor, and can be of negative effect on a person's health, especially to vulnerable and older people (Ven et al., 2010). This effect can be reinforced because of an increase of smog and can increase the number of casualties per day during summer (Lundgren and Kjellstrom, 2013). The effects of UHI are also noticeable in public areas and effects shopping and walking areas, which can lower the turnover in for example the retail sector.

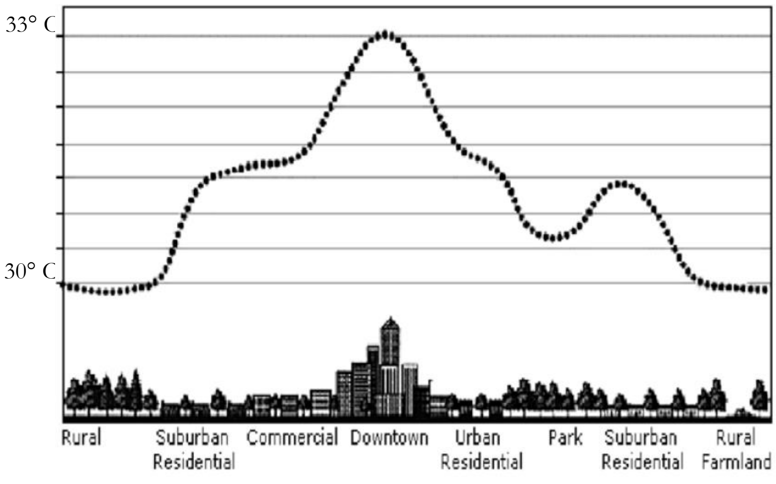


Figure 2: The urban heat island effect (UHI) visualized for an urban area (Ven et al., 2010)

2.2 Climate change scenarios used in the Clico tool

In the Clico tool there are combinations of climate change scenarios used, to calculate the costs of climate change for 2050. These scenarios are based on predicted scenarios from the IPCC rapport which the KNMI'06 specified for the Netherlands (see Figure 3).

These scenarios mainly differ in the degree of air circulation patterns and global mean temperature rise, which affects the secondary climate change effects used in the Clico tool. The Clico tool uses maps based on precipitation levels for 2050 based on the W+ scenario (worst-case scenario), which is also used for soil subsidence and drought. The decrease of safety per dike ring is based on both W+ and W scenarios and doesn't include extra seawater height, because of melting of Antartica or Greenland (Klijn et al., 2007).

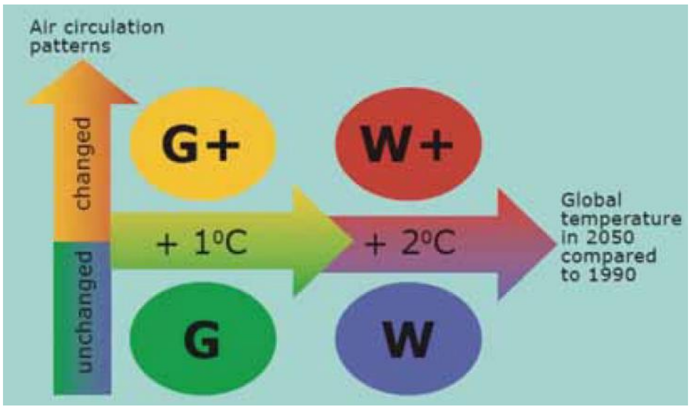


Figure 3: Different climate change scenarios for the Netherlands. Where G stands for 'moderate' and W for 'warm' scenario (Albert et al., 2014).

2.3 Sectors affected by climate change in the Clico tool

The sectors affected by climate change are very diverse, broad and sometimes hard to study. That's why the Clico tool only focusses on damage caused by the above mentioned climate change effects, but there are more criteria. First of all, the damage should have a monetary value, the relationship between climate change effect and the damage should be well studied, and the (spatial) data needed should be freely available. For an overview of the sectors used in this thesis and affected by climate change see Table 1.

Table 1: Overview of the sectors affected by the climate change effects used in the Clico tool.

	Natural sectors	**Social sectors**	**Occupation and network sectors**
Water safety	Agriculture, Recreation	Mortality Employment	Houses Infrastructure e.g. roads, rail roads, airports Vehicles
Flooding (from precipitation)	Agriculture	Employment	Houses Infrastructure
Drought	Water usage for gardens Agriculture		Decay of pile foundation
Heat stress		Labor inefficiency Extra air-conditioning Mortality Healthcare	

Within these sectors there are multiple sub-sectors such as different kinds of employment, multiple forms of infrastructure and different agriculture, but this will be further discussed in the methodology section of this research.

Table 2: Overview of the sectors affected by the climate change, but not investigated in the Clico tool.			
	Natural sectors	**Social sectors**	**Occupation and network sectors**
Water safety		Aid Power failure Evacuation Health effects e.g. fung)	Communication, Infrastructure Sensitive objects and buildings Evacuation cattle
Flooding (from precipitation)		Aid Power failure Access to public buildings e.g. Police and fire department.	Communication Infrastructure
Drought	Loss of biodiversity Forest fires Salinization Damage to aquatic environment		Infrastructure Subsidence of houses and Pipelines
Heat stress	Loss of biodiversity		Infrastructure Roads

There are also sectors which are not studied in the Clico tool, because of a lack of data or because they simply don't have a monetary value, e.g. a loss of biodiversity. For an incomplete overview of these sectors, see Table 2.

2.4 Overview of other (spatial) climate change costs models

The research field of this thesis is very wide because it includes the effects of climate change effects, future scenarios and cost calculations. A small overview of this field is given in the next chapter and in Figure 6.

2.4.1 HIS-SSM method

One of the Dutch 'standard' methodologies to investigate flood damage because of a dike breach to municipalities is with the so called 'Hoogwater informatie systeem, schade en slachtoffer module' (HIS-SSM method). This method is used by the 'Rijkswaterstaat' (Ministry of infrastructure and environment) to calculate the speed of flooding, the water movement patterns, the water level and the costs concerning flood damage (Nieuwenhuizen, 2003). Unfortunately this method doesn't include climate scenario's or other climate change effects, which makes it unusable for local policymakers to use in order to investigate the effects of climate change in the future within their municipality (Kok et al., 2004)(de Moel et al., 2012). In this thesis the relationship between water height, damage factor and costs is used based on the HIS-SSM method as you can see in Figure 4. This integration in this thesis is further explained in the methodology section of this report.

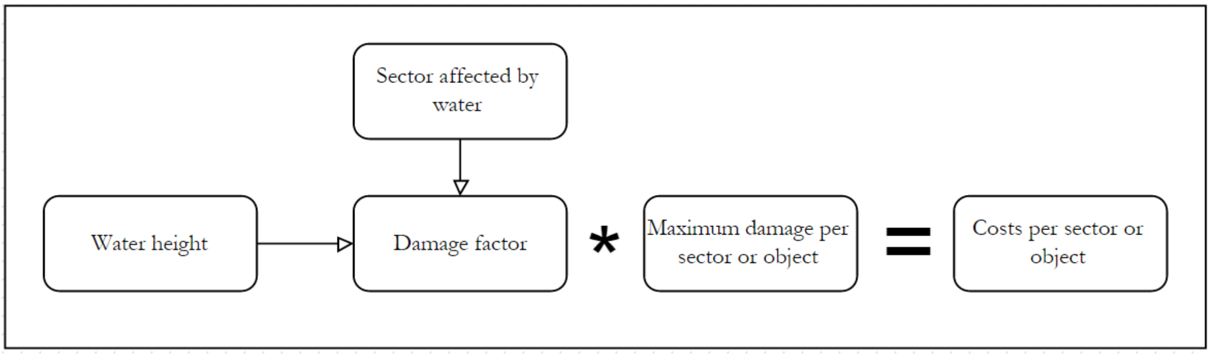


Figure 4 Steps taken from HIS-SSM method, for flooding. Arrows indicate that the combination of water height and the sectors affected by water height determine the damage factor.

2.4.2 ARIO model

A very new approach with a model called ARIO is used to calculate flood damage to businesses for the Netherlands (Vilier et al., 2013). This model challenges the classic HIS-SSM model for their approach on calculating the costs flooding can cause to businesses, stating that the HIS-SSM method underestimate the costs, especially for the loss of production (Vilier et al., 2013). This underestimation is significant, and is caused by the damage function approach used within the HIS-SSM model. These damage functions determine the damage factors which are also used in this thesis, therefore it's critical to evaluate them. In the HIS-SSM method the damage functions done to the loss of business, is linearly related to the damage flooding caused to property, because it's integrated in the maximum damage done to sectors. This is different for the ARIO model, which uses other large scale flooding's (such as the recent flooding in Thailand 2011, Japan 2011 and hurricane Katrina and Sandy) as input in the ARIO model.

The difference in outcome is substantial, as you can see in Figure 5, where the damage to the loss of business is exponential for the ARIO model and linear for the HIS-SSM method (Vilier et al., 2013).

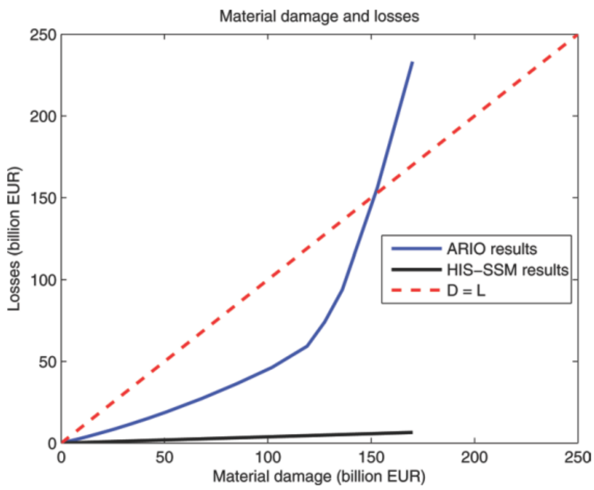


Figure 5 Extra losses because of interruption of business, because of flooding. These losses are relative to the material damage done by flooding (Vilier et al., 2013) .

2.4.3 HydroS

There are models made for the effects of extreme precipitation which also include future scenarios, such as the HydroS model made by (Immerzeel et al., 2010). This model is based on a combination of principles based on water inflow and drainage for a pixel size of 250 by 250 meters. These maps also include the effects of land use, storage of water and inundation depths for the different W scenarios of Table 3. The results of the HydroS model are also used as in this thesis as an input, which will be further discussed in the methodology section and are basically outlined in Figure 6.

Table 3: Precipitation based on repetition time					
		W scenario		**W+ Scenario**	
Repetition time(1/y)	Present	2050	2100	2050	2100
10	54 mm	66 mm	78 mm	60 mm	66 mm
25	61 mm	75 mm	89 mm	68 mm	74 mm
100	79 mm	98 mm	117 mm	88 mm	97 mm

2.4.4 STOWA

STOWA is a Dutch platform which is used to estimate flood damage and flood costs for heavy precipitation for the Dutch water boards on a large scale (Hoes et al., 2013). It uses the same principles as the HIS-SSM method with damage based on inundation depth (Hoes et al., 2013), but it uses more damage factor functions for different objects and has more maximum damage categories (Hoes et al., 2013). The STOWA platform can estimate the costs for a lot of different scenarios including the effects of certain measures against flooding. In this thesis the maximum damage per object or per hectare for flood damage is integrated in the model from the STOWA platform if possible, which will be further explained in the methodology section and is basically outlined in Figure 6.

2.4.5 Research program knowledge for climate and climate change for spatial planning

(Ven et al., 2010) investigates the effects of climate change for different scenarios with a primary focus on urban areas. This research is done as part of the Research Program Knowledge for Climate and climate change for spatial planning (RPKC). Their focus is on mitigation strategies for the Dutch urban areas, therefore they assess the effects of climate change thoroughly, including the effects of heat stress and drought (Ven et al., 2010). The methods used are quite similar as in this thesis, by focusing on the same four climate change effects, but (Ven et al., 2010) mainly focusses on weaknesses and strengths for certain areas against the effects of climate change, without integrating the costs in their research. In this thesis the data of the effects of pluvial flooding are integrated in the model as an input, which will be further explained in the methodology section and is basically outlined in Figure 6 below.

2.5 Conclusion

In this thesis a combination will be made between the different climate change effects influencing the costs of climate change based on the Clico Tool. This means a division will be made between, drought, heat stress, flooding because of extreme precipitation and flooding because of a dike breach. Within these climate change effects there will be different sectors which will be taken into account, but also sectors which are ignored because of a lack of data or scientific basis. The sectors which will not be taken into account are part of the discussion within the results, because these sectors would also further increase the costs.

Furthermore the climate change scenarios are used in this thesis in a rather ambiguous way. Overall the W scenario or the W^+ scenario is used, but depending on the results and the availability of information, the approach of a worst-case and best-case scenario is taken. This to quantify the range of damage costs which are created by the differences in climate scenarios which will be further explained in the methodology section of this report.

There are different scientific opinions and models about how to approach problems which are related to the costs of climate change for the Netherlands, as can be seen in the previous sections of the review. In this thesis a combination of the outcomes of the results from different elements from these models will be used in the form of input data, as a basis for the methodology or as an input for the discussion. The HIS-SSM method is used as a method to calculate the costs for flooding because of a dike breach, with use of the damage factors and parts of the damage costs, as can be seen in Figure 6. The methodology of STOWA is used to calculate the costs for extreme pluvial flooding, with similar damage functions as the HIS-SSM method and damage costs. Furthermore the results of RPKC are used as an input for extreme pluvial flooding, and the methodology is used for the effects of drought and heat stress as can be seen in Figure 6.

3. Methodology

The main idea of this thesis is to design and deliver a spatial model that estimates additional costs of the effects of climate change for the Netherlands for the year 2050 compared to the present. This model will be created in ArcMap 10.1, with the use of the spatial tools of Modelbuilder. The additional costs of climate change are based on a combination of different datasets calculated for different climate scenarios (W and W+), which depend on the availability of data of the climate change effects for these scenarios. With the use of a spatially explicit model, it is possible to investigate which effects of climate change are relevant per municipality and what the costs of damage are. To verify the strength of the model an OAT sensitivity analysis is performed.

To create this spatial model, the review of the previous section is used in combination with the Clico model. The climate change effects are divided into the four different categories which are also used in the Clico tool. The models discussed in the review are integrated into these climate change effects categories, which you can see below in Figure 6. For flooding because of a primary dike breach, the methodology of the HIS-SSM method is used. For flooding because of extreme pluvial, the STOWA methodology is used, including their associating damage factors and maximum costs per object. For drought and heat stress, the methodology and the sectors affected are mainly from RPKC. The main input data is from a diversity of sources, including RPKC and the HydroS model, which you can see in Figure 6. In the next section a detailed description of the data is given.

3.1 Data and model

The model consists out of multiple sources of Dutch spatial data, including infrastructural, land use, urban areas, organizational and demographical data. For the climate change effects for flooding there is a multitude of spatial data used, including the effects of soil subsidence, chances for dike breach, extreme pluvial data from different sources and inundation depths. For drought and heat stress, mostly demographic data, urban heat island maps and sensitive areas of wooden pile foundation are used. For more details you can read the next section of the report, which includes the main steps for the spatial model.

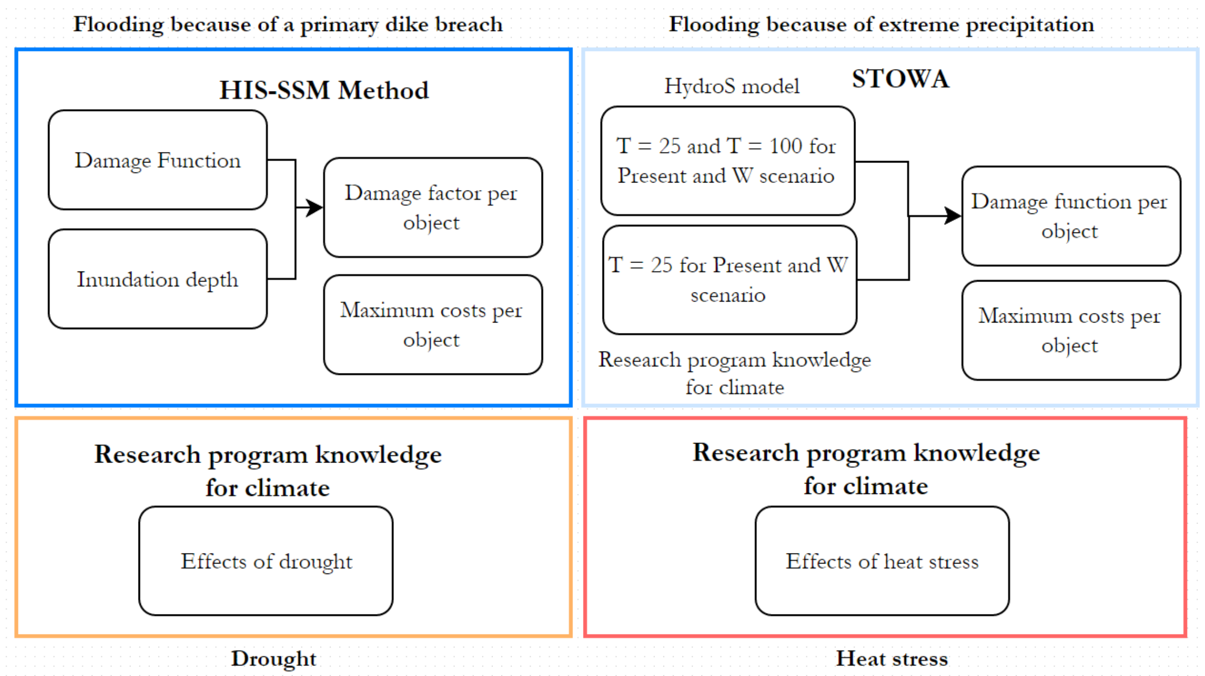


Figure 6 Models used from the review, for a primary outline of this thesis. The arrow indicates the direct influence on the damage factor.

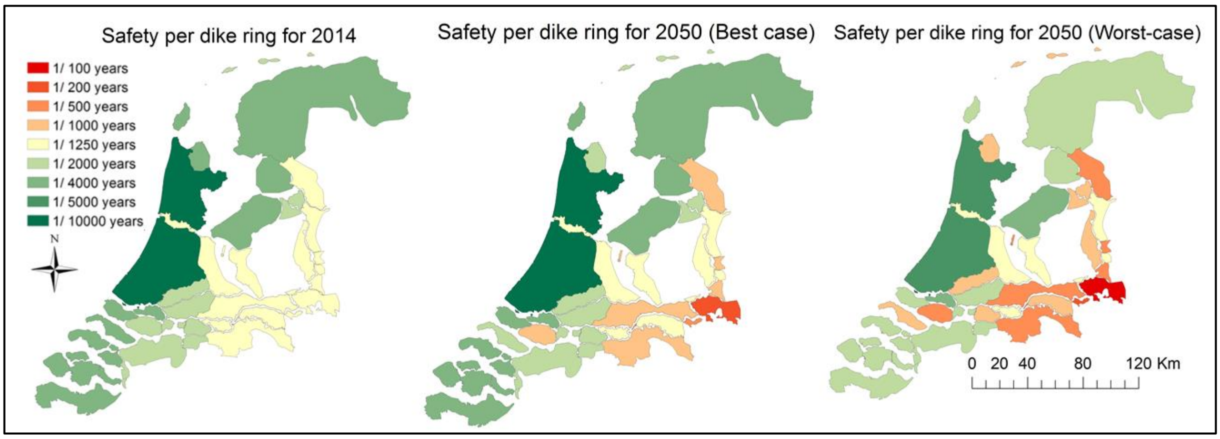


Figure 7: Different flood chances per dike ring, for the present situation and for a worst-case and best-case climate change scenario for 2050 (Klijn et al., 2007).

3.1.1 Flood data for a primary dike breach

In the spatial model the water level due to a primary dike breach consists of three major components, the increase in chance of a dike breach to occur because of climate change, an increase in water height of inundation and an increase of inundation because of soil subsidence. In this research the increased chance of a dike breach to occur is divided in a worst-case, and a best-case scenario for 2050. These scenarios are based on the 'ruimte voor water' project and these measures can result in a variety of breach chances per dike ring, as investigated by(Klijn et al., 2007). Both situations for 2050 are created with the assumption that the 'ruimte voor water' project will continue as planned.

The data of the inundation height from a primary dike breach is from the Dutch 'risicokaart', which is made possible by different municipalities and the Dutch ministry of infrastructure and environment. This map is made, with a combination of scenario analysis and basin modelling, for the unlikely situation that all primary dikes fail. The inundation height is based on the scenario with the highest water heights per location which is a essentially a worse-case scenario. An important assumption within this research is that inner dikes can hold the weight of the water in the situation that primary dikes will breach, which is dependent on how and where the primary dikes will breach (Klijn et al., 2007)

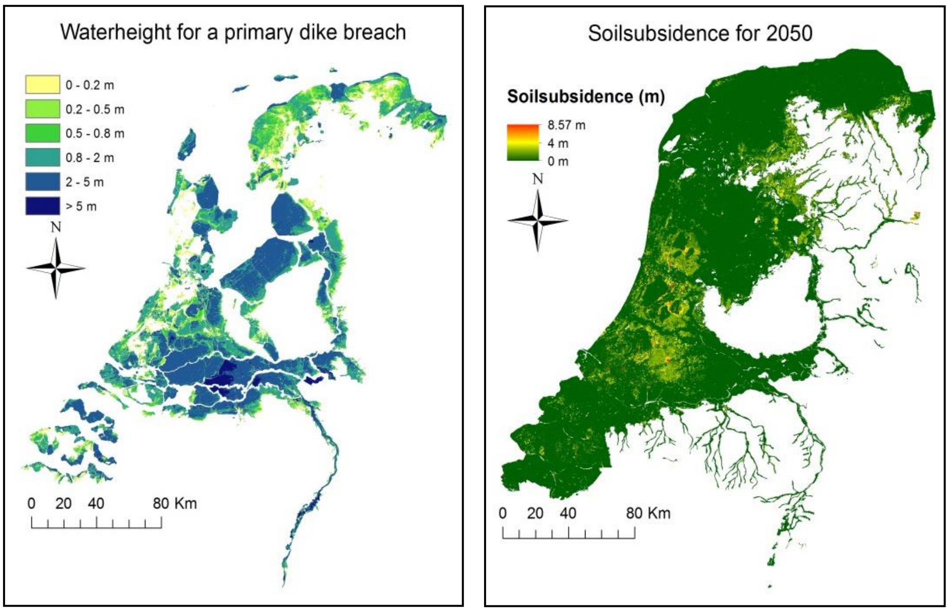


Figure 8: left: Water height after a primary dike breach. Right: Soil subsidence height for 2050. Both are summed to calculate the relative water height for the 2050 scenarios.

The soil subsidence map is a combination of two studies done by Alterra, TNO and Deltares (2010), in which they investigate the trend in drainage patterns for the Netherlands. By extrapolating this trend, they made soil subsidence predictions for 2050. This 100 meter raster soil subsidence map for 2050 is used in this model to calculate the increase in relative water level height by flooding, because of a dike breach, this data is visualized in Figure 8.

The demographic data in used at the end of the arrows in Figure 11 is used to calculate the costs per municipality or the population data from the CBS is used to calculate the costs as can be seen in Table 4.

3.1.2 Flood data for extreme precipitation

As can be seen in Figure 6 and Figure 11, there are two different datasets used to calculate the costs for heavy precipitation. Both use extreme precipitation runoff maps with a repetition time 25 years for the present, and for the year 2050. This gives a total of 8 different datasets for the W scenario, which is the heaviest precipitation scenario. The RPKC model has made maps with a 100 years repetition time, for the present and for 2050 which are investigated separately. Both datasets are based on raster data with a 100 m resolution for the entire Netherlands.

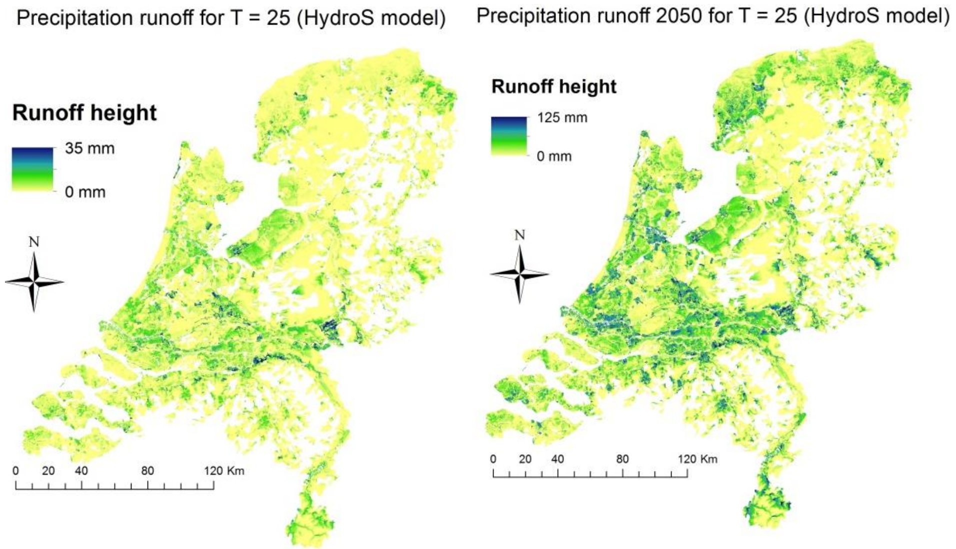


Figure 9: Runoff height for an extreme precipitation repetition time of 25 years. Left is for the present scenario and right is for 2050. Note that the legend is different for both scenarios (Immerzeel et al., 2010).

3.1.3 Overview of flooded objects and sectors

To indicate the costs of the effects of flooding for both precipitation and a dike breach it needs to be determined which objects are affected by flooding. These objects and sectors are based on the HIS-SSM method (for a primary a dike breach) or the STOWA research (for pluvial damage), as can be seen in Table 4.

Table 4: Overview of objects and sectors affected by flooding in this thesis

Data	File name	Author	Costs
Land use (ha):	LGN7	Alterra	STOWA: (Hoes et al., 2013) (Arcadis et al., 2006)
Potatoes Sugar beets Grass Grains Maize Fruit Arboriculture Horticulture Build-up Greenhouses			
National roads (m):	TOP10NL_2013	Kadaster	STOWA: (Hoes et al., 2013)
Highway Freeway Other roads Railroad			
BAG	BAG_januari_2014	Kadaster	STOWA: (Hoes et al., 2013)
Area of buildings (m^2) Type of buildings Area of airports (m^2) Age of buildings			
Demographical data	District and neighborhood map for 2012 and 2013.	CBS	HIS-SSM Method: (Kok et al., 2004)
Number of people Number of vehicles WOZ Height of buildings			
Recreation area Urban green	CBS Statline		STOWA: (Hoes et al., 2013)
Employment data (jobs):	CBS Statline (2012)	CBS	HIS-SSM Method: (Kok et al., 2004)
Industry Utility Construction Quarrying Trade and commerce Financial sector Transport Care Government			

3.1.4 Drought data

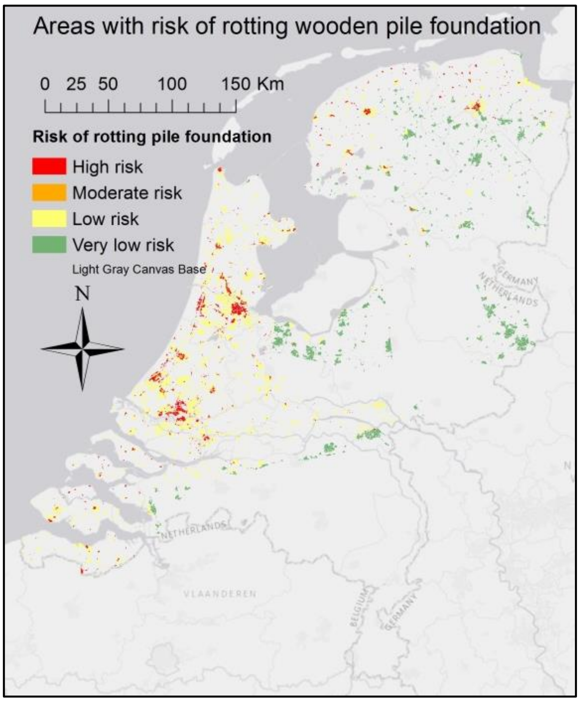
The costs of drought are divided into three major categories as can be seen in Figure 11:

- The damage to sensitive pile foundation
- the damage to agriculture
- the damage to gardens and parks

It is assumed that the increase in drought is distributed evenly in the Netherlands resulting in the lowering of groundwater level, which can damage sensitive pile foundation. In this thesis a study of Deltares is used, in which they investigate the areas where groundwater levels are decreasing because of drought and where wooden pile foundation is common. Deltares combined this information to create sensitivity maps for property with wooden pile foundation, as can be seen in Figure 10 (Hoogvliet et al., 2012).

3.1.5 Heat stress data

The effects of heat stress and their association costs are calculated by the increase of 2 °C for the entire Netherlands (for W and W+ scenario). The UHI effect is separately investigated for the urban areas, with a local study done in Rotterdam for 2010-2012, which is extrapolated for the entire Netherlands for multiple land uses (van Hove et al., 2014). This extrapolation is done by Alterra and Geodan to investigate the amount of days with a (24 hour) minimal temperature of 20 °C for the entire Netherlands. This (24 hour) minimum temperature is important because of the health effects associated with it, especially during the night.



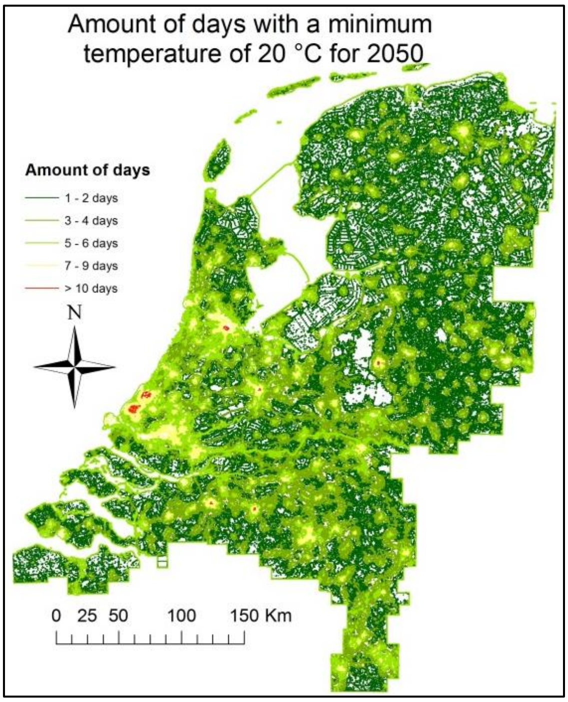


Figure 10: left: Areas with a risk of damage to wooden pile foundation because of rot (Hoogvliet et al., 2012). Right: UHI effect visualized in the amount of days above 20 °C (van Hove et al., 2014).

3.2 How to calculate the costs?

To indicate the costs of the above mentioned climate change effects, choices need to be made how to approximate these costs. These choices based on literature, can over- or underestimate the costs of specific climate change effects, that is why it is important to define the steps thoroughly. Figure 11 is a basic overview created per climate change effect, from the review and the datasets which are available for this research. In the next part of this section the spatial model will be further explained per climate change effect.

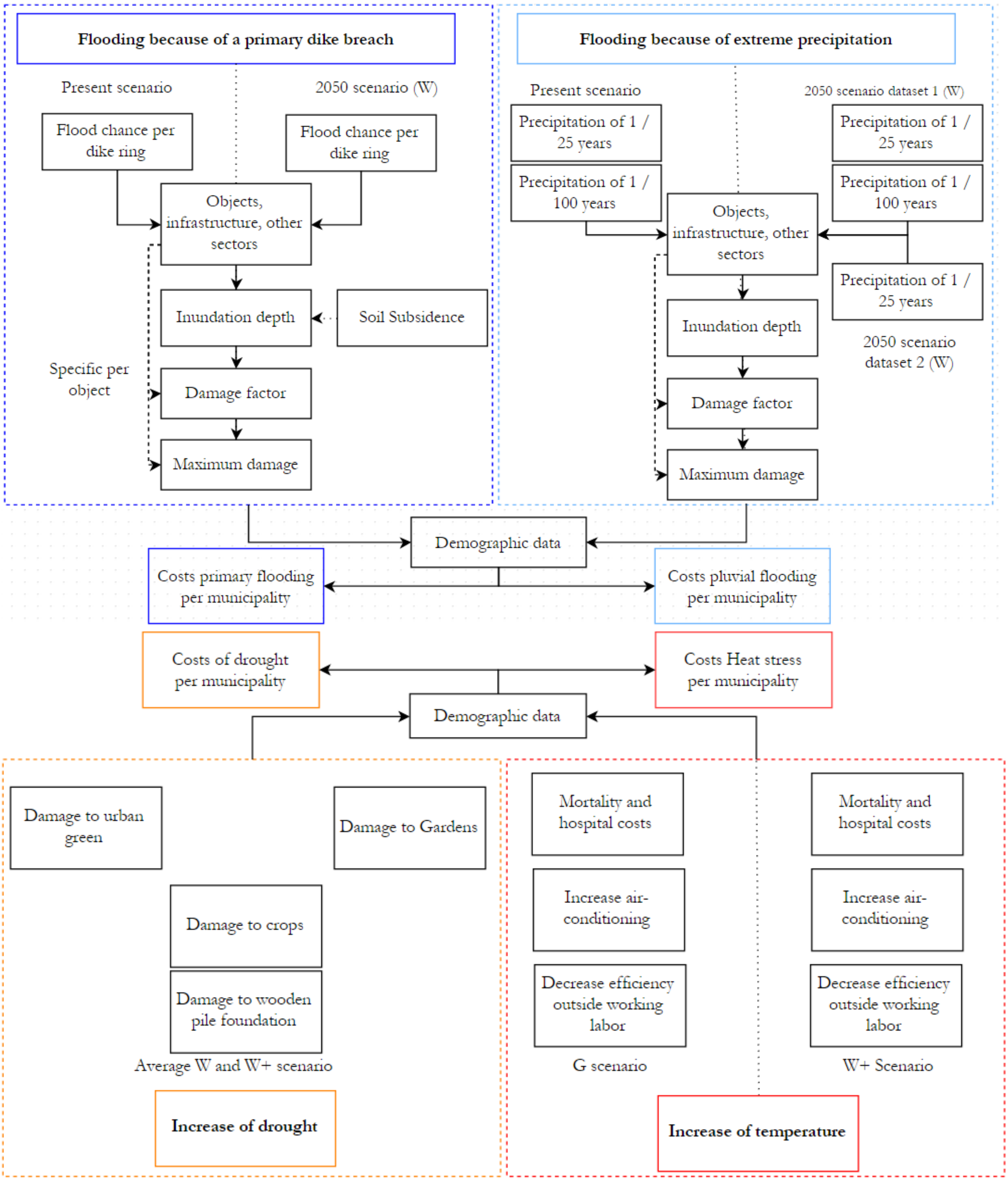


Figure 11: A basic overview of the spatial model to calculate the additional costs for climate change

3.2.1 Calculating the costs for flood because of a dike breach

The additional costs for a dike breach are calculated as a combination of inundation depth, flood chance per dike ring, soil subsidence and the accounted damaged sectors based on the HIS-SSM method (Kok et al., 2004). The inundation depth and the soil subsidence are summed and transformed to vector data, without simplification. This new inundation height is the basic overlay for the damage factor, which is applied to every specific damaged sector, based on the HIS-SSM method (Kok et al., 2004). The flood chances per dike ring are added to every flooded sector, so the expected yearly additional costs can be calculated per scenario. These flood chances are based on different climate change adaptation strategies from the 'ruimte voor de rivier' project, which are translated to a worst-case and a best-case scenario per dike ring (Klijn et al., 2007).

To calculate the damage costs to different sectors because of a dike breach, the costs are calculated for the two scenarios shown in Figure 11 and are divided into eight different categories:

- Damage to houses and shops.
- Damage to agriculture.
- Damage to (rail) roads and airports.
- Damage to urban areas and urban green.
- Damage to cars.
- Mortality.
- Loss of labor and employment.
- Damage to recreational areas.

For the damage to houses and shops it is assumed every shop and house has the same value of belongings inside. The damage done to these belongings is proportioned to the surface area of the property, which is also done in the HIS-SSM method (Kok et al., 2004). To estimate the value of the property itself, the average 'estimation of property' (in Dutch 'WOZ') per municipality is used. To differentiate between low-rise, high-rise and normal property, CBS municipality and neighborhood maps are used with averages per municipality. So it is assumed that the differences in property value are evenly distributed over all the property in a municipality.

The damage to roads is calculated according to the HIS-SSM method, with the use of the length of the road and road type divided into three categories presented in Table 4 (Kok et al., 2004). To calculate the costs for rail roads, the length and the amount of tracks per flooded area are used from the TOP10 dataset.

To calculate the damage to agriculture it is assumed that the total flooded surface area of a specific crop cannot be saved. This means that the height of the water does not influence this result, which is according to the HIS-SSM model (Kok et al., 2004). In the HIS-SSM model they do not differentiate per crop, in this thesis there is a differentiation used for crops according to the STOWA research in combination with the LGN dataset (Hoes et al., 2013). For the prices of crops per hectare the research of Arcadis is used in combination with the STOWA report (Arcadis et al., 2006).

For airports (selected from the BAG dataset) and urban areas in general, the area size is the only determining factor to calculate the costs for damage and drainage to these sectors based on the HIS-SSM method (Kok et al., 2004).

To calculate the damage done to cars, mortality, loss of labor, recreational and urban green areas, statistical data is used from CBS Statline in combination with the district and neighborhood maps from CBS, as can be seen in Table 4. To calculate the additional costs for these sectors, spatial homogeneity for these sectors is assumed, which is an important assumption in this research. This means that the costs are calculated in a way that if a part of the surface area of a municipality or neighborhood is flooded, a sub sequential part of people, cars, industries and recreational areas will be affected by this specific flood height, without the use of their exact location.

For the loss of jobs and damage done to industries, the HIS-SSM method is used, in which different labor sectors are grouped in categories from CBS Statline (Kok et al., 2004). Every category has its own maximum damage costs, but the same damage factor is applied per inundation height, which is the same as in the HIS-SSM method as can be seen in appendix 3.

In Table 4 an overview of the different labor sectors is presented. Subsequently these areas are intersected with the different flooded areas and the damage factors are applied per flood height, which have their own damage factors based on the inundation height.

All costs per sector are calculated as yearly expected costs, which need to be interpolated and accumulated for the years between 2050 and the present. In combination with the discount, the costs are multiplied by 10.38 (as can be seen in the next section of discount costs). The total costs caused by the effects of climate change for a primary dike breach are a summation of all the above damaged sectors, for a worst-case and a best-case scenario for 2050 (Klijn et al., 2007). The costs for the same damaged sectors for the present need to be subtracted from the total costs of 2050 to get the additional costs. A total overview for calculating the additional costs for a dike breach is presented in Figure 12.

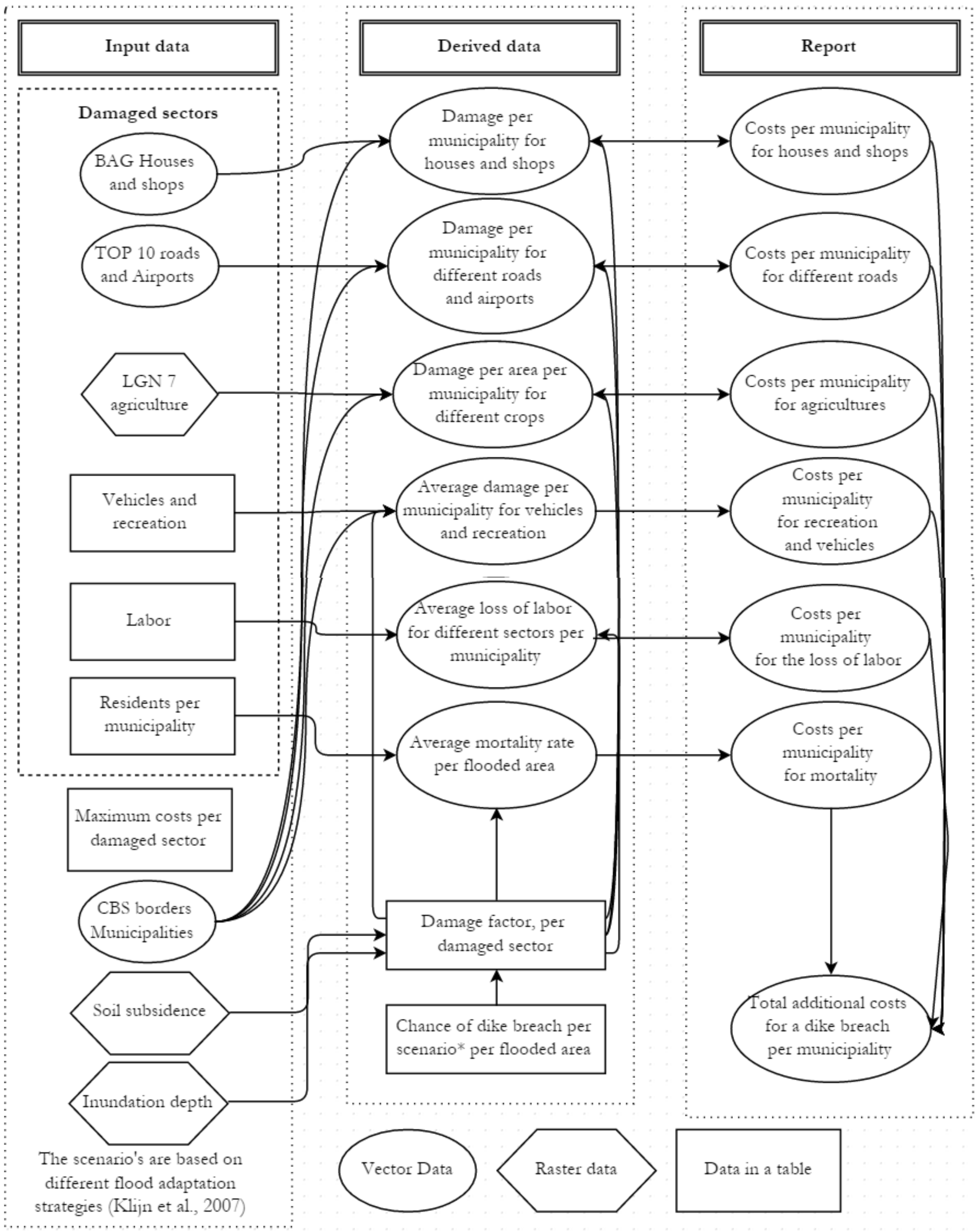


Figure 12: An overview of the structure to calculate the damage and additional costs for a flooding because of a primary dike breach for the Netherlands.

3.2.2 Calculating the costs for flooding because of heavy precipitation

The damage done by heavy precipitation is calculated for two different datasets for a total of five different cases for the W scenario and for the present, as can be seen in Figure 11. The costs of this type of flooding is divided into five categories based on the STOWA research (Hoes et al., 2013):

- Damage to houses and shops.
- Damage to roads.
- Damage to agriculture.
- Damage to recreation.
- Damage to gardens.

To calculate the costs to houses, shops and roads the same principles are used as for the previous section, flooding because of a dike breach. The difference is the damage factor and maximum damage used, which are higher for a flooding by a dike breach than for a pluvial flooding (Kok et al., 2004).

For agriculture, the damage factor and maximum damage are taken from the STOWA report for every crop as can be seen in Table 4. The differentiation in crops is the same as in the LGN dataset. The costs of the damage caused by precipitation are calculated per flooded area per crop. The flood level determines the damage factor and the crop determines the maximum costs, just as in the STOWA research (Hoes et al., 2013).

To calculate the costs for recreation areas and gardens, CBS Statline is used to calculate the relative amount of recreation and gardens in a municipality. Because homogeneity of both sectors is assumed, every flooded area will damage a sub sequential part of those sectors.

Recreation is divided into intensive and extensive recreation areas. Both recreational areas are divided into different categories. Intensive recreational areas are outside sport areas and recreational areas for daily use (in Dutch called 'dagrecreatief terrein'). Extensive recreational areas are open nature and forest areas. These categories are also used by the STOWA report (Hoes et al., 2013).

In order to calculate the additional costs for extreme precipitation scenarios with a repetition time of once every 25 years and once every 100 years, it is needed to know the difference between the costs in 2050 and the present. For the houses, shops and roads, the affected areas are determined with overlays with the precipitation data. The runoff data is converted to a vector dataset and split into different damage factor categories to as can be seen in Appendix 2. Areas with a damage factor of 0 are filtered per sector, because it does not change the costs.

The different runoff areas with damage factor are intersected with every house and shop, every parcel of land with crops as classified by the LGN dataset, and all the parts where roads are flooded. The fraction of recreation and gardens is calculated for every flooded area to determine the costs for these sectors (as explained in the methodology section). After the addition of the damage factors, the data is merged and an overlay with the municipalities is made, to classify the costs per municipality. The costs are added together per damaged sector per municipality per scenario. This entire process is repeated for the different repetition times for the present and for 2050 for both datasets. The difference between the 2050 and the present scenario are calculated per municipality, to determine the additional costs for climate change effects for these sectors and a discount is applied to compare the costs between 2050 and the present.

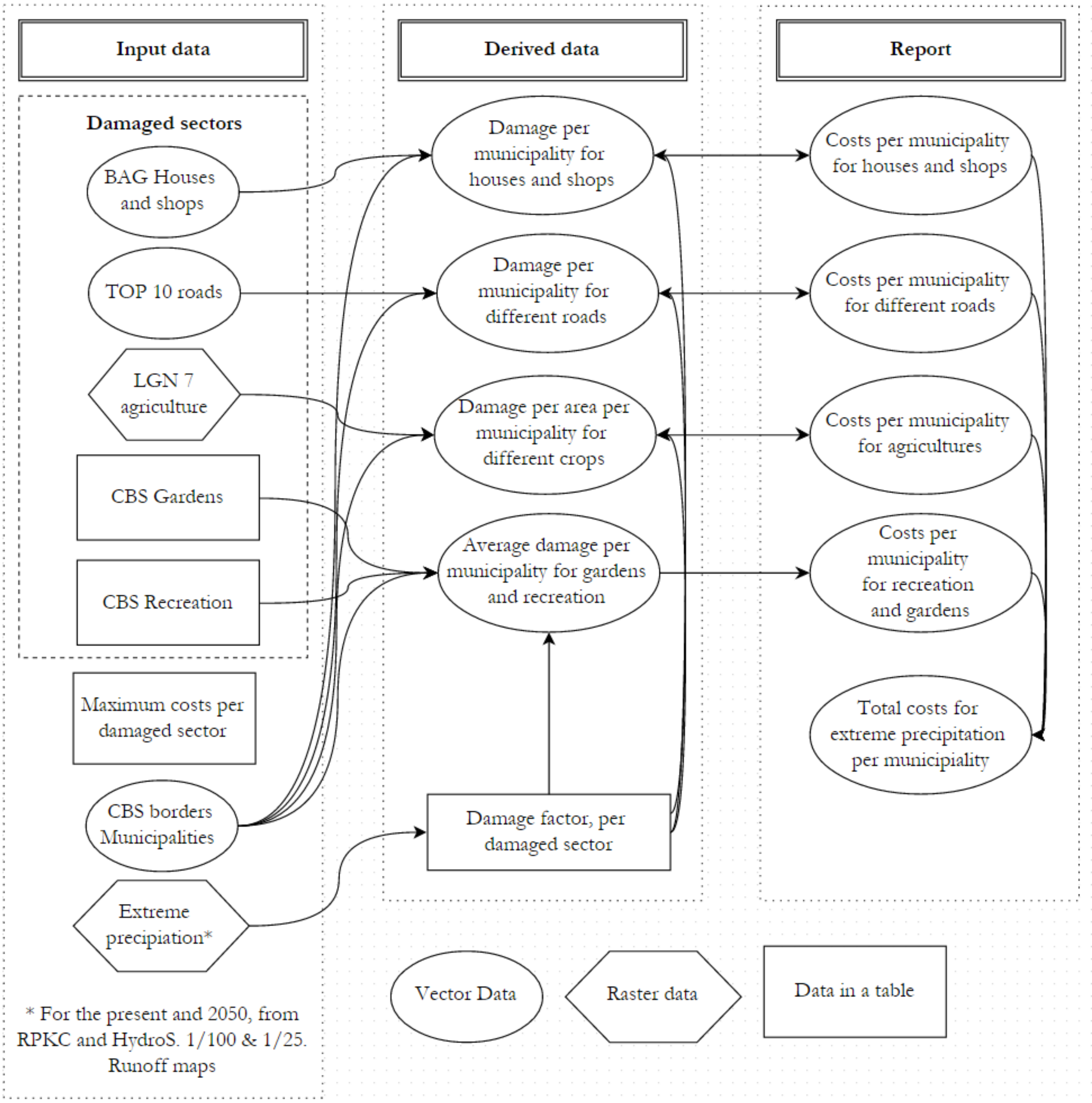


Figure 13: An overview of the structure to calculate the damage and additional costs for extreme precipitation for the Netherlands.

3.2.3 Calculating the costs for drought

Because it is assumed that drought effects are distributed evenly for the entire Netherlands, location is hardly an important factor for this climate change effect (Ven et al., 2010). However, the area and the costs for different crops are calculated based on their location and their respective municipalities. The effects of climate change on crops are investigated by Alterra, (Wit et al., 2011) for the Northern part of the Netherlands and by Arcadis (Arcadis et al., 2006). They estimate a loss in yield of 5% to 35% because of an increase in drought for 2050. This number can vary per crop because of the growing season, the mitigation strategies used by the farmer and the soil type. For this thesis a worst-case of 35% yield loss is assumed, and a 5% best-case scenario for 2050.

In order to calculate the additional costs of climate change effects for drought, there are three spatial datasets used, and multiple tables from CBS Statline as input data. The effects of climate change increase drought and therefore damages sensitive pile foundations, agriculture, gardens and parks is investigated.

The effects of drought on sensitive pile foundation is determined with the use of sensitivity maps which are used by RPKC, see Figure 10 (Ven et al., 2010). With the use of the BAG dataset, the amount and age of houses and shops are counted in these sensitive areas. In combination with the maps created by (Hoogvliet et al., 2012) in which they located the sensitive areas for pile foundation, overlays can be made with the BAG dataset to investigate the amount and damage of property in those areas. The buildings older than 1960 are selected and overlaid with the high risk areas as can be seen in Figure 14. It is assumed that houses built before 1960 in high ground-water areas have a wooden pile foundation (Hoogvliet et al., 2012) (Ven et al., 2010). To determine the costs for sensitive pile foundation, it is assumed that a replacement of the wooden pile structure is needed, which has an estimated average cost of € 54.000 per structure (Hoogvliet et al., 2012). An increase of degradation to pile foundation is estimated on 60% for 2050, compared to the present situation (Hoogvliet et al., 2012).

The effects of drought on urban vegetation (public parks and trees) are based on the increase of maintenance within urban areas, which is investigated by a case study in Finland (Markus Holopainen, 2006). They noticed that during a dry summer (the summer of 2003) their maintenance costs increased with 3.3% within the urban areas of Helsinki (Markus Holopainen, 2006). In this thesis it is assumed that this kind of dry summers will increase for 2050, especially in the W^+ scenario. The increase of 3.3% in maintenance costs is therefore used as a reasonable increase in costs for the Netherlands. To calculate the costs of this increase in urban green maintenance, the total costs of maintenance are divided by the area of parks and public gardens. The area size of parks and public gardens used in this thesis, are from CBS Statline and are calculated per municipality.

The maximum costs of all those sectors can be seen in Appendix 1, the additional costs are calculated by the multiplication of the discount factor with an exception of the sensitive pile foundation. This exception is made because damage to pile foundation can only happen once, as opposed to the yearly cumulative costs of other damaged sectors as will be described in the next section. All the costs are calculated and intersected per municipality. To calculate the costs for private owned gardens, (Hoogvliet et al., 2012) estimated an average of €1,62 per household of irrigation costs.

Since the amount of warm (maximum daily temperature > 20 °C), hot (maximum daily temperature > 25 °C) and tropical days (maximum daily temperature > 30 °C) will more than double for the year 2050, for both the W and W^+ scenario (Bilt, 2009), it is assumed that the irrigation costs will double as well, to €3.24 per household for 2050. To calculate the increase in costs for a municipality, the amount of houses from the BAG dataset is used with the CBS district and neighborhood maps to filter the low and high-rise buildings. It is assumed that this results in filtered households with a garden and an increase in irrigation costs.

The damage and costs for agriculture are determined by the size of the area and the kind of crop for a municipality, the effects of drought on agriculture are chosen to be the same for the entire Netherlands.

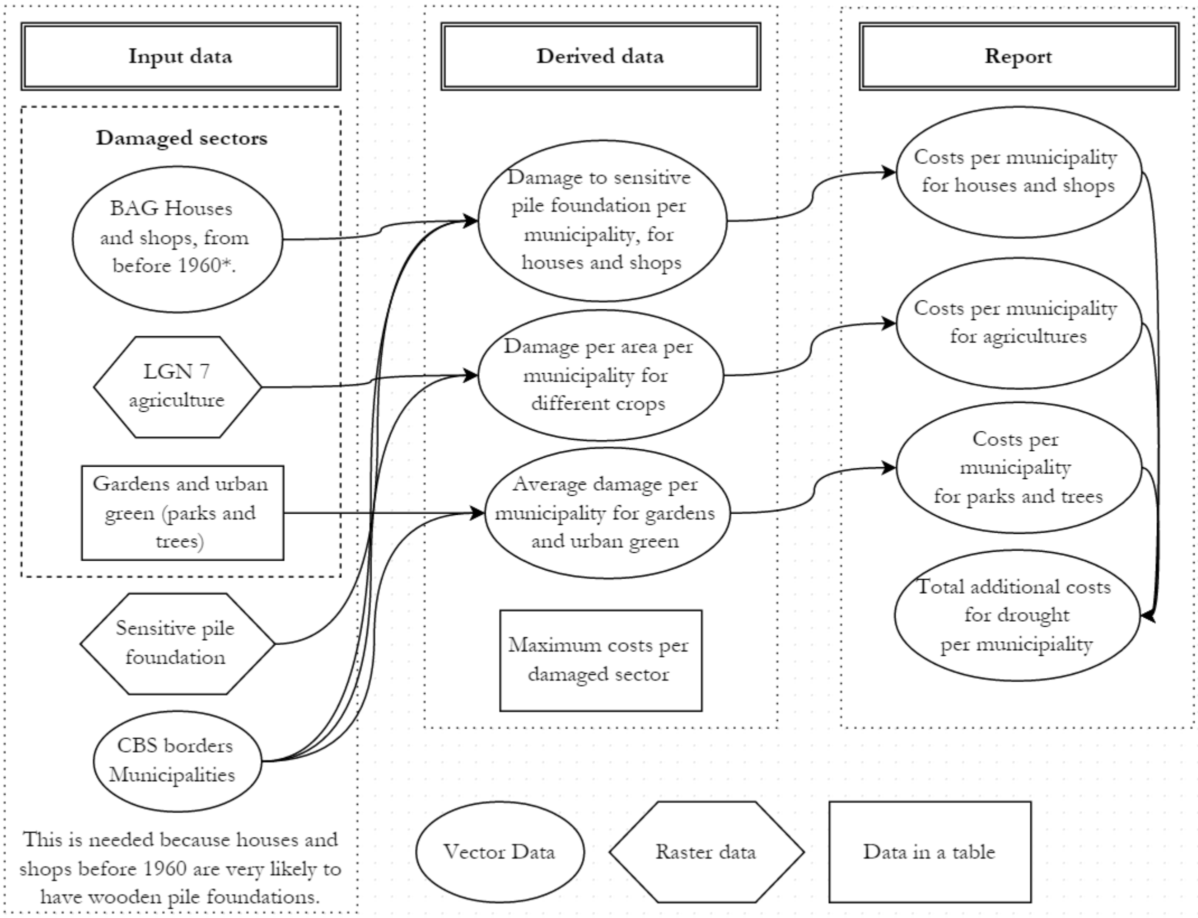


Figure 14: An overview of the structure to calculate the damage and additional costs for drought because climate change effects for the Netherlands.

3.2.4 Calculating the costs for heat stress

To calculate the additional costs for heat stress there are three datasets used in this report. The urban heat island effect is the dataset with spatial features, the other datasets are tables about the demographics per municipality from CBS Statline. This means that most of the costs for heat stress are based on homogeneity of people and households.

The costs of heat stress are divided into three sectors, which are visualized in Figure 11 and consist of:

- An increase in energy usage because of air conditioning.
- A decrease in outdoor labor efficiency.
- An increase in hospital costs and mortality.

An increase in air conditioning for 2050 is predicted for the W and W^+ scenario, because of an average increase of at least 2 °C for the Netherlands. The current market of air conditioning for the Netherlands is estimated at 6% with a predicted increase of 261% for West-Europe in 2050 (Isaac and van Vuuren, 2009). This study accounts for social economic changes, population growth and an increase in the energy efficiency of air conditioning. Although this increase in energy usage is calculated for West-Europe, it is assumed that it is applicable for the Netherlands as well.

To calculate this increase in costs for air conditioning per household, it is assumed that the amount of air conditioning will spread evenly according to the amount of households per municipality. This is calculated with the district and neighborhood map of the CBS.

The decrease of outdoor labor efficiency for 2050 is due to the increase of outside temperature which is 2°C for the W scenario. For inside working areas this increase in temperature is not important due to air conditioning and indoor climate systems. But for outdoor working areas (Dunne et al., 2013) calculated a decrease of outside labor efficiency of 5% - 10% for the Netherlands. This outside labor is divided over all the people in a municipality. Of all the people in a municipality, 44% of the people work (CBS Statline) and 7% work outside (Dunne et al., 2013). This decrease in labor efficiency is only present for the two hottest (summer) months per year.

Table 5: Increase of costs for 2050, of hospitalization and mortality for the summer months (Stone et al., 2013).

KNMI '06 Scenario	G	G+	W	W+
Mortaility	€ 1.300.000	€ 2.700.000	€ 3.800.000	€ 8.700.000
Hospitalization	€ 0	€ 0	€ 2.000.000	€ 14.000.000

To calculate the amount of mortality and hospital effects for 2050 the study of (Stone et al., 2013) is used. They calculated the difference in mortality and the amount of hospitalization with an increase of average (24 hour) daily temperature measured in the Bilt, the Netherlands. With this increase of hospitalization and mortality per temperature they could calculate the costs for multiple climate change scenarios, which can be seen in Table 5. The average daily temperature is measured in a rural area, which means that Table 5 is an underestimation of the effects of mortality and hospitalization in cities and urban areas (Stone et al., 2013).

In the model a best and worst-case approach has been chosen. With € 1.300.000 (G scenario) as a best-case and € 8.700.000 (W+ scenario) as a worst-case scenario for an increase in costs for mortality in 2050. The increase in costs for hospitalization is determined on € 0 (G scenario) as a best-case and € 14.000.000 (W+ scenario) as a worst-case scenario for 2050.

To quantify the peaks in average daily temperature for cities (UHI effect), Stone et al. estimated the extra costs because of an increase in mortality and hospitalization of the effects of UHI for the entire Netherlands on € 3.800.000. With the use of UHI maps discussed in the previous section, it is determined which cities have a UHI effect and which do not. The extra costs of UHI are divided over these municipalities, according to the amount of people living in these cities. For the amount of mortality and hospitalization the number of people living in a district are used and overlaid with the areas with the highest number of days with an average above 20° C degrees according to section 3.1.5 Heat stress data. For the municipalities with these characteristics, the amount of hospitalization and mortality are calculated according to the previous section. All these additional costs are summed and calculated per municipality with an intersection and presented in the next section of the report.

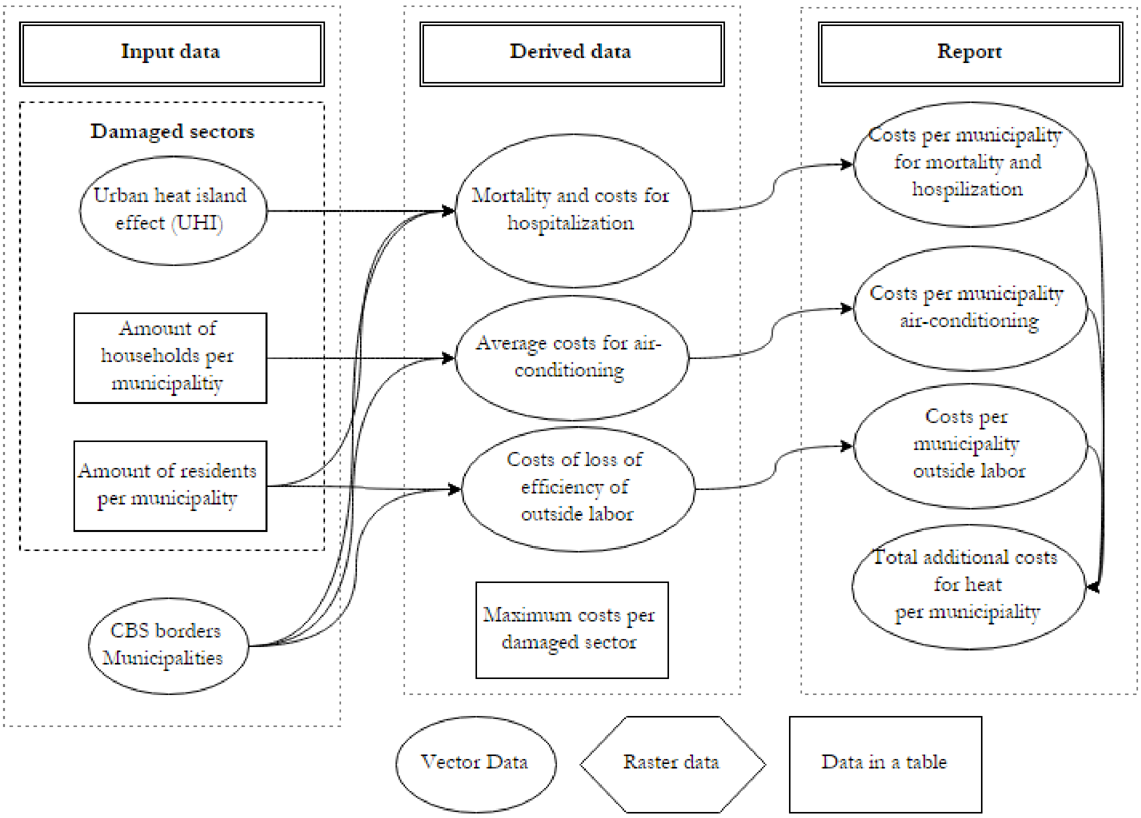


Figure 15: An overview of the structure to calculate the damage and additional costs for heat stress for the Netherlands.

3.3 Discount and interpolation of costs

To calculate the costs for 2050, it is important to determine the costs for all years between 2014 and 2050 as well. In some cases the costs are only once, e.g. to replace the wooden pile foundation in sensitive areas. In other cases the costs are reoccurring (e.g. the effects of drought on crops) or calculated as expected yearly costs (e.g. flooding costs because of a dike breach). When the additional costs for 2050 and 2014 are calculated for a reoccurring event, the costs for the years in between are assumed to be linear. So if the expected additional yearly costs for e.g. a dike breach for Amsterdam in 2050 is € 3.600.000, the yearly accumulated costs will be more than € 63.000.000, for every year between 2014 and 2050 as can be seen in Figure 16. Because these are 'future costs' it is common in scenario and cost-benefit analysis to apply a discount on these costs.

This discount is due to the potentiality of money in the present, which is higher than money in the future, mainly because of interest. In this thesis the discount rate is set at 2.5%, which is a common discount rate for climate change models, but low for economic models, which use a discount rate varying between 3 and 6 percent (Weitzman, 2007). After the discount of 2.5% is applied for every year, the total costs between 2014 and 2050 will be around € 37.000.000, as can be seen in Figure 16. If the same discount is applied for the same amount of years, the discount factor can be used as a constant. For 36 years with a discount factor of 2.5%, the discount factor used in this thesis is 10.38.

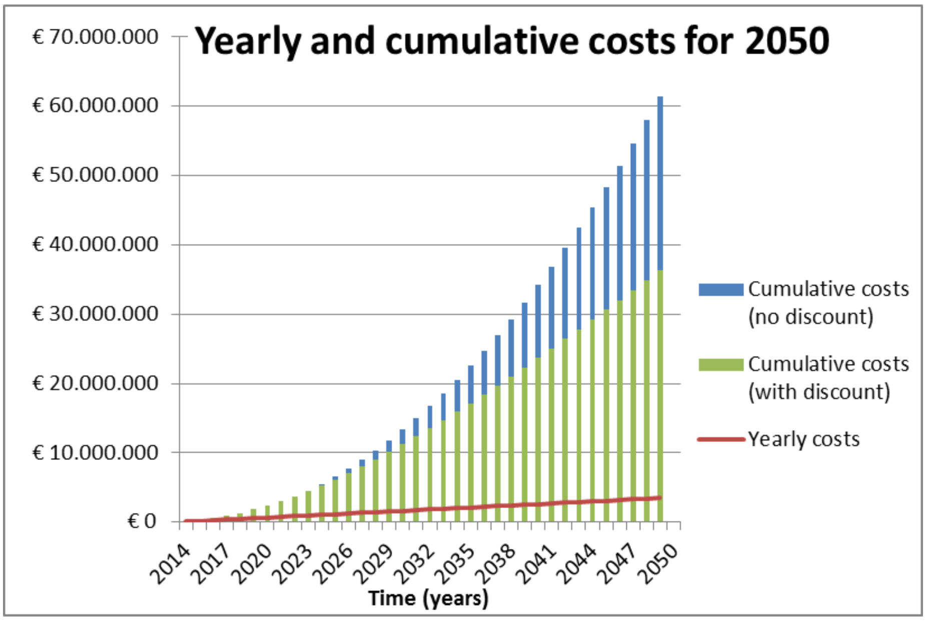


Figure 16: An example of the effects of discount and cumulative costs for the costs of a € 3.600.000 yearly expected dike breach in 2050.

3.4 Sensitivity analysis

For this research it is chosen to perform a one at a time (OAT) sensitivity analysis for the different damaged sectors, per effect of climate change combined with a minimum and maximum sensitivity Index (SI_{max}). One of the simplest ways to apply this sensitivity analysis is to investigate the effects of the minimum and maximum damage costs by calculating their relative change for the minimum damage costs as described by Hamby (Hamby, 1994). The OAT investigates the effect of each parameter with an increase of one third (33%, 66% and 100%, 133% and 166%) of the expected damage.

The SI is calculated by using the minimum and maximum damage costs per parameter, with the formula below, the maximum and minimum damage costs can be seen in Appendix 1.

$$SI\text{max} = \frac{Mmax - Mmin}{Mmax}$$

Mmax and Mmin are the maximum and minimum output additional costs per parameter, which in this case are the total costs, which results in a SI_{max} per parameter per municipality which can be used to compare parameters.

The OAT sensitivity analysis is chosen because of the relative short computation time with the spatial model used in this report. The parameters for the maximum damage are applied in the end of the model, which saves computation time. Still, one round of calculating all the parameters takes about 20 hours.

The SImax is chosen as a first indicator for which parameters are most sensitive. The ten most sensitive parameters are calculated with incremented steps to calculate and plot the sensitivity index for these parameters.

$$S = \frac{\dfrac{M(e_1,\ldots,e_i+\Delta e_i,\ldots,e_P) - M(e_1,\ldots,e_i,\ldots,e_P)}{M(e_1,\ldots,e_i,\ldots,e_P)}}{\dfrac{\Delta e_i}{e_i}}$$

In the OAT sensitivity analysis the S is the sensitivity index per Δe_i, in this case from 33 % to 166 % in incremented steps of 33% for the ten most sensitive parameters. Because all the parameters are linear the relationships between the parameters will be constant per parameter. Still, the S shows the sensitivity of these parameters and can show the variability per municipality. This variability is comparable with the absolute costs per municipality, again because of linearity.

4. Results

This section shows the different results of the additional damage costs divided over the four different effects of climate change. For the four different climate change effects, the total effects are visualized on a map for the entire Netherlands and there is a focus on different damaged sectors. Finally the results of the sensitivity analysis are presented for the different parameters.

4.1.1 Total additional costs for extreme pluvial flooding

The total addional costs of climate change for the above mentioned damaged sectors can be divided into two repetition time scenarios (25 and 100 years), both from the W climate scenario. These scenarios have a different impact on the additional costs for municipalities, as you can see in Figure 17. Furthermore the affected sectors can differ per municipality, as you will see in the next chapters.

The actual costs of a flooding caused by extreme precipitation with a repetition time of 100 years is higher, than for a repetition time of 25 years. Nevertheless, the additional costs for an extreme precipitation event with a repetition time of 100 years is lower than for a repetition time of 25 years. This is due to the saturation of the soil and the capacity of the infrastructure in urban areas. Most soils and the main water infrastructures can handle 64 mm of precipitation, and have more trouble with 75 mm of precipitation (Immerzeel et al., 2010). As you can see in Figure 9, the difference between the runoff values is enormous, although the difference in precipitation is minimal as can be seen in Table 3.

For urban areas the additional costs caused by extreme precipitation are mostly determined by the damage done to houses and shops, and are minimal for agriculture, roads, recreation and gardens. This differes per repetition time as can be seen in Figure 18.

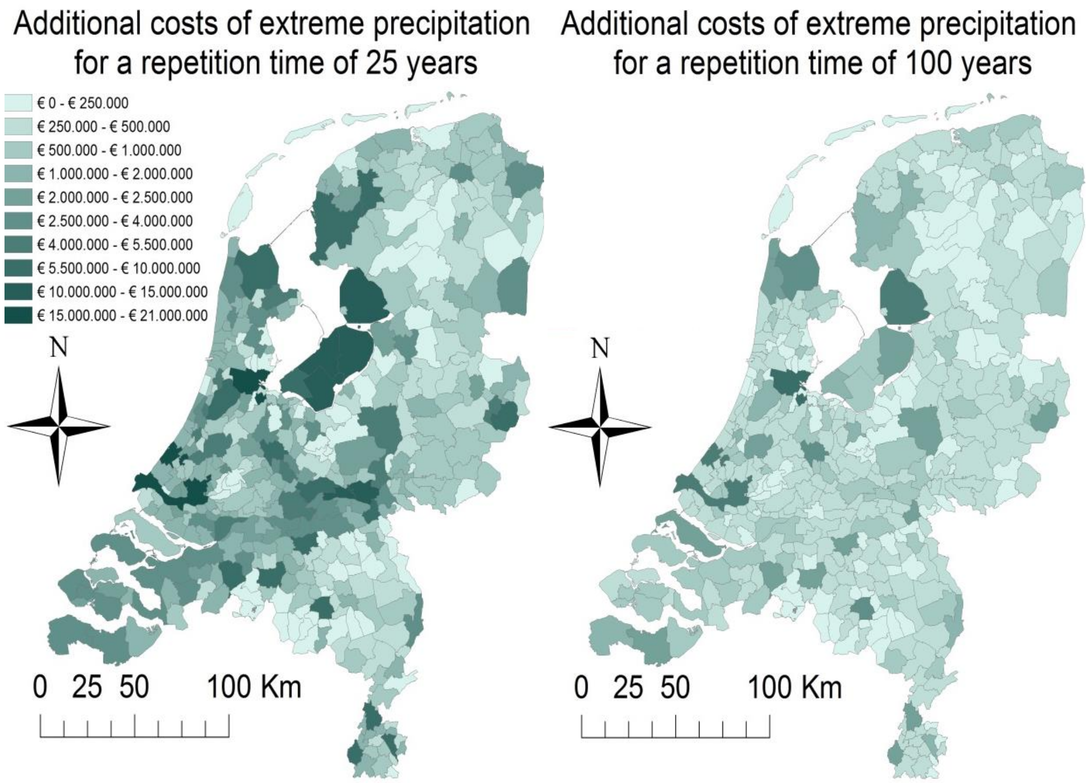
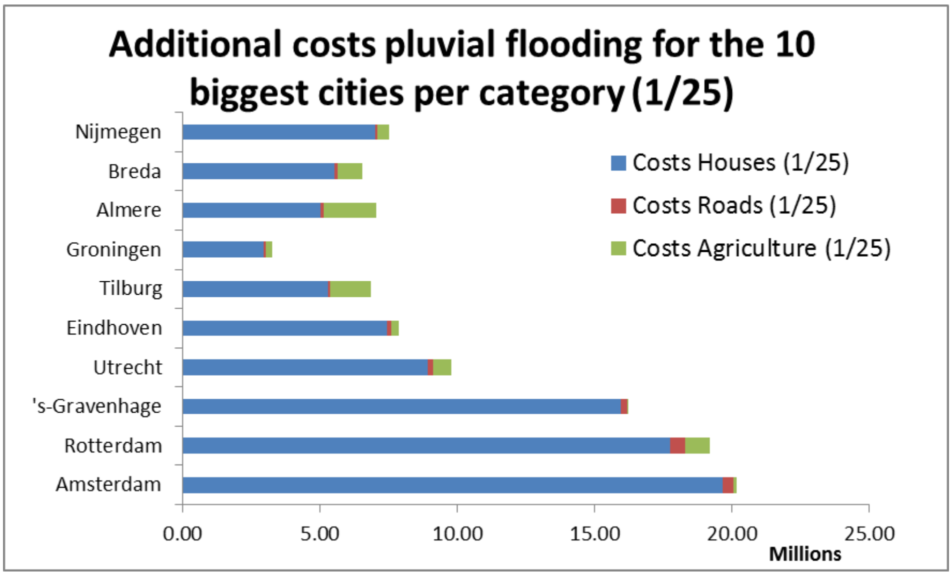


Figure 17: The additional costs for extreme pluvial flooding for the entire Netherlands per municipality, for both the 25 years and the 100 years repetition time scenarios, based on the HydroS dataset.

The ten municipalities with the highest costs from pluvial flooding caused by climate change are dense urban areas with high costs to shops and houses, or municipalities with large areas of 'expensive' agriculture, such as the 'Neder-Betuwe' which has large areas of arboriculture. There are also areas such as the 'Noordoostpolder' which are almost completely covered with agriculture, and thus have a high potential for additional costs for this sector (see Figure 19). The same can be seen for the municipalities 'Zeewolde' and 'Lelystad'. The costs for recreation, gardens and urban green are minimal compared to the costs for houses, roads and agriculture. The next section of this report mainly focusses on these sectors.



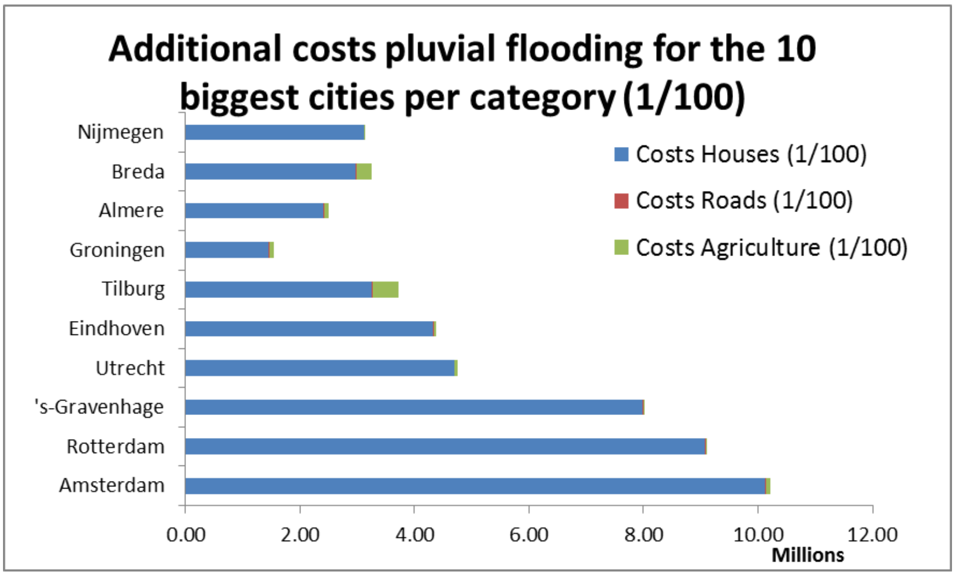


Figure 18: The Total costs for extreme pluvial flooding for houses, agriculture and roads. These costs are determined for a repetition time of 25 (top figure) and 100 (bottom figure) years.

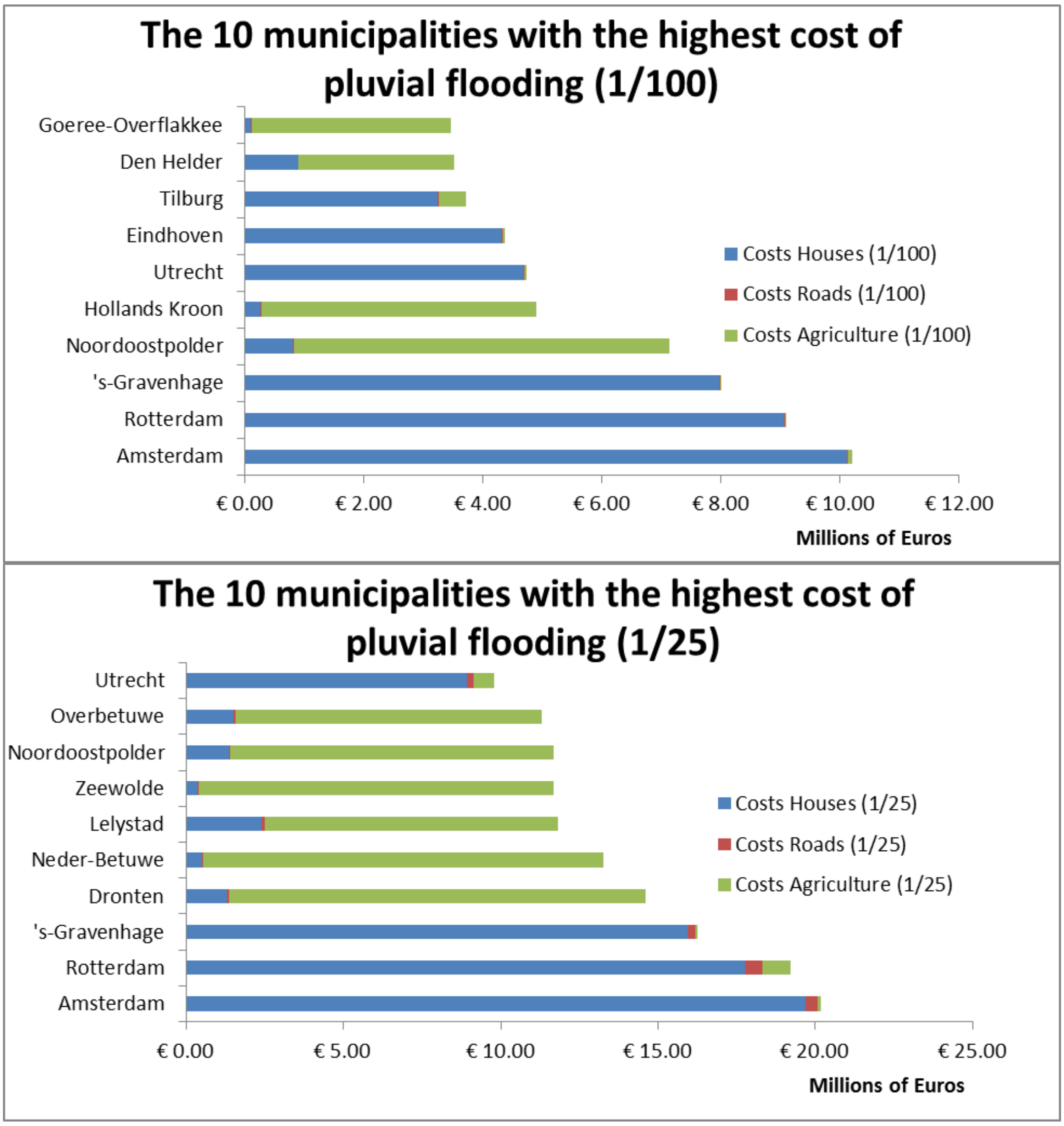


Figure 19: The ten municipalities with the highest costs of pluvial flooding for a repetition time of 25 years (top figure) and 100 years (bottom figure) and the affected sectors.

4.1.2 The additional costs of extreme precipitation flooding for houses and shops

The additional costs for municipalities due to extreme pluvial flooding are mostly determined by houses and shops, especially for urban areas as can be seen in the previous section in Figure 19 and in Figure 20 . This has numerous reasons as (Ven et al., 2010) pointed out, mostly due to non-permeable surfaces, which don't allow water to sink into the soil. But also the low capacity of water infrastructure and the lack of vegetation is part of the increase in inundation depth, and thus the costs.

This could mean that there is a relationship between urban areas (amount of people living in a municipality) and the amount of additional costs of pluvial flooding (see Figure 21). This relationship is non-existent for municipalities with small amounts of residents, or rural areas. In rural areas the size of the houses and the surrounding surfaces are more dynamic, which are important factors for the costs of extreme pluvial flooding. This dynamicity reflects in the relationship between the additional costs of extreme pluvial flooding and the amount of people living in a municipality for the 100 municipalities with the lowest amount of residents, which can be seen in figure 19.

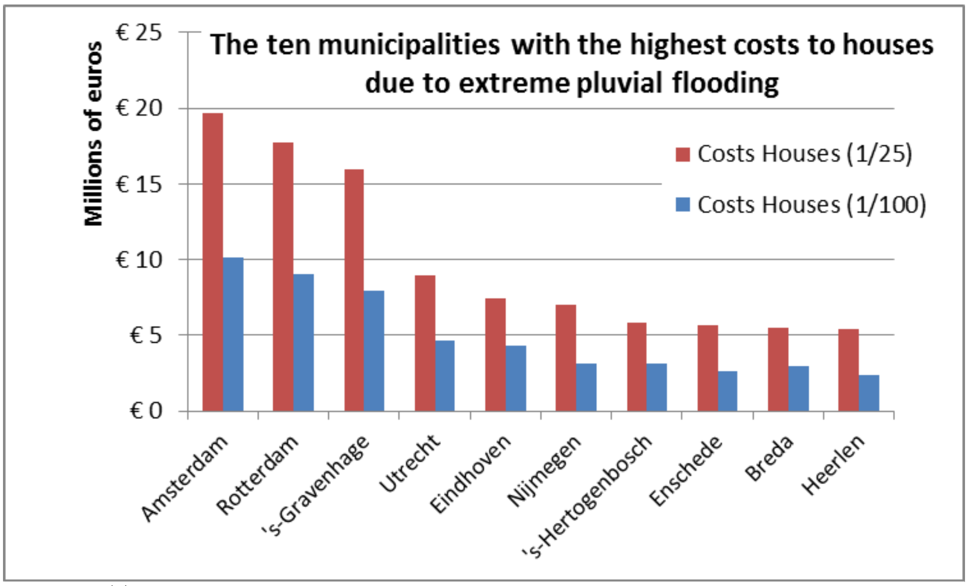


Figure 20: The ten municipalities with the highest costs to houses due to extreme pluvial flooding.

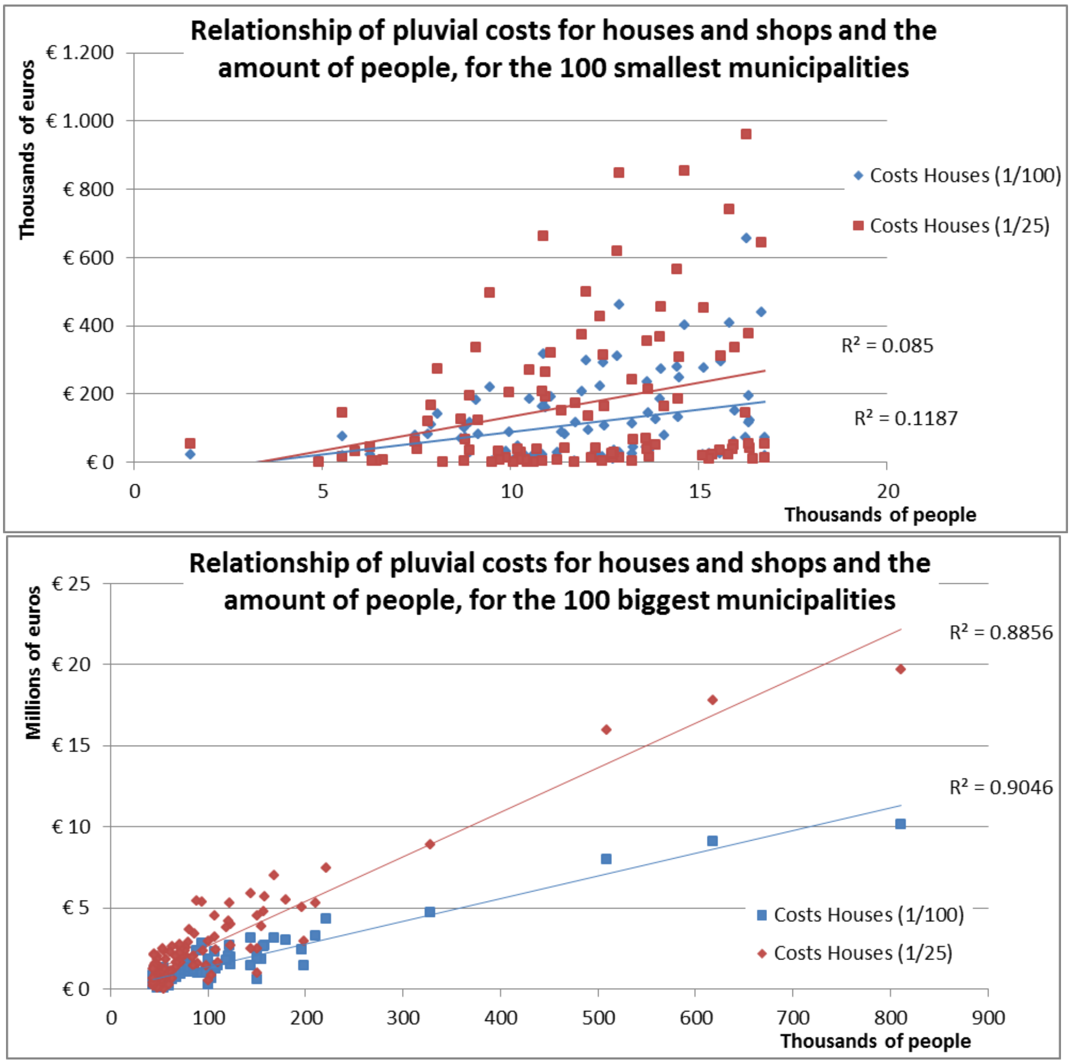


Figure 21: The relationship between pluvial costs and 'bigger municipalities', for the 100 municipalities with the least residents (top figure) and for the 100 municipalities with the most residents (bottom figure).

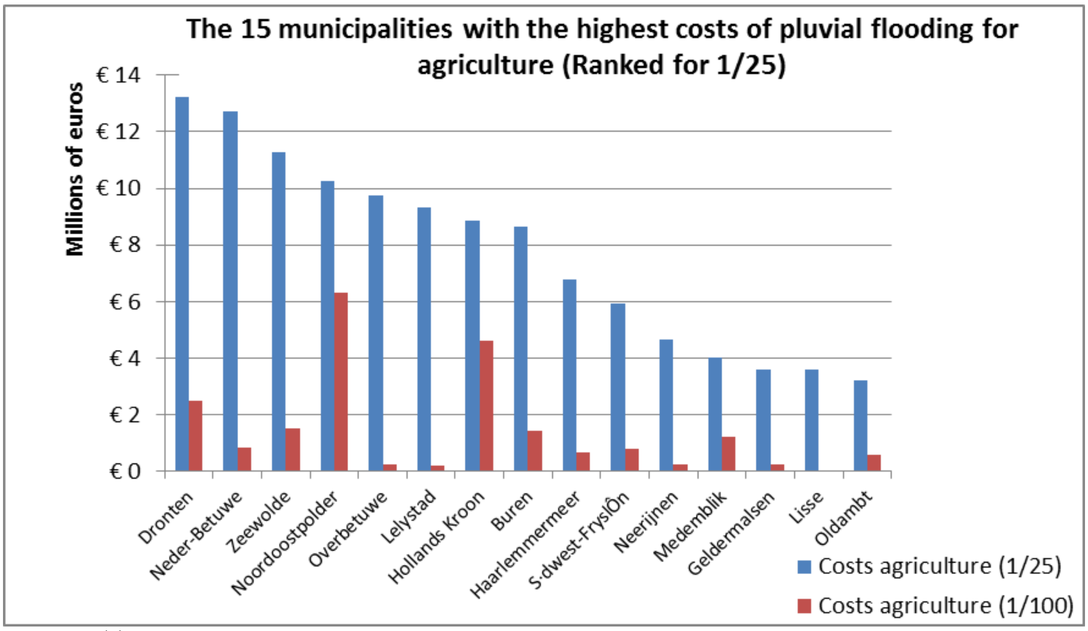


Figure 22: The 15 municipalities with the highest costs of pluvial flooding for agriculture, for both repetition times. The costs are ranked for a pluvial flooding with a repetition time of 25 years.

4.1.3 The additional costs of extreme precipitation flooding for agriculture

Overall, municipalities with more expensive agriculture can expect higher additional costs for agriculture, but for some municipalities this is not the case for both types of flooding. This is typical for agriculture, because agriculture has a very steep damage function, which can be seen in Appendix 2 (Hoes et al., 2013). Overall it is assumed that a pluvial runoff flooding of 10 mm is enough to destroy crops in general, including arboriculture. Pluvial flooding with a repetition time of 100 years destroys every crop, for the present scenario and for the 2050 scenario(Ven et al., 2010). This results in the same costs for both scenarios, and thus almost no additional costs for a pluvial flooding once every 100 year for agriculture, which can be seen for Lelystad, Overbetuwe and Lisse in Figure 22.

4.1.4 The additional costs of extreme precipitation flooding for urban green (parks), intensive recreation and gardens

The costs for urban green, gardens and intensive recreation, are exactly what can be expected based on the way of calculating the costs. Cities that have a combination of large areas of pluvial flooding and large areas of parks, gardens and recreation have the highest additional costs. This means that for the model the costs are mostly related to urban areas and bigger cities, because these are the areas with large flood areas. Nevertheless that can also be seen for municipalities with large areas of recreation or urban green, such as Rijswijk or Purmerend.

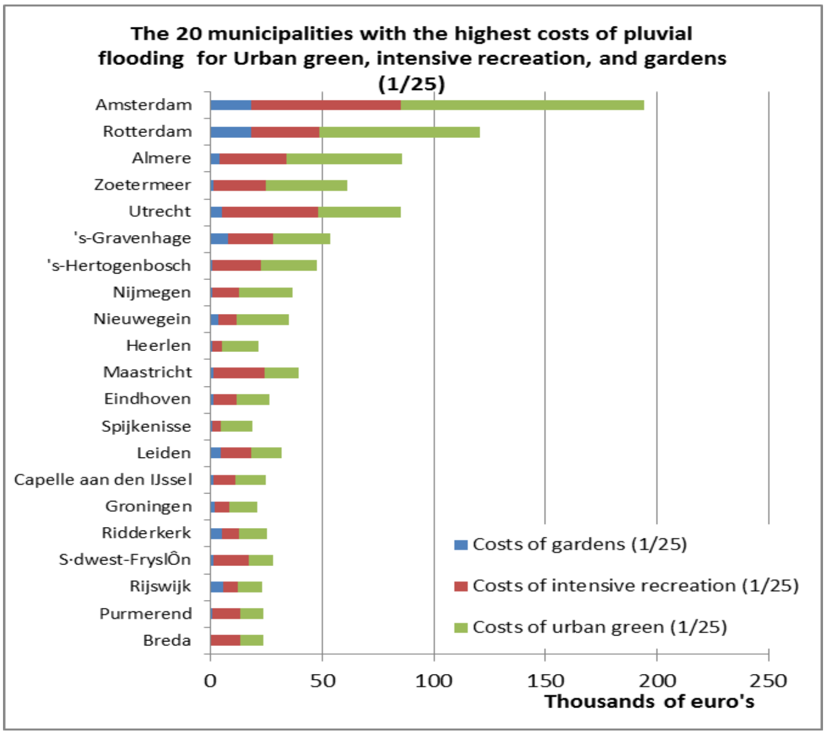


Figure 23: The 20 municipalities with the highest costs of pluvial flooding for urban green, intensive recreation and gardens. These additional costs are calculated for a repetition time of 25 years.

4.1.5 Discussion of the total additional costs for extreme pluvial flooding

The first thing to notice is the difference in the costs between a pluvial flooding with a repetition time of 25 years, compared to a pluvial flooding of 100 years. Unintuitively the additional costs for a flooding with a repetition time of 25 years is a factor two higher compared to the costs for a pluvial flooding with a repetition time of 100 years. This is even stranger when it is seen that the difference in precipitation for a repetition time of 25 years is 14 mm (75 – 61 = 14 mm) and for 100 years is 19 mm (98 – 79 = 19 mm) as can be seen in Table 3. Furthermore more precipitation means the soil becomes more saturated, which increases the inundation depths. This is the case for urban areas, where the water infrastructure can not handle the increase in precipitation (Ven et al., 2010). So where does this difference in additional costs come from?

This has everything to do with the saturation of the soil, the way of substracting the costs of the present scenario from the 2050 scenario and the way the damage factors are added. The inundation height and the runoff are minimal for a pluvial flooding of once every 25 years in the present, compared to a flooding with a same repetition time in 2050, as can be seen in Figure 9. So the costs are not determined by the difference in precipitation, but the difference in runoff depth. This difference is determined by the degree of saturation of the soil and the water capacity of the water infrastructure, which also shows a weakness in the model. The saturation of the soil is one of the most important elements which determines the runoff depth, but this variable is not included in the model at all, it is only determined by the extreme precipitation. This means that two extreme showers directly after each other do not influence one another in the model. An increase of heavy precipitation would also mean an increase in two heavy showers affecting each other, which means that another variable that explains this time lagg between showers should be introduced. Overall, more (extreme) precipitation means a changing ground water height and an increase of infrastructure is needed just to keep the saturation levels similar as today(Ven et al., 2010).

The damage to houses and shops from pluvial flooding is the most costly for the Netherlands. But the approach to calculate the costs has some serious flaws in the methodology to determine these costs for

2050. The cellar is one of the most important costs for flooding to houses, which is included in the average costs (Hoes et al., 2013), but in this research it is not determined which properties actually have cellars. Another important variable is the doorstep height of a house, because the door is one of the main entrances for the water, and thus the height of the doorstep actually tells something about the water height in the property (Ward et al., 2013). Furthermore there are some national trends such as urbanization which can increase the costs for 2050 for houses and shops.

One element which is not considered in the methodology of calculating the costs for (pluvial) flooding is the vulnerability of crops to water. The vulnerability of agriculture to pluvial flooding is highly dependent on the time of the year, in this research the growing stage of the crop is not taken into consideration and thus the costs for agriculture because of pluvial flooding are overestimated. National trends, such as the influence of climate change on the growing stages of crops or the diversity of crops in 2050 is not considered as well. Also the price for an acre of agriculture will decrease, which will decrease the additional costs even further (Arcadis et al., 2006).

The additional costs for urban green, gardens and intensive recreation as they are calculated in this research are highly debatable. This is primarily because the costs are not calculated in a spatial way, but based on CBS statistical data in combination with the total flooded area in a municipality. This means that flood areas can be counted for houses and shops, while the same area can be counted for gardens and parks. Furthermore as stated before, flood areas are mostly a result of a lack of water infrastructure in combination with the degree of saturation of the soil. But gardens, areas with vegetation and recreational areas are considered soils with a high degree of water uptake (Ven et al., 2010), which means that the costs for these sectors are overestimated. This overestimation results in an increase in error for the additional costs of these sectors.

4.2.1 The total additional costs of flooding because of a primary dike breach

The total additional costs for a dike breach are determined by soil subsidence, flood height and the chance for a dike ring to breach in 2050 minus the chance for a dike ring to breach in the present, as can be seen in Figure 7. The highest additional costs are between the rivers of the Netherlands, this is due to a combination of an increase in flood chance per dike ring and high inundation depths. This is different for the western coastal areas in the provinces of Noord-Holland and Zuid-Holland, these provinces are more sensitive to soil subsidence as can be seen in Figure 8. Additional costs can be seen in the municipalities of Amsterdam and Rotterdam, due to soil subsidence as can be seen in Figure 24.

The area between the IJssel and the Rhein (dike ring number 48 'Rijn and IJssel') has very high additional costs mainly due to the project 'ruimte voor water' which is part of the project 'ruimte voor de rivier', as can be seen in Figure 24. The decrease of the safety of that particular dike ring will increase in flooding chance from a flooding every 1250 years in the present, to a flooding once every 100 years in 2050, which has major effects on the estimated yearly costs.

The municipality Zevenaar and the other eight municipalities with the highest costs per municipality are partly or mainly within dike ring number 48. For this dike ring the difference between the cost of the worst-case scenario and the costs of the best-case scenario for the effects of climate change are twice as high. This means that for the worst-case scenario the additional costs of flooding for the highest nine municipalities are about twice as high, depending on their location and within which dike rings they are located, as can be seen in Figure 25.

The costs of climate change for the coast areas alongside the Waddenzee in the provinces Groningen and Friesland and in Zeeland the additional costs are only present for the worst-case scenario, due to a combination of an increase in flood chance compared to the present flood chance per dike ring and because of the flood height when flooded.

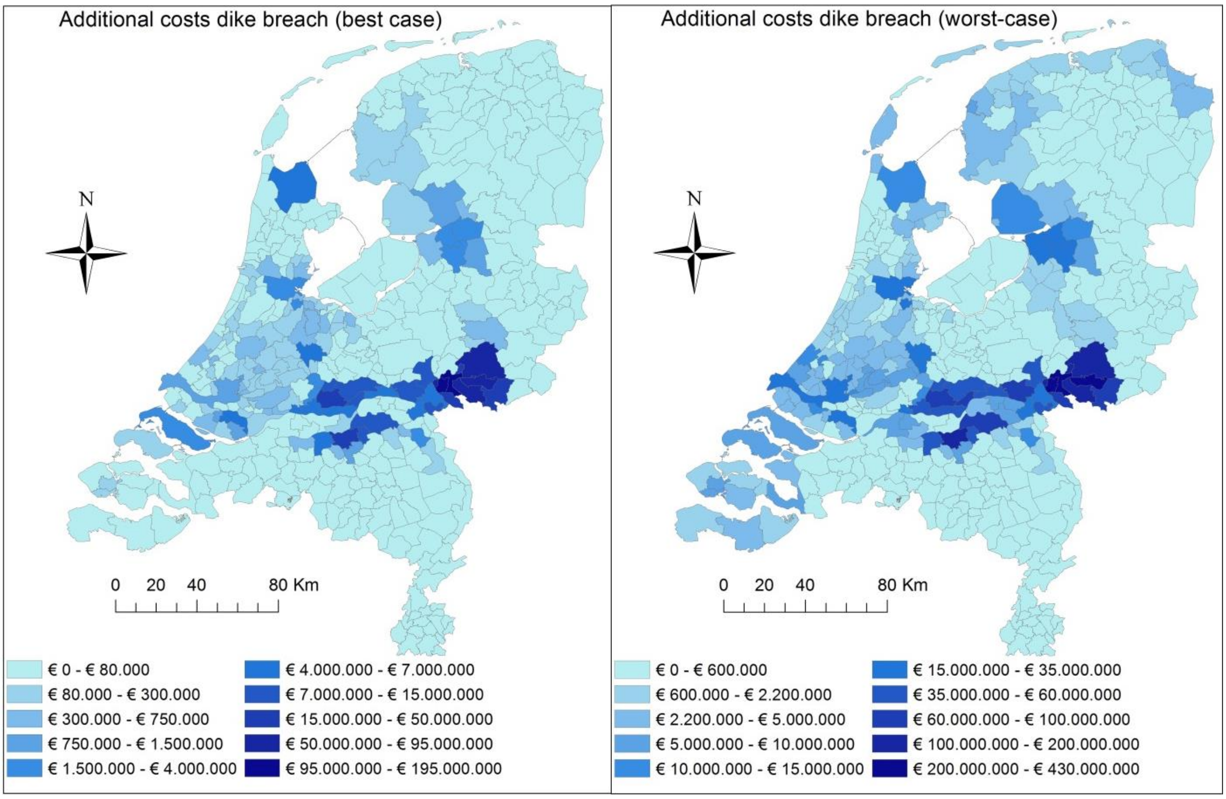


Figure 24: The additional costs for the effects of climate change for a primary dike breach. Note the difference in legend.

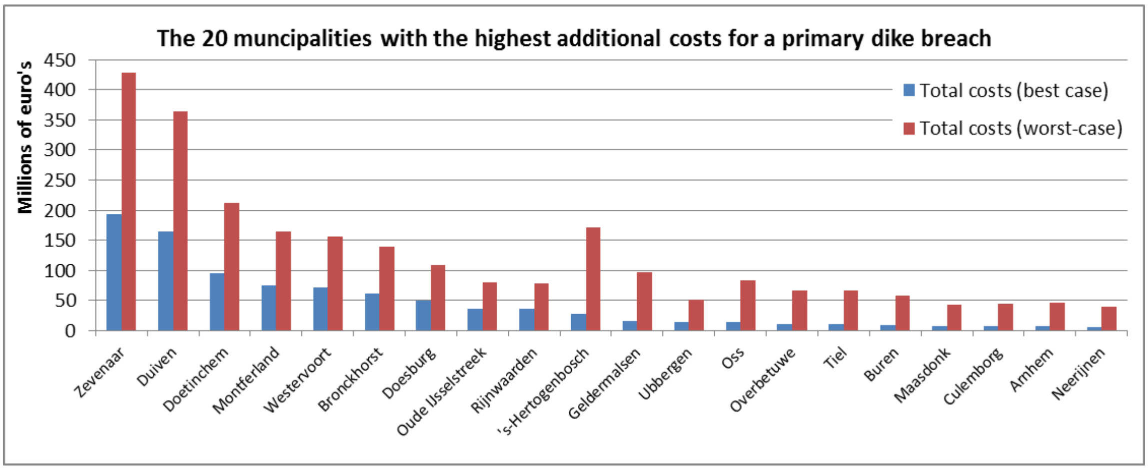


Figure 25: The 20 municipalities with the highest additional costs for a flooding because of a primary dike breach. For both scenarios, which are based on the 'ruimte voor water' project.

4.2.2 The distribution of the total additional costs for flooding because of a primary dike breach.

The distribution of the total additional costs for a dike breach is different per municipality, furthermore there are some major differences in the division of additional costs compared to the additional costs for pluvial flooding. As can be seen in Figure 26, the main sources for the additional costs for flooding are the damage done to labor, houses, shops, mortality and rail roads. The additional costs for horticulture and agriculture are minimal compared to pluvial flooding. This is because the damage function is different compared to the damage function for pluvial flooding which can be seen Appendix 2. Furthermore, the municipalities with agriculture as a major land use (as discussed in the previous section about pluvial flooding) are protected by dikes with no difference in the chance of exceedance (see Figure 7). The municipality with one of the highest additional costs for agriculture is Hollands kroon and the Noordoostpolder, which will be investigated further in the next section.

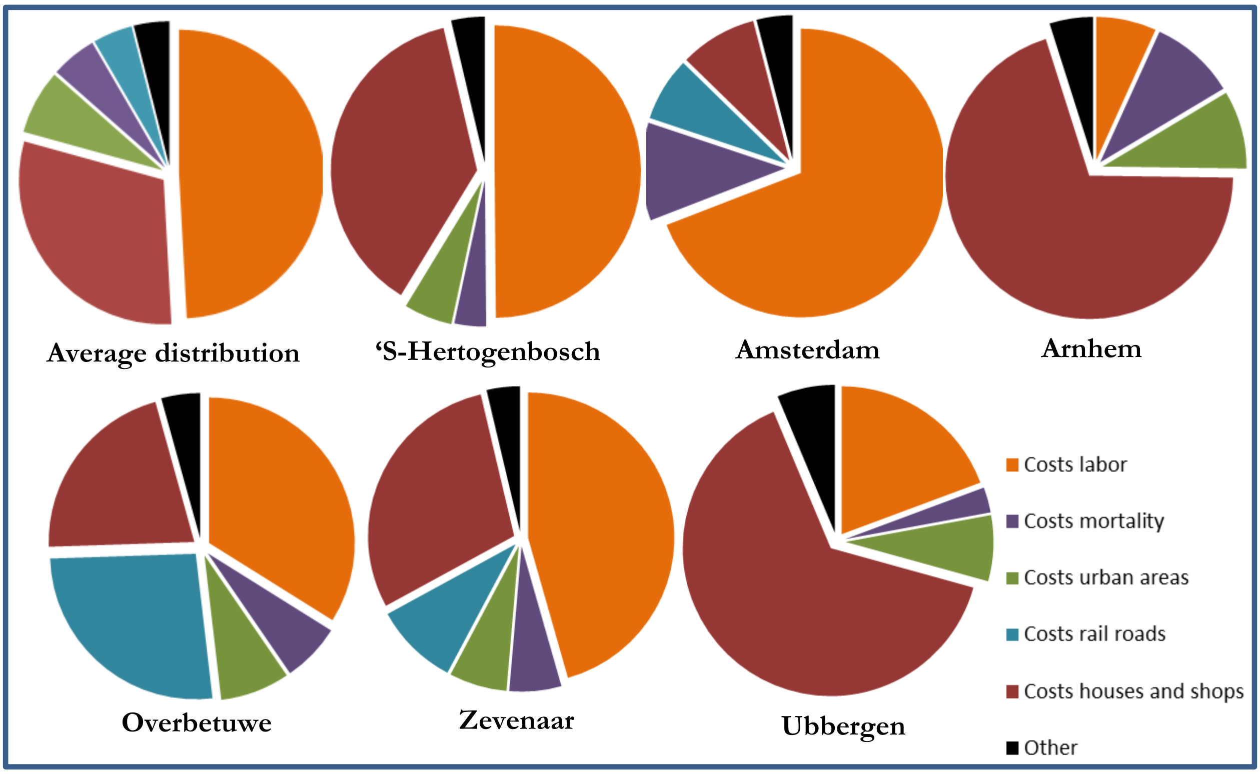


Figure 26: Different distributions of the total additional costs for a dike breach for the best-case scenario. The average distribution for the additional costs and for three rural municipalities and three urban municipalities are shown.

Table 6: Amount of jobs (x 1000) for three rural municipalities ("CBS-Statline, amount of jobs per industry," 2012)								
	Industry	construction	trade	transport	financial services	government	healthcare	Area (km^2)
Overbetuwe	1.65	0.83	4.35	1.31	3.4	1.58	1.99	115.2
Ubbergen	0.16	0.09	0.5	0.02	0.26	0	2.57	38.6
Zevenaar	1.71	0.51	3.16	0.66	3.43	1.26	2.47	57.9

The reason the municipality Arnhem has lower costs for labor compared to other urban municipalities is due to the size of the flood area compared to the size of the municipality and the way the costs are calculated for labor as can be seen in section 3.2.1. For Ubbergen a small municipality with a population below 10.000 people, with high additional costs for flooding, the costs are mainly determined by the damage to houses instead of labor, while almost the entire municipality is flooded. This is mainly because the amount of labor is low for the categories investigated, even compared to the smaller size of the municipality with other rural municipalities, as can be seen in Table 6.

4.2.3 The additional costs of houses and shops for flooding because of a primary dike breach.

As shown in the previous section, the additional costs for houses and shops are a major part of the total costs for flooding because of a dike breach. These costs are also one of the most accurate because of the way of spatially calculating them, instead of aggregating them for an entire municipality.

Because of the difference in costs between cities, it is chosen to present the costs relatively to the total additional costs for that municipality. The total additional costs for houses are 30.1% (best-case) to 31.8 % (worst-case) of the total additional costs for a dike breach. It is expected that bigger cities, with a higher population would have more additional costs to houses compared to the total additional for that municipality. This is not necessarily the case due to the costs for labor which are higher in cities as well, as can be seen in Figure 27.

4.2.4 The additional costs of infrastructure for flooding because of a primary dike breach.

The additional costs for damage to rail roads are one of the 5 main costs for a dike breach. 4.4% of the additional costs for a dike breach are from the flooding of rail roads and 2.4%of the additional costs of flooding are because of the flooding of roads. Because these costs are calculated spatially it is interesting to see the difference between bigger cities, Amsterdam and Utrecht have higher additional costs due to the flooding of rail roads, while's-Hertogenbosch and Arnhem have higher additional costs due to the flooding of roads, as can be seen in Figure 28.

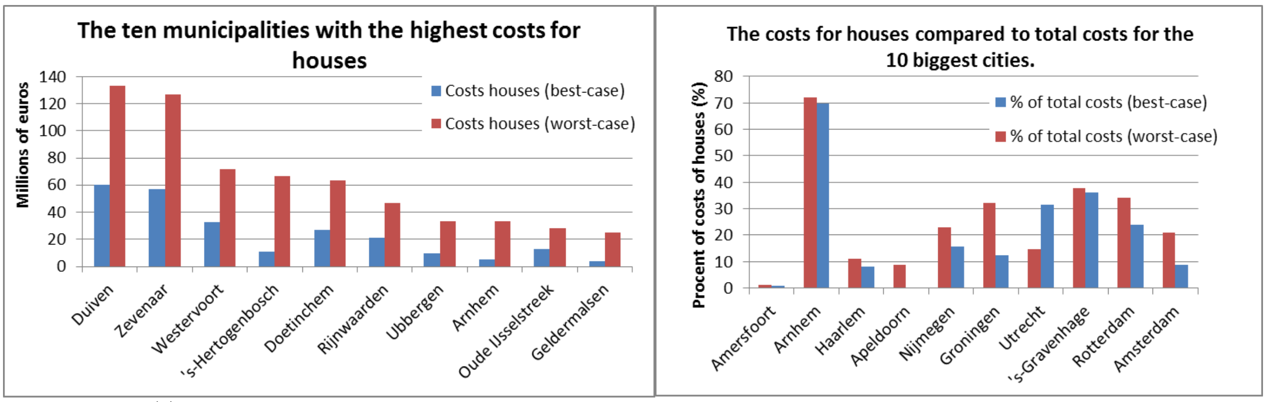


Figure 27: left: The additional costs for houses for the ten highest municipalities, right: the additional costs of houses compared to the total costs for a dike breach, for the ten biggest cities, with costs for a dike breach.

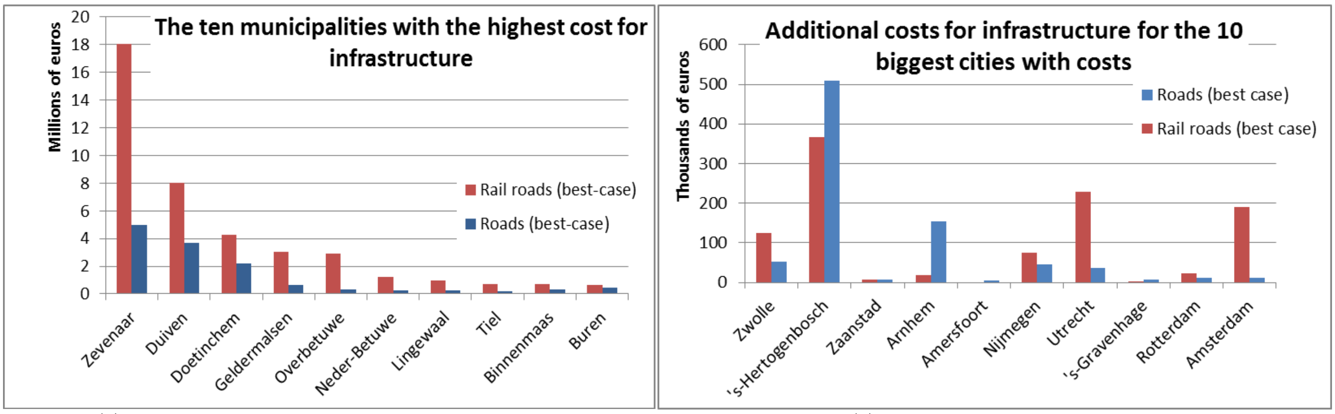


Figure 28: The ten municipalities with the highest additional costs for infrastructure. These additional costs are ranked for the costs of rail roads, for the best-case scenario.

The ten municipalities with the highest costs to infrastructure are of course loacated near or between the main rivers of the Netherlands, due to the increase of flood chance for those area as can be seen in Figure 28.

4.2.5 The additional costs of agriculture for flooding because of a primary dike breach.

The additional costs for agriculture are not really interesting, because the contribution of agriculture compared to the total costs is about 0.1% for the best case and 0.2 % for the worst-case scenario. Still, there are two municipalities which stand out compared to the other municipalities between or near the main rivers. These municipalities are Hollands Kroon and the Noordoostpolder as can be seen in Figure 29. Both municipalities have large areas of agriculture and a doubling increase in flood chance. For the Noordoostpolder this increase in chance goes from once every 4000 years to once every 2000 years, for Hollands Kroon this is from 2000 to 1000 years, for the worst-case scenario respectively. The other municipalities in Flevoland do not have any damage to agriculture due to flooding, because the flood chance stays the same for those areas and there is no soil subsidence taken into account for those areas as can be seen in Figure 8.

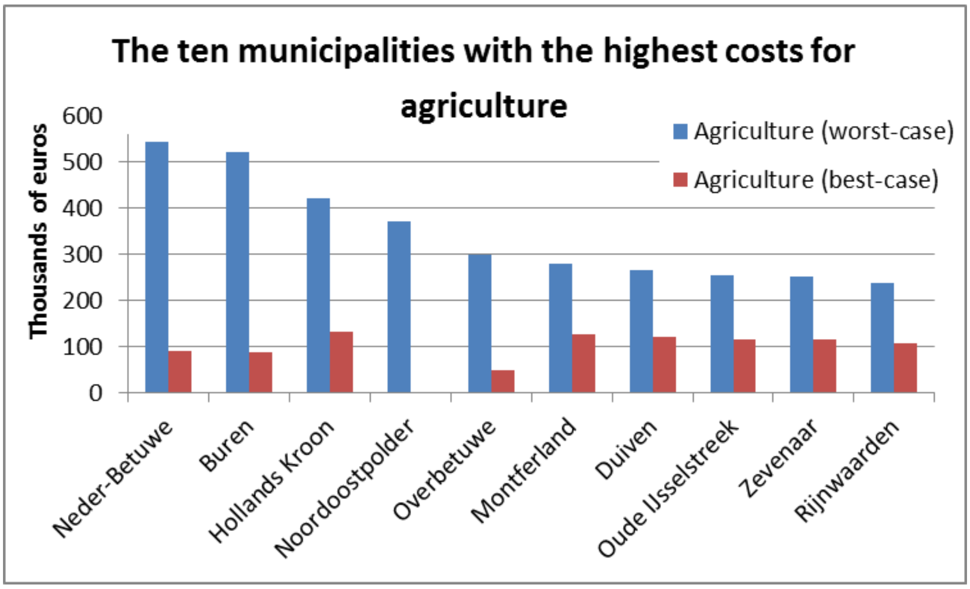


Figure 29: The ten municipalities with the highest additional costs for agriculture due to a dike breach.

4.2.6 Discussion of the total additional costs for flooding because of a primary dike breach.

It is important to note that in this research there is no increase of water height taken into account for the effects of climate change, only an increase in flood chance resulting from this water height. For the W+ and W scenario the increase of water height in 2050 is about 30 cm (which can differ per location), but in 2100 the water height per dike ring can increase up to a maximum of 1.3 m (Ven et al., 2010). This would mostly increase the additional costs for the provinces Zeeland, Groningen and Friesland, because in these provinces there is potential for costs due to an increase of flood height, as opposed to Flevoland where the flood height is already at a height (around 3 meters) that costs are at a maximum, as can be seen in Figure 8. Two other factors which have not been taken into account are the flood duration and the flood speed, which are partly taken into account via the damage factor, which is similar to the HIS-SSM methodology.

For dike ring 48 the inner and most important areas will be compartmented if the project 'ruimte voor water' will be in effect (as can be seen in Figure 7). This means a flood can occur once every 200 years, instead of once every 100 years as a worst-case scenario. Important industry and new household projects in that scenario will move to the compartmented areas and the additional costs will decrease (Klijn et al., 2007).

Some dike rings will have a decrease in the chance of flooding for 2050, for example dike ring 22 ('Het eiland van Dordrecht'). In these cases the costs are calculated as a benefit for climate change effects, this is caused by dike rearrangements and policy and obviously not by climate change itself. In this case the flood chance will be set the same for 2050 as for the present. Though, it does show the arbitrary way of calculating the costs in general, because the flood chances used in this report takes the policy of water boards into account. Maybe a better way to calculate the direct effects of climate change is with the use of the methodology of Aerts(2008) which was also used by the Deltacommissie (Aerts et al., 2008). This methodology uses the increase in sea-level rise and river discharge to estimate the flood probability for the year 2050 without any policies.

The worst-case scenario as presented per dike ring in Figure 7 is originally determined for 2040 as the absolute maximum chance for a dike breach to occur (with included safety factors), and the additional costs are therefore a heavy overestimation of the costs and only meant to compare with other municipalities (Klijn et al., 2007). The 'best-case scenario' is a more realistic indicator for the additional costs because it uses the expected exeedance chance and will therefore be used in further examples.

The main elements which determines the costs for houses from a dike breach is the value of the house (WOZ), the inundation depth and the flood speed of the flooding. According to the HIS-SSM method the flood speed to destroy a house with all the belongings is between 4 – 8 m/s. This is not integrated in the model and is partly accounted for in the damage factor (Appendix 3) similar to the HIS-SSM method (Kok et al., 2004).

The social prospects for 2050 are not integrated in the model as well, the amount of houses, the property value of the houses and the property value of the belongings inside the houses will increase, according to an increase in general wealth (Aerts and Botzen, 2011). Furthermore a small increase in population and houses within dike ring areas will increase the flood risk and the costs in 2050 (Aerts and Botzen, 2011).

According to the HIS-SSM methodology the length of the infrastructure for both roads and rail roads is the determening factor to determine the additional costs in comparison to the area of the infrastructure. The area size of the infrastructure is only partially accounted for by the type of infrastructure (e.g. highway, freeway and other roads) and the amount of tracks of rail roads in a particular flooded segment.

Therefore, the exact amount of lanes and the size of the lanes is not included, which is different for the STOWA method where the area of the roads is determined and a price per area is used to calculate the costs.

Another important aspect is the cell size of the flood data, the cell size is 100 meters which is large compared to the size of roads and infrastructure. Sometimes roads and rail roads are elevated compared to the surroundings to minimize the damage of pluvial flooding and potential elevated water heights. This is not specifically integrated in the flood data, because of the cell size of the flood data.

The accessibility of certain important areas is not integrated in the model as well. Important areas such as hospitals and fire stations and the accessibility of those areas can be greatly reduced because of certain flooded areas, this would increase the costs tremendously.

4.3.1 The total additional costs of drought

The additional costs for drought are mostly present in the west along the coast of the Netherlands, as can be seen in Figure 30. This is the case due to the effects of degradation of pile foundation in those areas. Furthermore the relative difference between the best-case and the worst-case scenario for the effects of drought are minimal compared to the other effects of climate change. This relative difference in costs is minimal because the effects of drought on the degradation of sensitive pile foundation are one of the main additional costs for the entire additional costs investigated in this report. This means that even with the differences between the worst-case and the best-case scenarios for the sensitive pile foundation, the influence on the total additional costs is enormous. This means that in Figure 30 both maps are basically a presentation of the additional costs for pile degradation.

About 94% of the additional costs for drought are based on costs for pile degradation, for the best-case scenario and 90% from the worst-case scenario. The additional costs for agriculture are about 2.5% for the best case-scenario and 6.0% for the worst-case scenario. The costs of agriculture are visible in Flevoland and around the main rivers. The costs for urban green (parks and trees) are 3.2% for the best-case scenario and 4.0% for the worst-case sccenario. This leaves the costs for gardens at almost nothing compared to the other sectors, with 0.1% for both the worst-case and best-case scenarios.

Every municipality will have some damage from drought in 2050, this is due to the damage to parks, trees and gardens. Limburg, Noord Brabant and the east of the Netherlands have a minimal amount of costs because of the lack of sensitive pile foundation and a lack of agriculture in those areas (see Figure 30).

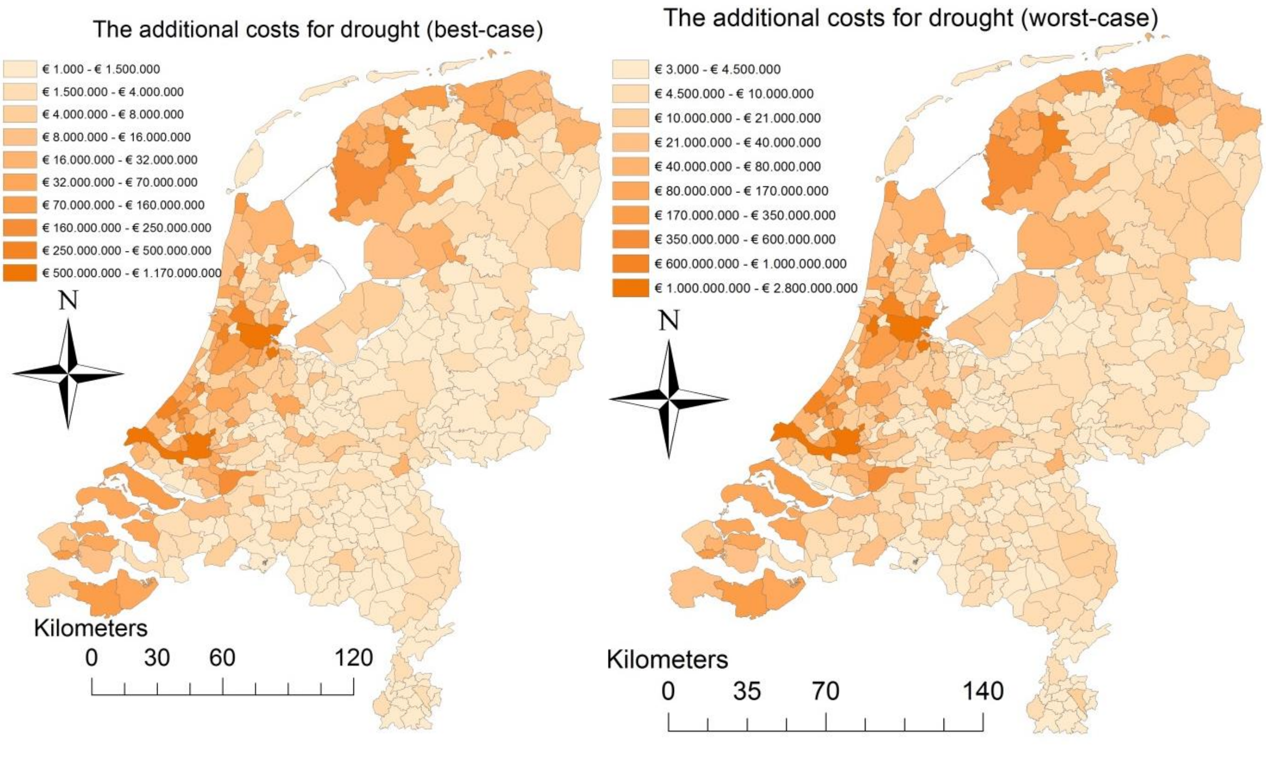


Figure 30: The total additional costs for drought for the Netherlands for the worst-case and best-case scenario. Note the difference in legend for both maps.

4.3.2 The additional costs of sensitive pile foundation because of drought.

As said in the previous section are the effects of the degradation of sensitive pile foundation one of the most costly sectors for the effects of climate change investigated in this report. For most of the urban areas in the Netherlands this effect is relevant because of the effects of drought on the ground water levels. Furthermore, there are no 'cheap' or easy solutions for this matter, the only solution is renewing the foundation of the buildings, or demolish them (Hoogvliet et al., 2012). Almost all the bigger cities in the Netherlands have costs for this sector, except for the bigger cities in Noord-Brabant, Limburg and in the east of the Netherlands. This means that cities with the highest costs are almost the same cities with the highest number of residents, as can be seen in Figure 31 and Figure 32.

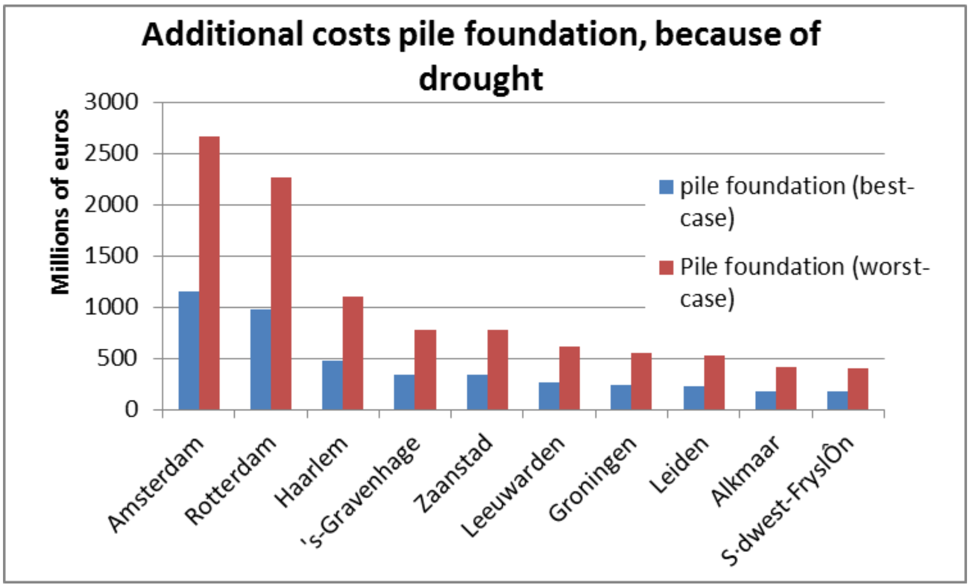


Figure 31: Additional costs of drought for the cities with the highest costs to pile foundation.

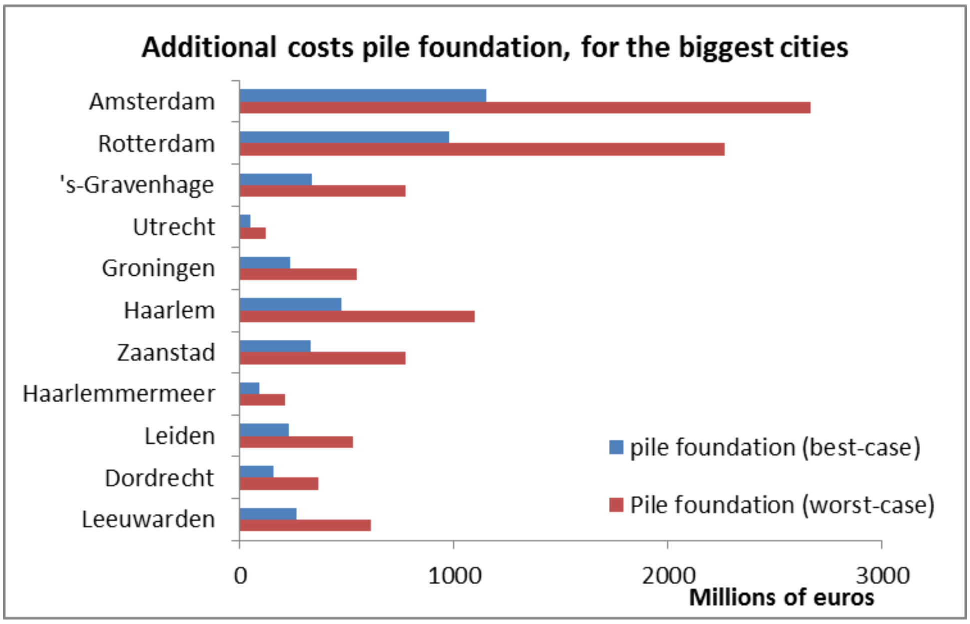


Figure 32: Additional costs of drought to pile foundation for the biggest cities with costs.

4.3.3 The additional costs for agriculture because of drought

The damage to agriculture because of drought is heavily investigated in literature. For this research the effects of drought are assumed to be homogeneous for the entire Netherlands, which means that municipalities with large expensive amount of agriculture will have the highest costs for this sector. The difference in additional costs between the worst-case scenario and the best-case scenario differ about a factor seven, 5% of loss of yield compared to 35%, with the addition of the discount factor. The ten municipalities (listed in Figure 33) with the highest costs for agriculture because of drought combined, have 20.0% (best-case scenario) of the entire costs for this sector.

4.3.4 The additional costs for trees, parks and gardens because of drought

The additional costs for trees, parks and gardens are very straight forward. The costs are calculated based on the area for parks and trees estimated by CBS Statline, this means that a municipality with more parks has higher costs for drought than a municipality with less trees or parks (see Figure 34). For personal gardens this is a bit different as can be seen in section, the costs for this sector are based on the amount of households, so this is mainly for the bigger cities as can be seen in Figure 35.

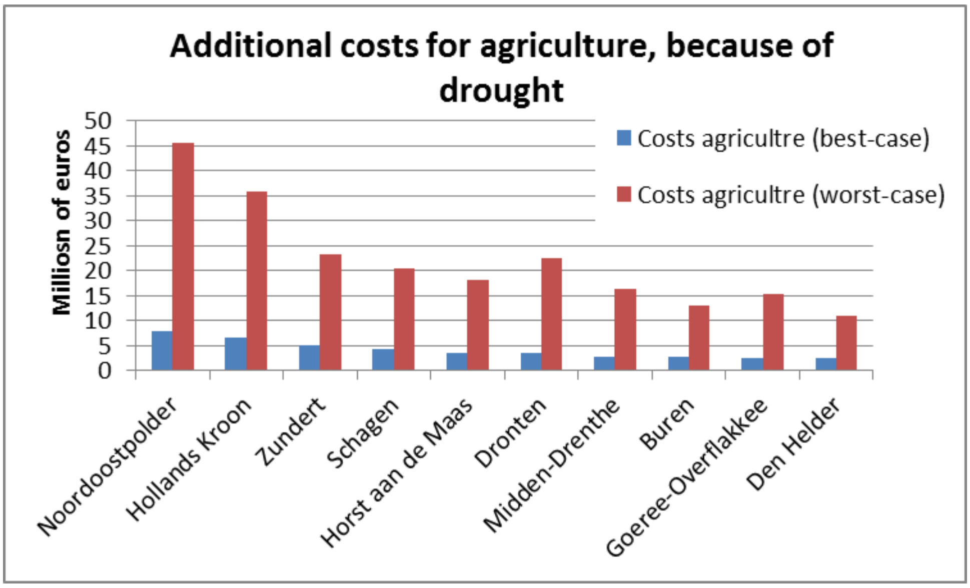


Figure 33: The ten municipalities with the highest costs for agriculture because of drought.

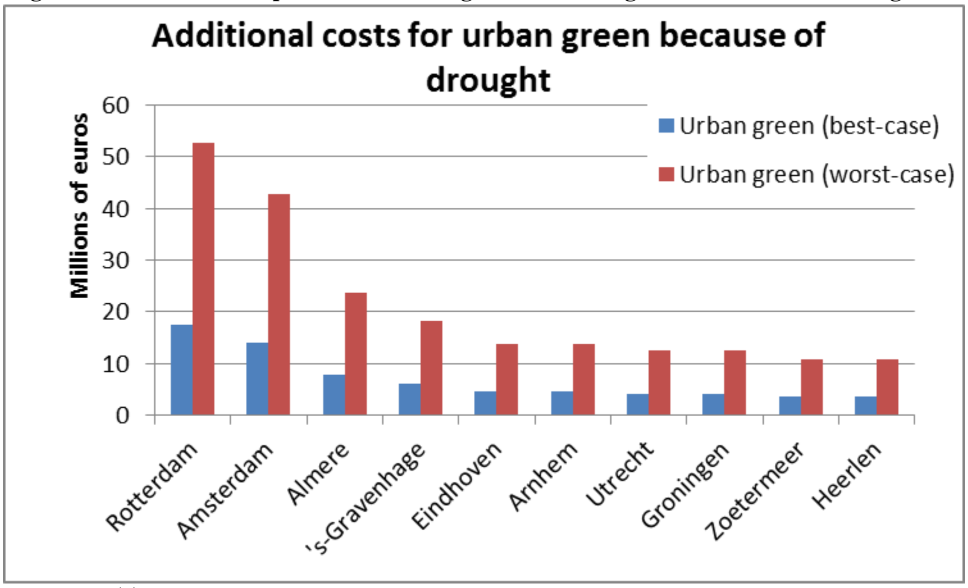


Figure 34: The additional costs for urban green (parks and trees) because of drought, for both the worst-case and the best-case scenario

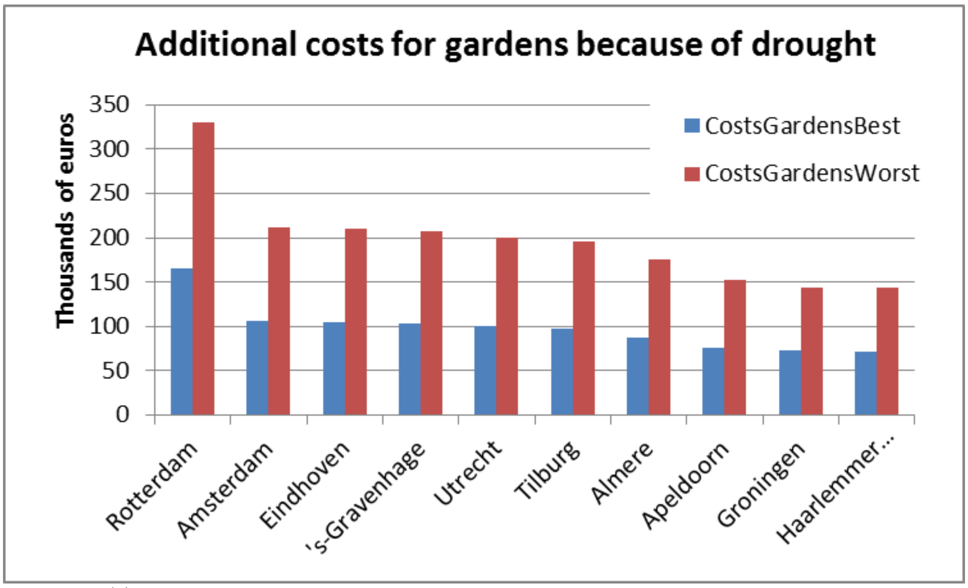


Figure 35: The additional costs for personal gardens, because of drought, for both the best-case and the worst-case scenario.

4.3.5 Discussion of the total amount of costs for drought

The additional costs of sensitive pile degeneration are the largest for this section of the report and one of the main costs for the entire report. This means that this sector is very sensitive for changes in parameters. In this thesis it is assumed that buildings before 1960 have a wooden pile foundation, and thus are sensitive to pile degradation (Ven et al., 2010). But Hoogvliet (2012) did a similar research and concluded that buildings before 1940 are a better approximation to base assumptions on. Pohl (2014) also assumed that Rotterdam has about 20.000 houses with wooden pile structures in sensitive areas, which can be compared with the research done in this thesis (Pohl et al., 2014). In this thesis the effects of degeneration of sensitive pile foundation are calculated for all the municipalities for buildings older than 55 years, but to calculate it with Hoogvliet (2012) method, it is also calculated for buildings older than 75 years (see Table 7). The differences are major, but this is due to difference in sensitivity areas used. In this research both the areas with 'high risk', and 'moderate risk' are used as sensitive areas, as can be seen in Figure 10. This means that compared to both studies, the results in this thesis are highly overestimated. This is important to keep in mind when the costs are of pile degeneration are compared with other sectors.

A big gap in this research is the assumption of homogeneity for drought. Drought is dependent on the soil type and the groundwater level (Ven et al., 2010), which is integrated in the research for pile foundation, but not for the other sectors, which overestimates the costs for these sectors.

Table 7: The amount of houses with wooden pile foundation affected by drought for houses with different ages.

	Pohl (2014)	Ven (2010) < 1960	Amount of houses in model < 1960	Amount of houses in model < 1940
Rotterdam	20.000	-	43.630	36.352
The Netherlands	-	267.084	363.860	309.744

4.4.1 The total additional costs for heat stress

The total additional costs for heat stress are located around the bigger cities of the Netherlands, which is not quite unexpected. Although the average temperature of the Netherlands will increase for 2050, dense urban areas can absorb large amounts of sunlight, which can increase the temperature further. The relative difference between the best-case and worst-case scenario investigated in this report do not show different results, and therefore both maps in Figure 36 look similar. This relative difference is minimal because the total costs for heat stress are mostly determined by one sector.

This costly sector for heat stress is the effect on the efficiency of labor. The worst-case scenario of the effects of heat on labor is 84.5% of the total costs of heat stress and 88.7% for the best-case scenario. The additional costs for air-conditioning are 11.1% and 10.7% for the worst and best-case scenario. The additional cost for hospitalization is 6.2% of the total additional costs and the costs for mortality are lowest with 2.1% and 0.6% for the worst and best-case scenarios. This means that the maps shown in Figure 36 are for the most part a visualization of the decrease of efficiency of labor.

4.4.2 The additional costs of the decrease of efficiency of labor because of heat stress

The additional costs for the sector of the decrease in efficiency of labor are one of the costly sectors in this report. The additional costs for the decrease of the efficiency of labor can be seen in Figure 37. These costs are a linear relation with the population of the districts within municipalities as is explained in section 3.2.4**Fout! Verwijzingsbron niet gevonden.** and is further shown in Figure 37. The worst-case scenario is about twice as costly compared to the best-case scenario. It is not exactly twice as much because of the discount factor, which is shown in different sections already.

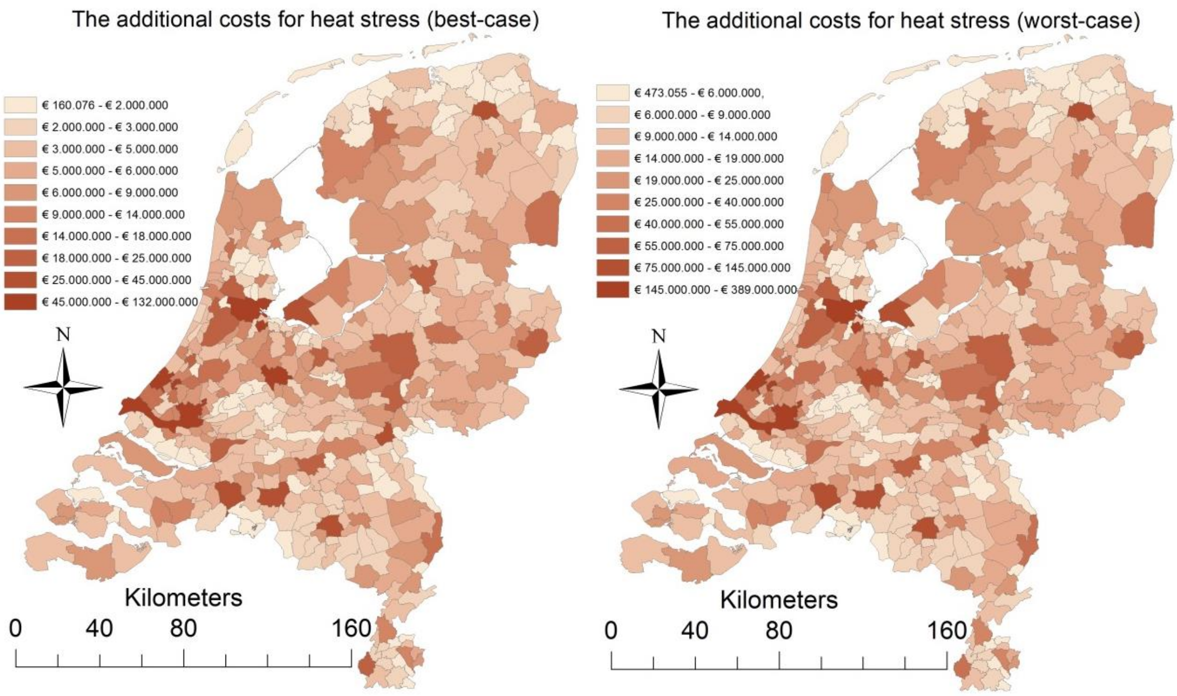


Figure 36: The additional costs for heat stress, for both the best-case and the worst-case scenarios. Note the difference in legend.

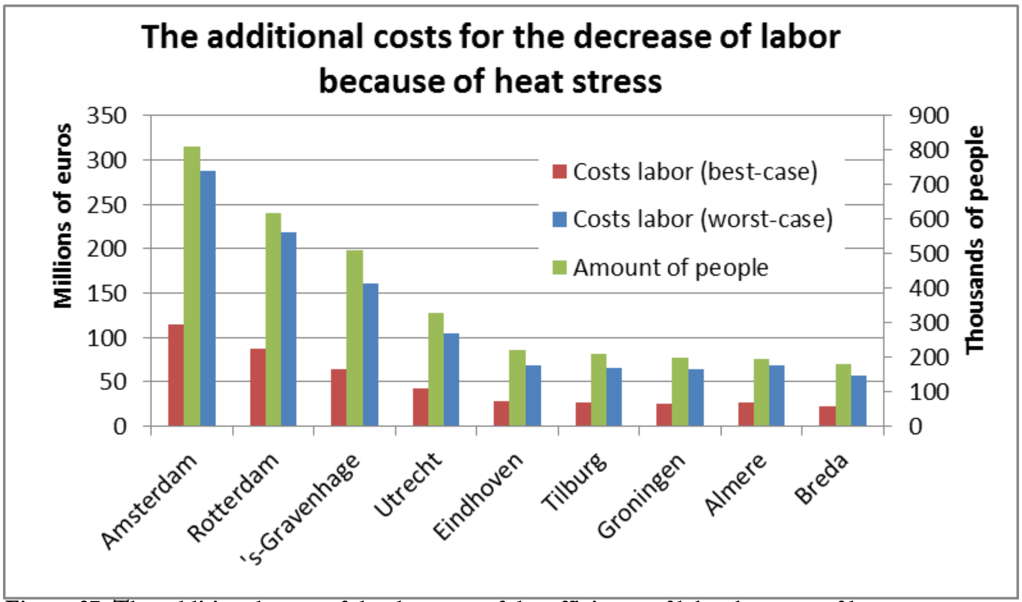


Figure 37: The additional costs of the decrease of the efficiency of labor because of heat stress, for the ten highest municipalities.

4.4.3 The additional costs for hospitalization, mortality and air-conditioning, because of heat stress.

Air-conditioning is based on the amount of households instead of people, this explains the difference in ratio between the different sectors shown in Figure 38. Still the additional costs in Figure 38 are exactly what are expected from the methodology in this report. Bigger cities have higher costs due to the amount of households and the higher population. Dense cities have a slight increase of mortality, but this effect is minimal compared to the other effects of heat stress.

4.4.4 Discussion of the total additional costs of heat stress

The total additional costs for heat stress are mostly from the decrease in efficiency in labor, but there are also some direct economic costs and benefits (tourism) due to heat stress, which are not integrated in this model (Stone et al., 2013). The kind of labor which is done in municipalities is also of importance to the costs of this sector. Some work is more vulnerable to heat than others. For instance construction work will always be vulnerable to heat, while agricultural activities in vehicles are easier to cool with air-conditioning (Stone et al., 2013). The precise effects of labor are therefore complex to predict, because of the differences in work, the different economic developments and the spatial distribution of labor for the Netherlands, for the present and the 2050 scenario.

There is lots of research about the increase in temperature for the Netherlands, but not about the effects on the levels of relative humidity which are associated with an increase in temperature (Dunne et al., 2013). This can increase the effects of heat especially in a country like the Netherlands, with lots of water. Since the increase of air-conditioning is assumed to be homogeneous and not spatially quantified, the effects can change per municipality. The same holds for mortality, even though the UHI effect is taken into account, there is no data used which describes the demographics in a spatial way. Older and weaker people are more vulnerable for the effects of UHI, which is not considered in this report.

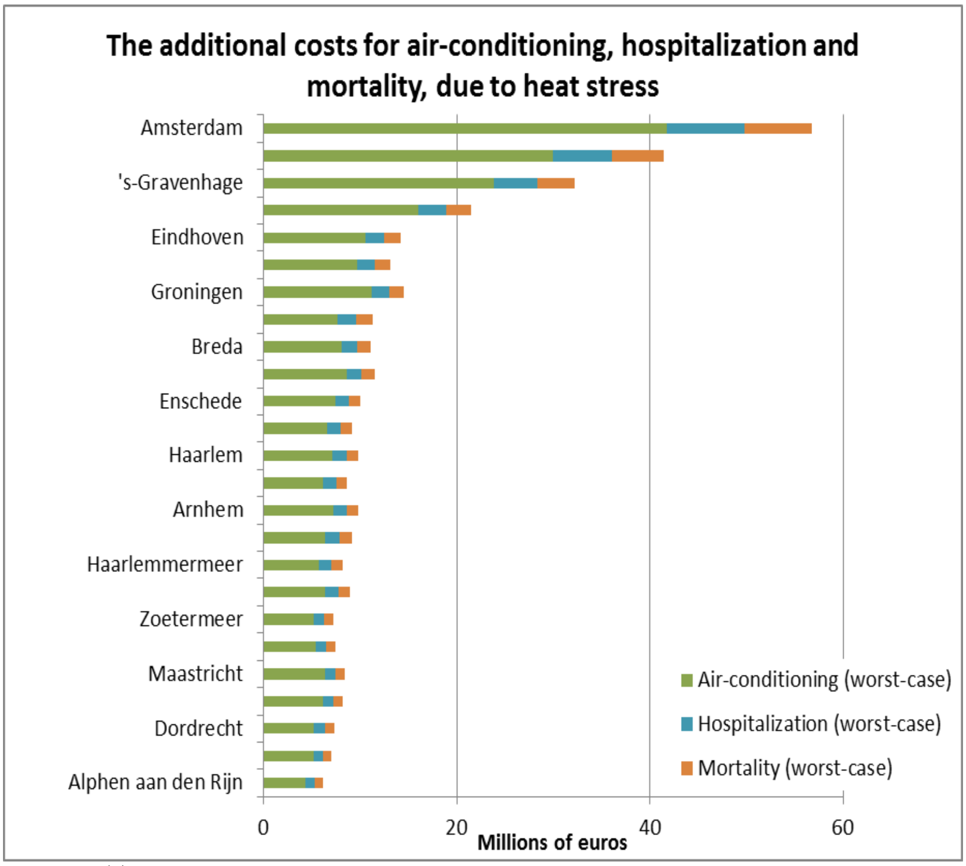


Figure 38: The additional costs for air-conditioning, hospitalization and mortality, due to heat stress. These numbers are for the worst-case scenario.

4.5.1 Sensitivity analysis

For the sensitivity analysis first the Si_{max} is determined for every damaged sector, which is called parameter in this section, based on the methodology of Hambly (1994). These parameters are investigated for a minimum and a maximum damage cost, compared to the expected costs which are presented in Appendix 3. The Si_{max} is determined and presented in the order of importance in Table 8 for the total additional costs. This table has some interesting and some expected results. The first three parameters for drought are expected, because of the high additional costs for drought in general, and the wide range between the minimum and the maximum damage costs. However the Si_{max} for 'pluvial flooding, houses and shops' on the fifth position is not as expected, especially compared to the Si_{max} for 'flooding, houses and shops': the additional costs for flood damage to houses and shops are a factor 5 higher than for pluvial flooding. This difference in Si_{max} is mainly due to the wide range in damage costs for the parameter 'pluvial flooding, houses and shops' which has a range of €250 ± €100, compared to the WOZ ± 20% difference for the 'flooding, houses and shops'. Flooding only affects specific flood areas, while pluvial flooding is affecting the entire Netherlands. It would therefore be interesting to map the Si_{max} for the entire Netherlands per municipality. Although these maps would give similar results as the costs maps in the previous sections. Even though the costs for the effects of flooding on labor are the highest for flooding, it is interesting to see that in the sensitivity analysis shows something different. The Si_{max} for the parameters 'flooding, houses and shops' and flooding 'rail roads' show comparable numbers. This is due to the small range of costs for the effects on labor which are used in this thesis.

The Si_{max} is different compared to the S, because the S uses fixed incremented steps as a basis instead of the maximum and minimum value. Furthermore only the first 10 parameters are used in the calculation of the S. Still the results are quite similar, for instance the slope of the first two parameters for drought are very steep compared to the other parameters. The parameter for 'heat stress, efficiency of labor' also has a steep angle compared to the other parameters.

The differences between the Si_{max} and the S are more apparent with the parameter of 'flooding, rail roads', which is the parameter with the lowest angle. Furthermore, the parameters 'drought urban green', 'pluvial flooding, houses' and 'pluvial flooding, agriculture' have similar slopes (and overlap each other), which is totally different for Si_{max}.

Table 8: Sensitivity analysis for SI_{max}, in order of importance.

Parameters	Si_{max}	Parameters	Si_{max}
Drought, pile foundation	$3.69*10^{-1}$	Heat stress, mortality	$4.81*10^{-3}$
Heat stress, efficiency of labor	$1.25*10^{-1}$	Heat stress, hospital	$3.10*10^{-3}$
Drought, agriculture	$7.15*10^{-2}$	Flooding, roads	$1.49*10^{-3}$
Drought, urban green	$2.20*10^{-2}$	Flooding, extensive recreation	$5.59*10^{-4}$
Pluvial flooding, houses and shops	$1.83*10^{-2}$	Drought, gardens	$3.05*10^{-4}$
Heat stress, air-conditioning	$1.82*10^{-2}$	Flooding, agriculture	$1.37*10^{-4}$
Flooding, houses and shops	$1.65*10^{-2}$	Flooding, intensive recreation	$1.21*10^{-4}$
Flooding, rail roads	$1.55*10^{-2}$	Pluvial flooding, urban green	$2.19*10^{-5}$
Flooding, labor	$1.09*10^{-2}$	Pluvial flooding, recreation	$1.26*10^{-5}$
Pluvial flooding, agriculture	$8.59*10^{-3}$	Pluvial flooding, gardens	$3.51*10^{-6}$
Flooding, urban areas	$6.24*10^{-3}$	Flooding, airport	$7.71*10^{-7}$

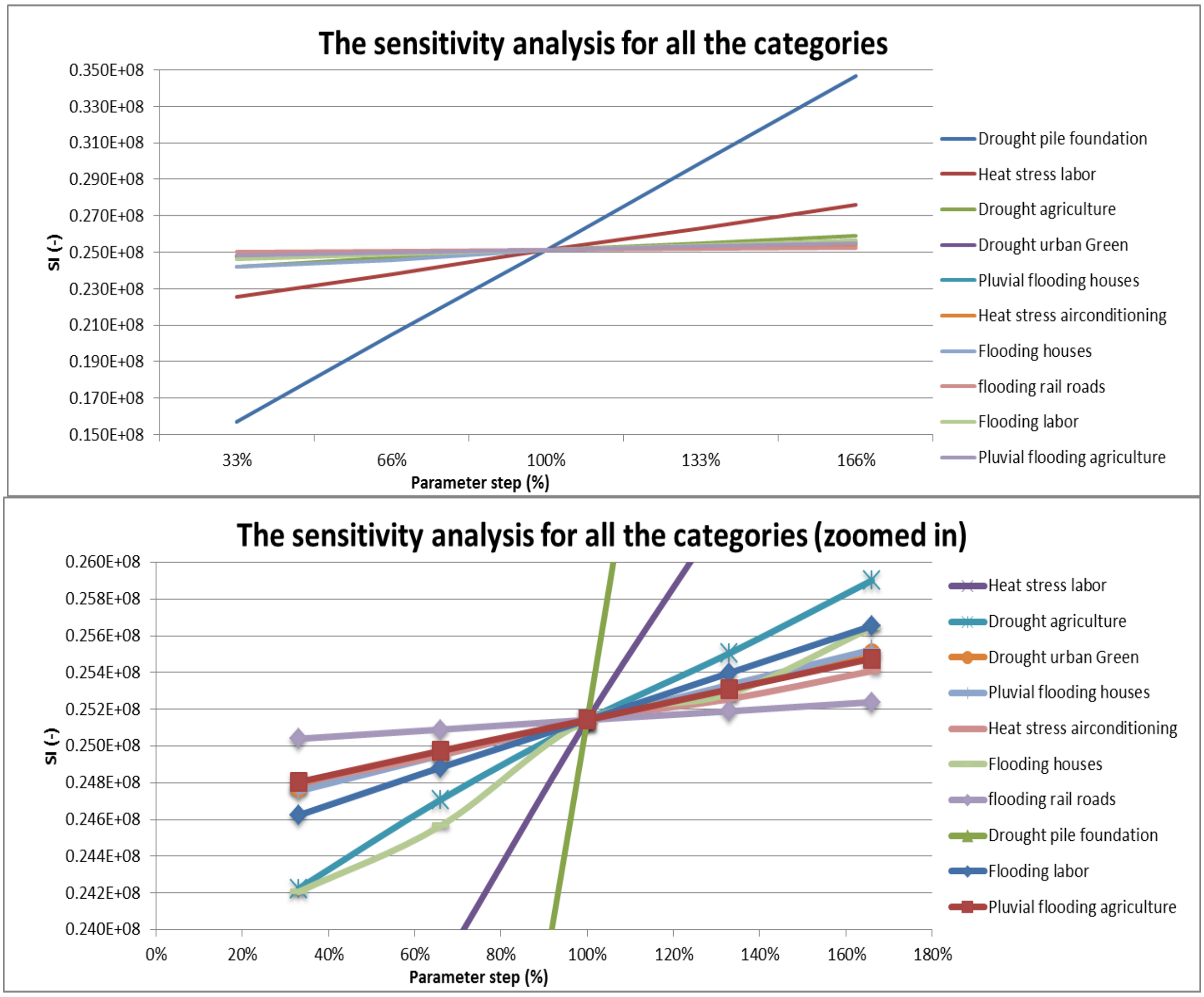


Figure 39: The sensitivity analysis S for the 10 parameters with the highest Simax. Top: the total figure. Bottom: This figure is zoomed in on the middle, to show the difference between parameters.

4.5.2 Discussion of the sensitivity analysis

The differences between the minimum costs and the maximum costs are very important to the sensitivity analysis because it give a first indicator for the costs. The expected costs are very important because it determines the S. These costs are taken from different sources as shown in Appendix 1, other sources are not considered. For instance the ARIO model, which is shown in the review of this thesis, shows very different costs for the parameter 'flooding, labor'. This uncertainty in the costs for this parameter is not used at all, and could increase the maximum costs for this parameter further. On the other hand, there are two sources used for the determination for the minimum and maximum costs for 'drought, pile foundation', which increases the sensitivity for this parameter further. This shows the arbitrary way of determining the damage costs and the way of calculating the sensitivity for the parameters.

5. Conclusion

What are the important steps and assumptions for the model?
The idea of this research is to create a spatial model, addressing the effects of climate change for the entire Netherlands on a municipality level. For this model the Clico tool is set as a basic outline, which describes the four different effects of climate change and the use of multiple sources of input data, such as CBS Statline and the source data of the Klimaateffectatlas.

To investigate the four effects of climate change further, the HIS-SSM method and the STOWA method are both integrated in the methodological framework of this spatial model. The methodology of RPKC is used as a basis for the effects of drought and heat stress. Based on the availability of data and methodology, the damaged sectors which are discussed and the damaged sectors which are excluded in the analysis are the essence of the results as presented in the review of this report.

The main assumptions in the model are based on spatial homogeneity for different damaged sectors, sectors such as labor, industries, people, property and wealth. The effects of climate change are considered to be homogeneous as well, for drought this means the entire Netherlands. For flooding because of a dike breach this means within the flooded area. Other important assumptions are the developments for the future, these developments range from land use changes to changes in economic growth and are sometimes considered and sometimes not. This is further elaborated on in the next section about the limitations of this research.

Which of the climate change effects (drought, flooding or heat stress) are relevant for the Dutch municipalities, and what is the order of importance?
For pluvial flooding one of the main findings of this thesis is the fact that showers with a return period of 25 years have higher additional costs than showers with a return period of 100 years, for almost every sector and every municipality. The areas with the highest additional costs for pluvial flooding are dense urban areas and the dense (costly) agricultural areas. The main cities (Amsterdam, Rotterdam and 's-Gravenhage) with the highest additional costs for pluvial flooding for a return period of 25 years have additional costs of about 20 million euros. For the main agricultural areas (Dronten, Neder-Betuwe and Lelystad) this is around 10-15 million euros. For a shower with a return period of 100 years this is about half of the additional costs compared to a shower with a return period of 25 years.

For flooding because of a dike breach the additional costs are divided over several damaged sectors, but overall the damage costs are determined (in this order) by the flooded industries (49%), houses and shops (30%), urban areas (7%), mortality (5%) and rail roads (4%). Interestingly, agriculture is not one of the main sources of the additional costs for this climate change effect.

The areas with the highest additional costs are the municipalities between the main Dutch rivers, due to high increase in flood chance. The additional costs for the municipalities in this area vary around from 100 to 400 million euros for the worst-case scenario and half these costs for the best-case scenario. The main cities (Amsterdam, Rotterdam and 's-Gravenhage), which are located in dike ring areas with relatively low flood chances, have the additional costs due to soil subsidence. The additional costs for these cities are between 3 million euros (best-case) and 20 million euros (worst-case). 's Hertogenbosch, Arnhem and Utrecht have the highest costs of the bigger cities of the Netherlands for this climate change effect.

For drought the additional costs are primarily caused by the degeneration of pile foundation. This is the main damaged sector for drought and for the additional costs in general. The additional costs for pile degeneration are spread around the coastal areas of the Netherlands, with the biggest cities having the highest additional costs. The additional costs for pile foundation for Amsterdam, Rotterdam and 's-Gravenhage are 2.7, 2.2 and 1.2 billion euros for the worst-case scenario. This is about half for the best-case scenario. The distribution of the damaged sectors for drought for the worst-case scenario consists out of degeneration of pile foundation (90%), agriculture (6%) and urban green (4%).

For heat stress the additional costs are primarily caused by the decrease in efficiency for outdoor labor (84%). The additional costs for the other damaged sectors are air-conditioning (11%), hospitalization (6%) and mortality (2%). The additional costs are proportional to the amount of people living in a municipality or the amount of households, so the bigger cities of the Netherlands have the highest additional costs. The additional costs for Amsterdam, Rotterdam and 's-Gravenhage are 290, 220 and 160 million euros for the worst-case scenario. The best-case scenario is about 2.5 times lower than that.

This means that for the biggest cities the effects of drought have the highest additional costs, mostly because of the degeneration of pile foundation. For the agricultural areas the effects of drought are the most costly as well, about 3 times more costly than the effects of pluvial flooding for a flooding with a repetition time of 25 years. The effects of heat stress and pluvial flooding affect the entire Netherlands evenly, but especially urban areas.

What is the sensitivity of the effects of climate change for the model?
The climate change effects of drought are in general the most sensitive to changes in damage costs for the Si_{max}. This is different for the S because of the difference in parameter steps. The parameter 'drought, pile foundation' is the most sensitive parameter for the sensitivity analysis, due to the high additional costs in general and the range of damage costs. The parameter 'heat stress, labor', is sensitive because of the high additional costs. The sensitivity of 'flooding, houses and shops' varies between the S and the Si_{max}, due to the difference in range of damage costs and parameter steps. 'Drought, agriculture and 'flooding, labor' are sensitive as well compared to the rest of the discussed parameters. The rest of the parameters are comparable with the exception of 'flooding, rail roads' which is relative high for the Si_{max} and lowest in comparison to the other parameters for S.

6. Limitations of this research

The many assumptions made to create this spatial model are the biggest limitations of this research. Although these assumptions are a necessity to do any research in this topic of science, the consequences of these assumptions should be considered for every result in this thesis. The additional costs of climate change are complex and subjective to changes in design. This can be seen for the inclusion or exclusion of damaged sectors, but also, for example, for the use of a discount for the costs in the future. This means that conclusions about the additional costs in this thesis are primarily useful for comparison between municipalities within the framework of this thesis only and not to rely on the absolute additional costs for one sector or municipality.

Furthermore the input data that is used in this thesis to describe the additional costs are chosen based on availability and have not been thoroughly investigated for accuracy or correctness. This is mainly due to the amount of datasets and the size of the data used in this report. The same holds for the chosen damage costs. The minimum, maximum and expected damage costs per damaged sector are chosen based on availability, with the consequence that some costs are more thoroughly investigated than others. Sometimes nuances are lost for these damage costs or assumptions have not been taken into account, this is the result of the sheer amount of input data and the unlimited amount of time which can be put into a research such as this, in order to make the results more precise.

7. Literature

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Appendix 1. Cost tables for the sensitivity analysis and the model

Different sources have been used to put together the costs tables below, the sources can be found in chapter 3.2. The column with expected damage is used as the baseline for the sensitivity analysis. The SI is not calculated for parameters with minimum and maximum damage costs similar to the expected damage costs.

Flooding by dike breach	Min	Max	Expected damage
Land use	€/ m²	€/ m²	€/m²
Airport	1223	1243	1233
Urban areas:	32	63	48.6
Recreation	€/ha	€/ha	€/ha
Intensive	87200	130800	108900
Extensive	70800	106200	88500
infrastructure	€/m	€/m	€/m
Highway	1730	2270	2100
Freeway	670	1090	980
Street	230	310	270
Rail road	5000	70000	25000
Vehicles	€/vehicle	€/vehicle	€/vehicle
	1070	1070	1070
Households	€/household	€/household	€/household
Low rise residency	WOZ-20%	WOZ+20%	WOZ
High rise residency	WOZ-20%	WOZ+20%	WOZ
Single family home	WOZ-20%	WOZ+20%	WOZ
Labor	€/job	€/job	€/job
Industry	334000	488000	411000
Utility	818000	972000	895000
Construction	40000	122000	81000
Quarrying	1943000	2097000	2020000
Trade and commerce	24000	38000	31000
Financial sector	98000	124000	111000
Transport	82600	102600	92600
Care	29700	29700	29700
Government	71400	71400	71400
Mortality	€/Person	€/Person	€/Person
	800000	800000	800000

Heat stress	Min	Max	Expected damage
	€/year	€/year	€/year
Air conditioning (per household)	35	95	60*
Outdoor labor (per worker)	387	968	667*
Hospitalization (per household)	0	0.83333	0.41666*
Mortality (total)	1.300.000	8.700.000	5000000*

* Number is an average of the minimum and maximum costs, and not researched thoroughly

Flooding by precipitation	**Min**	**Max**	**Expected damage**
Agriculture:	€/ha	€/ha	€/ha
Potatoes	2915	5.300	4108*
Sugar beets	1650	3.300	2475*
Grass	675	1.350	1013*
Grains	605	1.100	853*
Maize	750	1.500	1125*
Fruit	11880	13.200	12540*
Arboriculture	44820	49.800	47310*
Flower bulbs	26010	28.900	27455*
other agriculture	2550	5.100	3825*
Green houses	441000	441000	441000*
Infrastructure	€/ha	€/ha	€/ha
Highway	700	700	700
Freeway	700	700	700
Other roads	700	700	700
Nature	€/ha	€/ha	€/ha
Gardens	800	1200	1000
Internal recreation	800	1200	1000
Urban green	800	1200	1000
Households:	€/m²	€/m²	€/m²
Low rise residency	150	350	250
Single family home	150	350	250
Shops	150	350	250

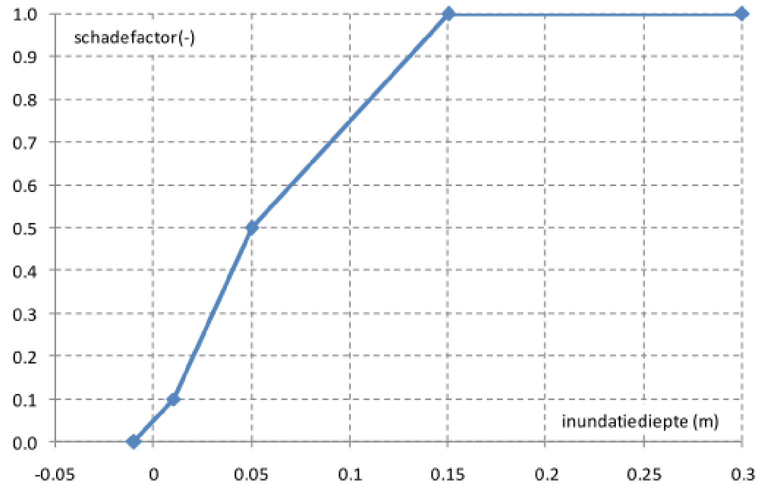
* Number is an average of the minimum and maximum costs, and not researched thoroughly

Drought	**Min**	**Max**	**Expected damage**
Agriculture:	€/ha	€/ha	€/ha
Potatoes	332	2328	1330*
Sugar beets	206	1442	824*
Grass	50	352	201*
Grains	46	325	186*
Maize	96	673	384*
Fruit	874	6122	3498*
Arboriculture	2733	19137	10935*
Flower bulbs	1282	8978	5130*
Green houses	19947	139631	79789*
Pile foundation	€/household	€/household	€/household
	54000	150000	108000*
Urban green	€/ha	€/ha	€/ha
	857	2597	1727*
Gardens	€/household	€/household	€/household
	1.62	3.24	2.43*

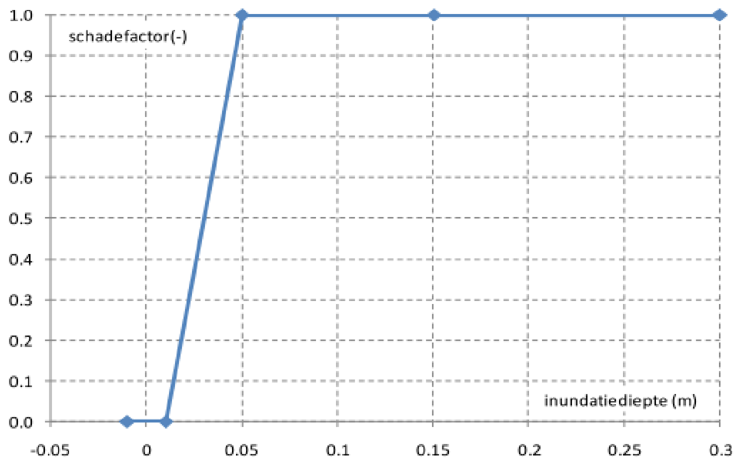
* Number is an average of the minimum and maximum costs, and not researched thoroughly

Appendix 2. Damage functions for pluvial flooding from the STOWA report

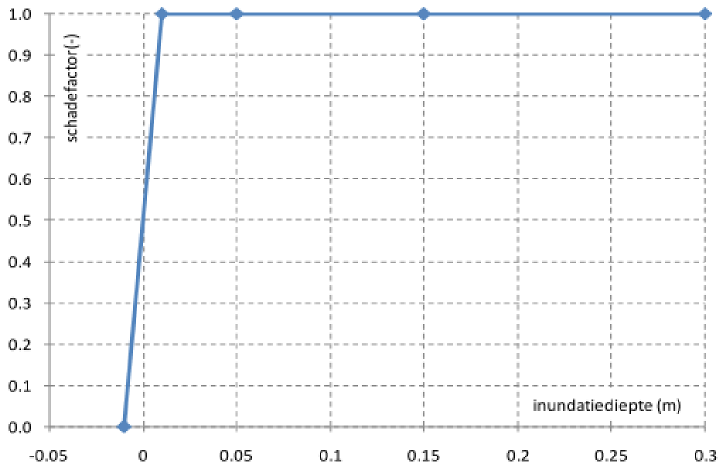
Houses and shops (Hoes et al., 2013)



Roads (Hoes et al., 2013)

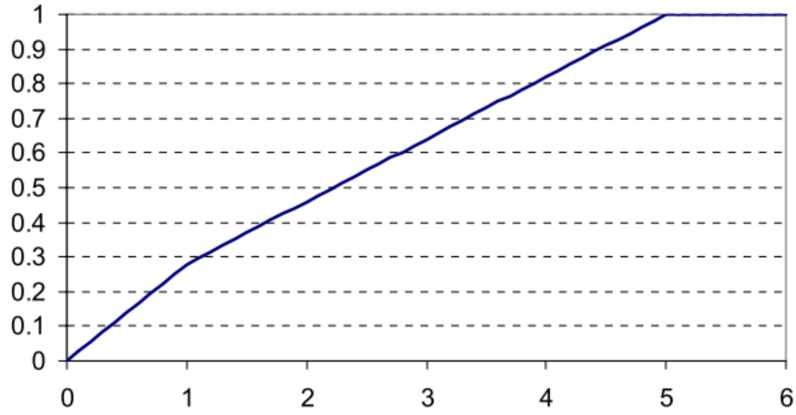


Agriculture (Hoes et al., 2013)

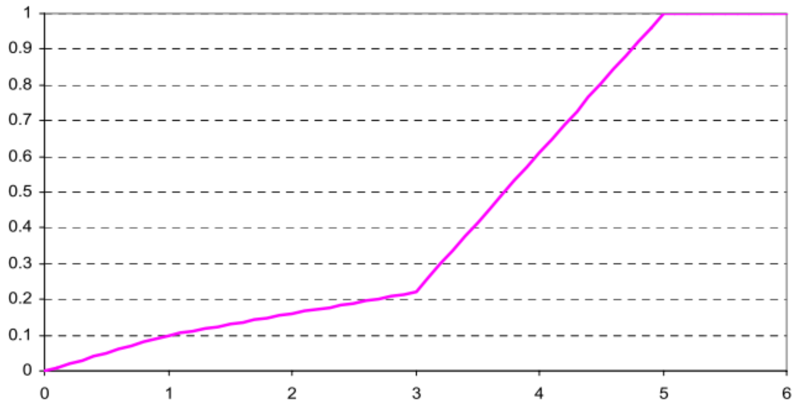


Appendix 3. Damage functions for flooding because of a dike breach from the HIS-SSM method

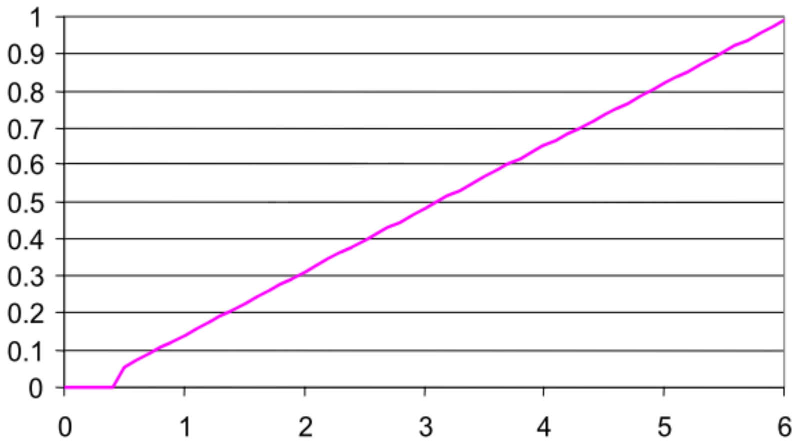
(Rail) roads (Kok et al., 2004)



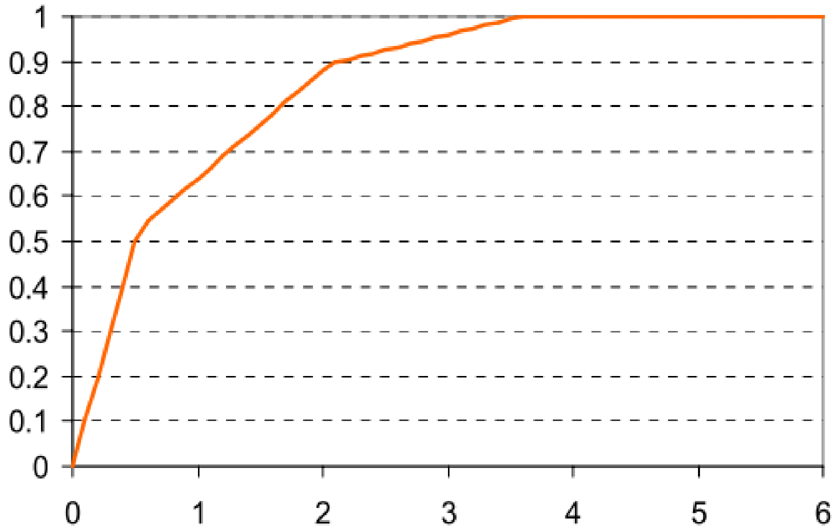
Industry and companies (Kok et al., 2004)



Vehicles (Kok et al., 2004)



Agriculture (Kok et al., 2004)



From top to down: low-rise buildings and high-rise buildings (Kok et al., 2004)