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Climate Change and Territorial Effects on Regions and Local Economies

Applied Research Project 2013/1/4

Final Report

Annex 6

Case Study The Netherlands

Bouwman, Arno
Knoop, Joost
Ligtvoet, Willem
Minnen van, Jelle

With contributions from Deltares

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Table of contents

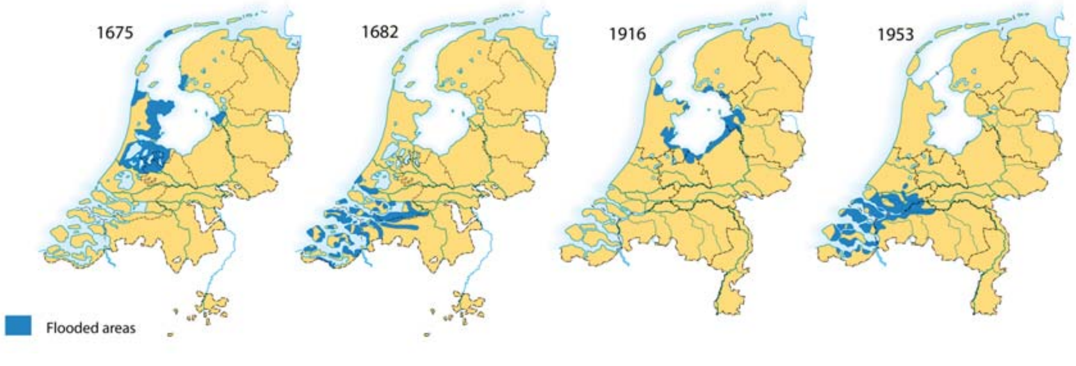
List of maps

0. Introduction

The Netherlands is part of some major deltas in Europe. The country has a long history in building dams and creating new land. For centuries the Dutch try to prevent the land to be swallowed by the water. It was the Frisians who, about 2000 years ago, built mounds on which they could live safely. It was the Zealanders who built dikes after the flood of 1134. It was the Dutch who with the use of windmills in the 17th century drained lakes (the Beemster). The invention of steam engines in the 19th century made it possible to drain larger lakes (the Haarlemmermeer, at which nowadays the airport Schiphol is located). The largest land reclamation project was the Dutch Zuiderzee Works in the 20th century (170.000 ha).

In addition the created (mostly agricultural) land, by building the 'Afsluitdijk' (enclosure dam) the Zuiderzee Works protect from flooding. Building the Afsluitdijk shortened the coastline considerably. The sea (Zuiderzee) nowadays is a lake (IJsselmeer) which plays an important part in the fresh water supply.

From the 14th century, on locations where no dunes exist, dikes protected the Netherlands against the sea. However, the sea broke through the dikes, and there were regular water emergency disasters (map 1). There were dozens of water emergency disasters with thousands of victims. The largest in recent history is the disaster of 1953. Almost 2,000 people were killed. This disaster led to the delta works (Bosatlas, 2010).



Map 1: A history of flooded areas by the sea.

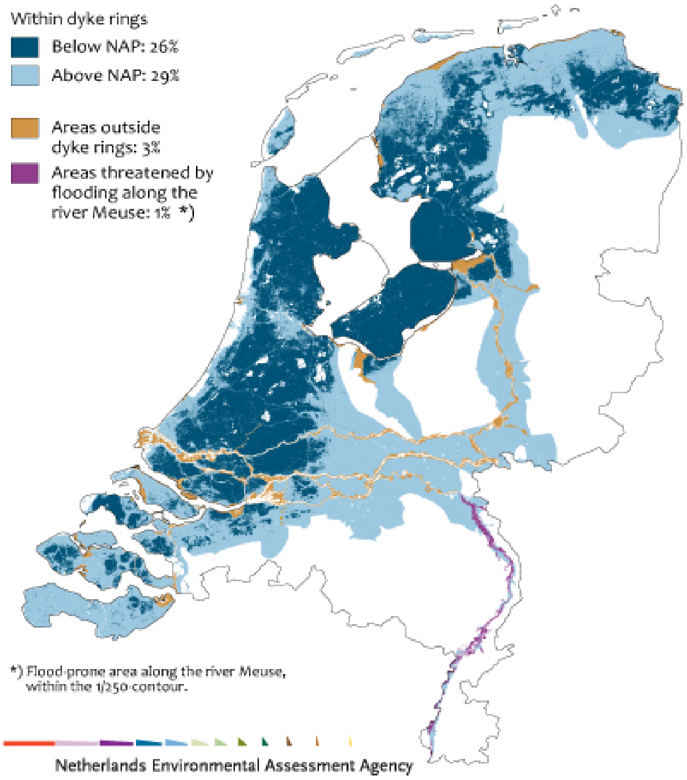
During the delta works many inlets in the southwest of the Netherlands were closed by dams which protect the hinterland against flooding. Two inlets were kept open because they are the entrance to the ports of Antwerp and Rotterdam. Along the route to Antwerp the dikes are raised. In case of severe storm surges the route to Rotterdam can be closed by a storm surge barrier, protecting a large part of the country against flooding.

Also the rivers in the Netherlands experienced numerous flooding. The dike breaches in the past were mostly caused by ice dams. When the thaw started, the water accumulated behind the ice dams. Nowadays extreme water levels are mainly caused by rain and ice melt in the Alpine regions. This was the case in 1993 and 1995 when high water levels threatened the dikes. However they did not breach, in 1995 over 200,000 people were evacuated by way of precaution.

The sensitivity of the Netherlands to climate change

The Netherlands are sensitive to climate change. Sea level rise as well as peak river discharges require precautionary measures. Map 2 shows the areas within the Netherlands that lie below Amsterdam Ordnance Datum (NAP), as well as the areas that are susceptible to flooding. Based on the current contour map and spatial planning of the Netherlands, we can state that:

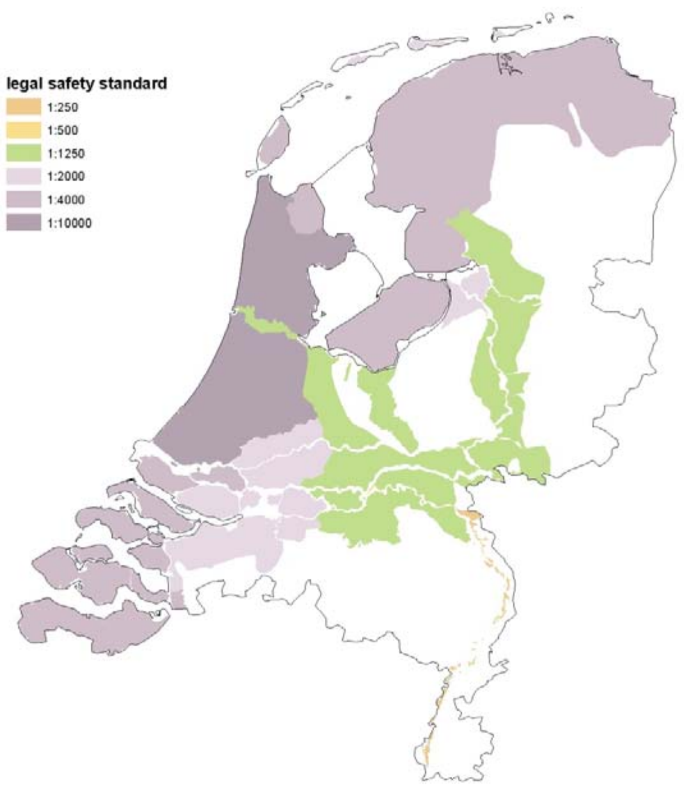
- 59% of the Dutch land surface (i.e. excluding the Wadden Sea, the IJsselmeer and other open waters) is susceptible to flooding. This 59% encompasses the areas both within and outside the dike rings, the so-called ‘river foreland’;
- 55% of the Dutch land surface is located within the dike rings, and is protected by dunes, dikes, dams and artificial structures;
- 26% of the Dutch land surface is below NAP;
- 29% of the Dutch land is above NAP but prone to flooding from rivers;
- 4% of the Dutch land surface is situated outside the dike rings and, therefore, is not protected by dunes, dikes, dams or artificial structures (PBL, 2010).



Map 2: Flood-prone area.

The Dutch flood defence system

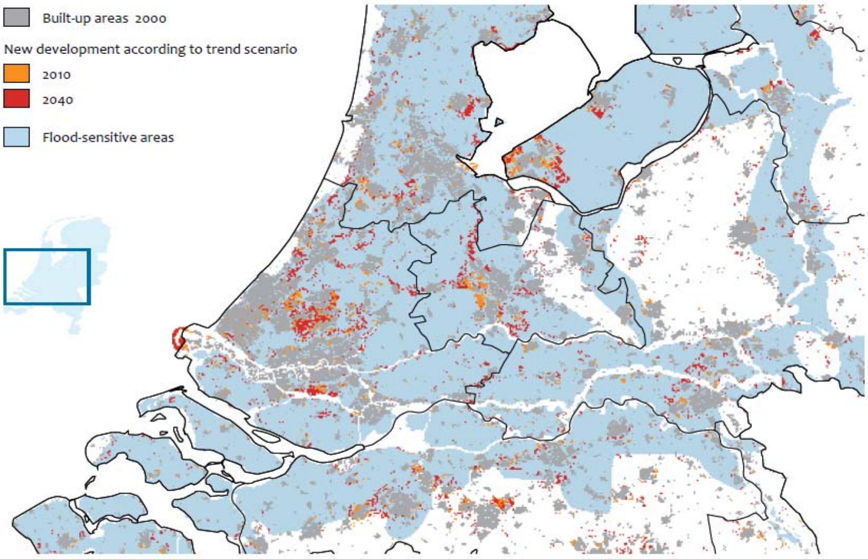
The Netherlands has an extensive system of so called primary and regional defences. The primary defences protect against floods from the North Sea, the Wadden Sea, the rivers Rhine, Meuse and Westerschelde, the Oosterschelde and the IJsselmeer. This concerns in particular those areas where potential flooding casualties or economic losses may result. The primary flood defences along the major rivers consist mainly of dikes. Only in a few places the primary defence is higher land. The area that is protected by a system of primary defences is called a dike ring. Each dike ring area has a safety standard for which the dikes should be resistant. The safety standard differs across the country, depending on the nature of the threat and the importance of the area (map 3).



Map 3: Safety standards for dike rings.

PBL scenario for future sensitivity

The PBL Netherlands Environmental Assessment Agency produced a trend scenario for 2040 for ‘the Netherlands in the future’ study based on two variants: one with moderate economic growth (1.7%) and moderate population growth (to over 17 million by 2040), and one with higher economic growth (2.1%) and a population of almost 20 million by 2040. In the trend scenario, the majority of new urban development takes place in the urban areas of the western Netherlands (the Randstad) and in those parts of the Netherlands most sensitive to flooding (map 4).



Map 4: Built-up areas in flood sensitive areas.

This continues the trend of recent decades and means that, in the period up to 2040, the vulnerability of the Netherlands as a whole to flooding will continue to increase, in terms of the percentage of the population and economic value considered ‘at risk’. The potential economic damage due to flooding will increase in the period up to 2040 by a factor of between two and three, depending on economic growth and population growth. About 20 to 30% of this is due to new development (figure 1).

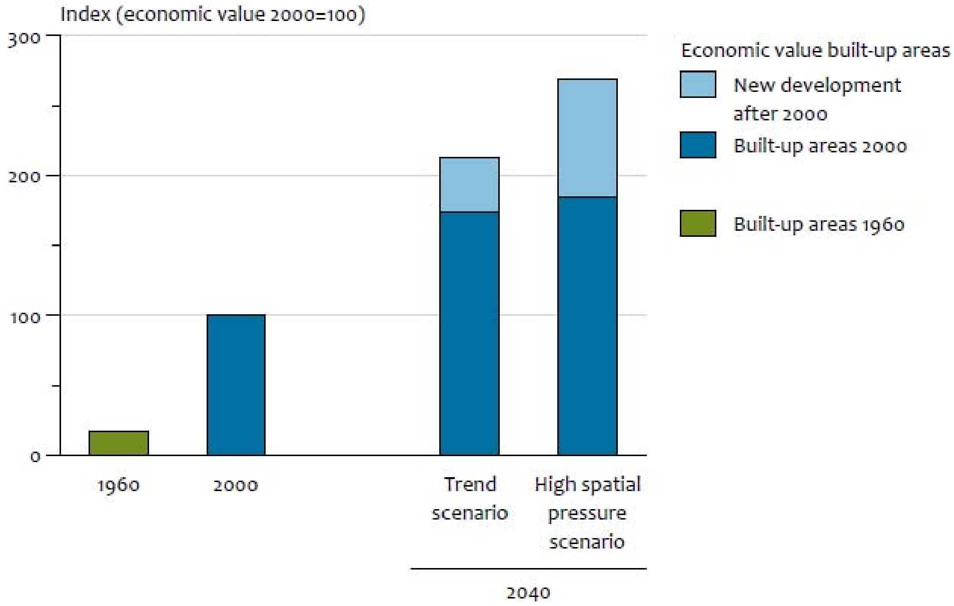


Figure 1: Potential economic damage in flood sensitive areas.

The trend scenario assumes that the protection level of the primary dike system is maintained in the period up to 2040, according to the standards defined in the Flood Defence Act. The most recent assessment of the dike system showed that 46% of the dikes meet these standards, 19% do not, and that there is as yet insufficient information available to be able to assess the other 35% (Ministry for Transport, Public Works and Water Management, 2006). A number of measures are to be taken in the period up to 2020 to ensure that the dike system as a whole meets the legal minimum requirements. Examples are the ‘Room for the River’ project, the strengthening of ‘weak links’ in coastal defences and the strengthening of the embankments of the Meuse and the Zeeland dikes. This means that the trend scenario assumes that the dike system will only fully meet the required standards from 2020 onwards.

1. Outline of the report

The objective of the different case studies is to explore the vulnerability of in this case the Netherlands, according to the framework developed in this project, to give some insight in the plausibility of the proposed methodology and to analyse the transferability of the ‘local’ conclusions to other parts of the EU. In this report we integrated these objectives in a more general sensitivity analysis of the methodology with respect to the vulnerability of the Netherlands to flooding. The first chapter is about sea level rise along the Dutch coast in the past and in the future. In chapter 2 we analyse the sensitivity of the impact assessment to the chosen flood hazard assessment (JRC approach), the chosen spatial scale (NUTS3) and the choice of the impact indicators. Also in this chapter we make some comments on the choice of the scenario and of the climate models. In the subsequent chapter 3 we move from impacts to adaptation and vulnerability. In this chapter we assess the potential of the Netherlands to adapt to climate change in general and to increasing flood risk in particular and analyse the estimated vulnerability of the Netherlands to a potential increase in flood hazard. Finally, we summarize our main findings as well provide some overall conclusions in chapter 4.

Sea level rise along the Dutch coast

Between 1890 and 2008, the average sea level rise along the Dutch coast was in the range of 19 ± 2 cm (Dillingh, 2010; PBL, 2009, Figure 2). This rise is at the low end of the range of observations made along the European coast, varying between 1.7 mm.yr-1 and > 5 mm.yr-1 (EEA, 2010). Over the past decades, a significant acceleration of this increase has not been observed along the Dutch coast.

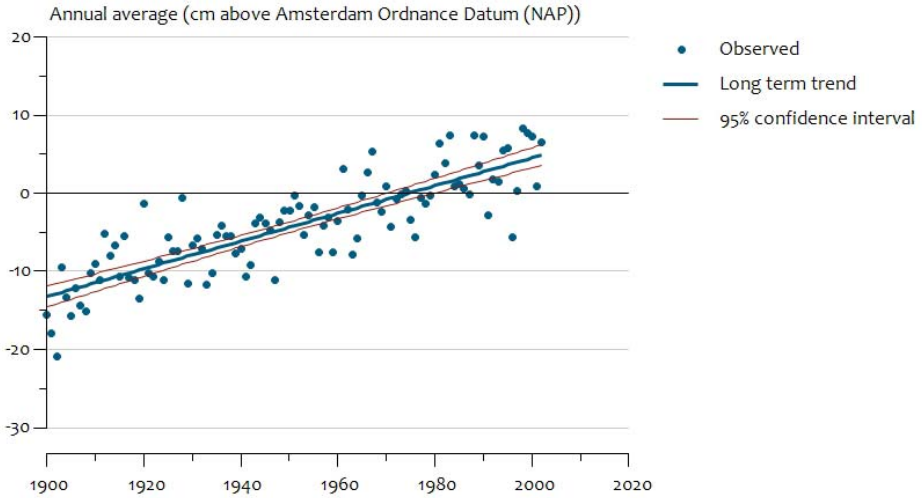


Figure 2: Sea level at the Dutch coast.

The most recent projections on sea level rise for the Netherlands cover a range of 35 to 85 centimetres for 2100 (KNMI, 2006). In the case of high-end/worst-case estimates, the rise is between 130 and 150 centimetres (Delta committee, 2008; MNP, 2007, Figure 3). Until 2200, the sea level may rise –in the worst case- by 2 to 4 metres, compared to 1990 levels (Delta committee, 2008). Given the technical adaptive capacity of the Netherlands and the considered safety margins, the delta region of the Netherlands could be kept safe until 2100, even in the case of such an extreme sea level rise, but in the long term, spatial measures could be required (MNP, 2007; Deltacommittee, 2008).

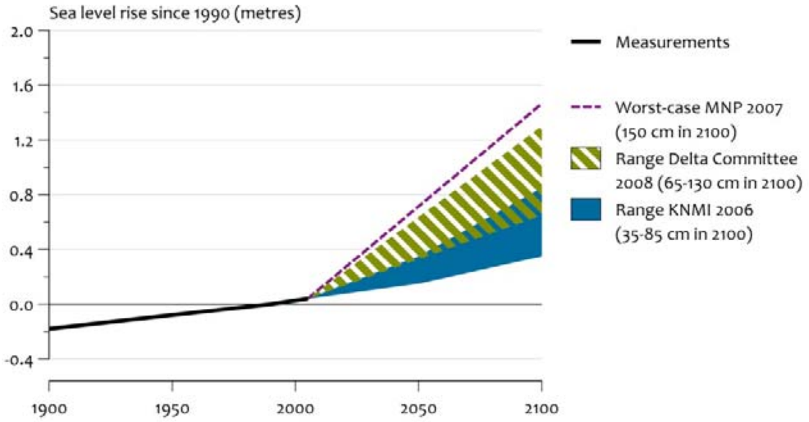


Figure 3: Sea level rise up to 2100.

2. The sensitivity of the used method

For the case study on the Netherlands we focussed on flooding and analyzed three types of uncertainties that may influence the results of the impact assessment:

i) the flood hazard assessment methodology;

ii) the spatial scale of the impact analysis and consequently the sensitivity of the classification methodology towards outliers;

iii) the sensitivity towards the choice of impact indicators;

The assessment of the potential exposure to flooding within the ESPON framework is based on two models. For river flooding a projection of the JRC LISFLOOD model is used (H12A2 scenario run) and for coastal flooding the DIVA approach was taken (*Dankers, R. and Feyen, L.*, 2008; *Barredo, J., Salamon, P., Bódis, K,* 2008.). To examine the sensitivity of the hazard assessment method, the ESPON hazard map, based on these JRC/DIVA flood maps, was compared with a hazard map based on a Dutch scale worst credible flood map (WCF, www.risicokaart.nl).

To examine the sensitivity of the spatial scale we did an impact assessment on three different spatial levels (NUTS 3, municipalities and 2x2 km squares).

To examine the sensitivity of the classification methodology towards outliers, the regions with the highest score on exposure were left out.

To examine the sensitivity towards the choice of impact indicators the calculations were both done with an extended set of indicators and with a core set of indicators.

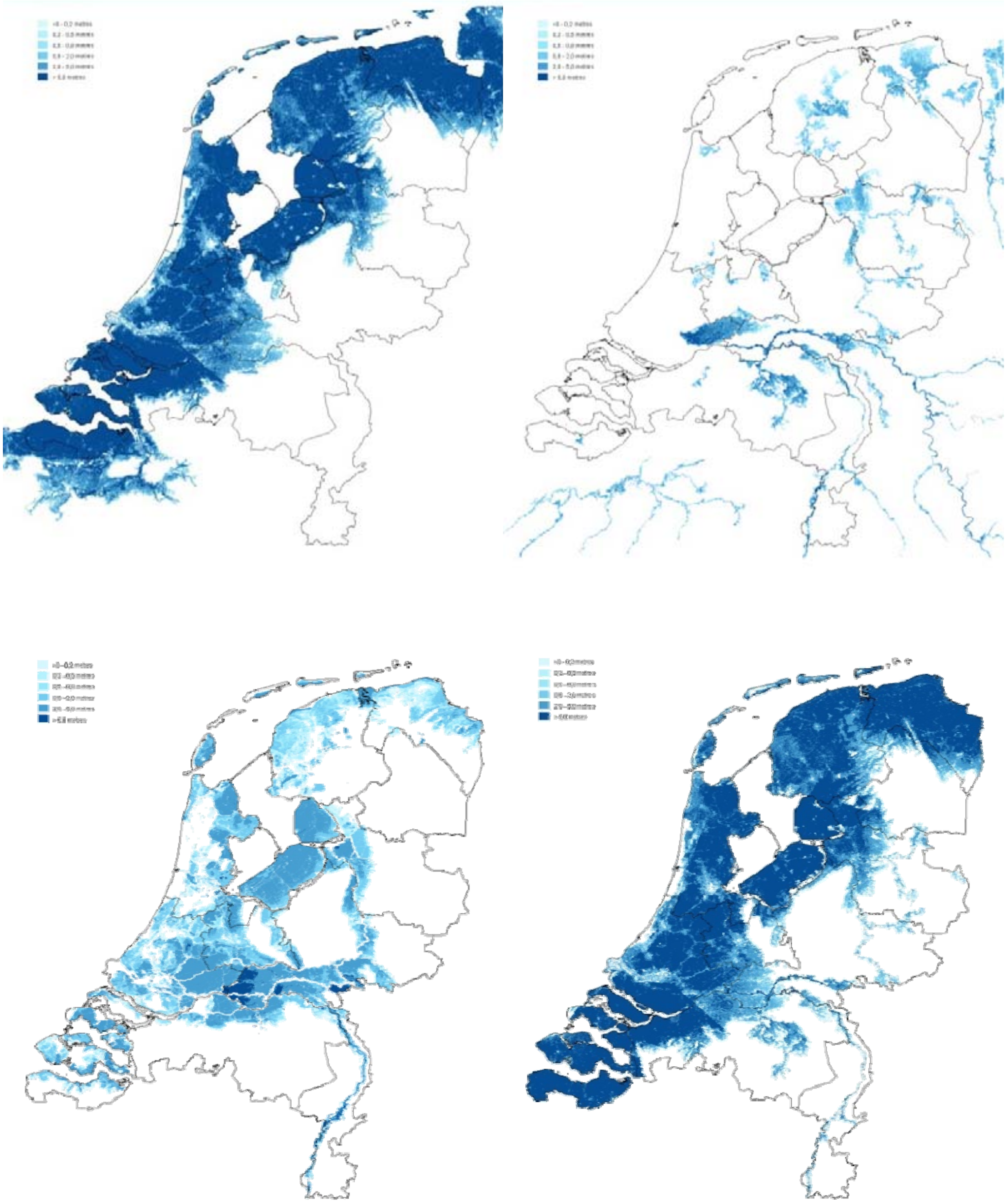
2.1 Differences in flood risk mapping between the JRC and the Netherlands

In the Netherlands, flood hazards are mapped by simulating a number of possible dike breaches, whether along the coast or along the large rivers. Each dike breach is regarded as a ‘scenario’ of subsequent effects. The hazard map shows the maximum water depths of all these flooding scenarios. Although the probability of these scenarios is lower than 1:1000 per year, the exact probability is not known.

Map 5 (bottom left) shows one of the hazard maps produced for the Netherlands government, the so called Worst Credible Flood map (WCF). It shows the maximum water depth at each grid cell of 100x100 meters resulting from all available flooding simulations, whether from sea or rivers. Flooding from small rivers or canals is not considered to pose a significant flood risk and is thus not shown on this map.

The European scale hazard map, based on the JRC Lisflood model (A2 scenario run) for river flooding and on a DIVA approach for coastal flooding (Dankers, R. and Feyen, L., 2008; Barredo, J., Salamon, P., Bódis, K, 2008.) was provided by the Joint Research

Centre. The hazard maps for fluvial flooding show water depths that are supposed to result from floods with a probability of 1:100 per year (Barredo et al., 2008b) (Map 5 top right). The hazard maps for coastal flooding show water depths that are supposed to result from a storm surge of 2 meter above mean sea level (Barredo et al., 2008a) (Map 5 top left). Map 5 (bottom right) shows the combination of these two JRC hazard maps for the Netherlands. In the combination, the map with the highest water depth is dominant. To make it easy, we call this combined map the Lisflood map.



Map 5: JRC coastal hazard map (top left) and JRC fluvial hazard map (top right) combined into JRC flood hazard map (bottom right). Worst Credible Flood Hazard map (bottom left).

Distinct differences between the maps of JRC and the Netherlands are the flood extent and the water depths. The JRC-map shows a much larger area along the coast which is potentially flooded than the maps from the Netherlands do. In contrast, the areas along the main rivers in the eastern part of the Netherlands stay dry according to the JRC-map, whereas the WCF map shows polders that are potentially flooded by Rhine and Meuse floods. In contrast, the JRC-map indicates flooding along some minor rivers, or in ‘supposed catchments’.

In general, what the hazard maps show depends on the following assumptions and/or basic data:

2. Choice of catchments.

   JRC uses a river network that is obtained from the pan-European River and Catchment database (Vogt et al., 2007). The algorithm that is used to derive slopes, flow direction and cumulated runoff from the digital elevation map, is hard to apply to flat areas such as the Netherlands.

   Moreover, the method to base water courses on a catchment map cannot deal with river bifurcations. The result is that large rivers, such as IJssel or Nederrijn, suddenly originate somewhere in the Netherlands instead of being mere branches of the Rhine which originates at the border between Italy and Switzerland.

2. Choice of the flood probability.

   The coastal hazard map of the JRC shows water depths resulting from a surge level that is 2 meters above mean sea level. This water level occurs almost yearly. However, because of protection by dunes and embankments, this water level will never cause any flooding.

   The fluvial flood map of the JRC shows flood water depths for 1:100 per year flood in minor rivers. In the Netherlands these are rather regarded as ‘pluvial floods’, caused by a drainage problem in minor rivers. Only less frequent floods in the major rivers (1: 200 – 1: 2000) are regarded to pose a ‘risk’.

3. Coastal, estuarine, fluvial or pluvial floods.

   JRC produces separate maps for coastal hazard and fluvial hazard. The fluvial maps intend to show flooding from main rivers as well as from smaller channels. Due to the catchment approach to achieve at water courses (point 1), the map produced is rather inadequate for the Netherlands. The Netherlands produces separate maps for floods resulting from breaches of the primary defences (coasts and main rivers), and for flooding caused by failing embankments along minor inland water bodies (rivers and canals).

4. Modeling flood water depths.

JRC uses a digital elevation model to obtain water depths, by extrapolating water levels using a planar approximation of the flood level, considering the local drainage direction. To obtain the 1:100 per year water levels in the river channel, JRC applies the rainfall-runoff model LISFLOOD, for each 100 x 100 meter grid cell. A Gumbel distribution is then fitted to the annual maximum values in every grid cell to estimate the probability of discharge levels with a 1:100 per year probability (Barredo et al., 2008b). Implicitly it is assumed that an unlimited amount of water is available for flooding, while in reality there is not enough water to fill up entire valley areas. Therefore, the JRC-method is likely to considerably overestimate water depths for wide river valleys and for embanked floodplain areas.

5. Flood defences.

   JRC uses digital elevation maps that do not take into account the existing flood defences and/or secondary embankments. A 1:100 per year flood will not cause significant flooding in the Netherlands, as the embankments are high enough. Similarly, dunes and embankments will prevent coastal flooding up until a certain storm surge level. Secondary embankments and other elements in the area behind the dike limit the flood extent. Two-dimensional simulations of the Netherlands do take account of this effect.

In summary: the JRC flood modeling approach is consistent and rigorous which makes it applicable for the whole of Europe. This is very important information for the pan-European assessment within the ESPON climate project.

Also the effect of sea level rise and changes in extreme water levels due to climate and land use changes can be estimated. Yet for the Netherlands hazard maps based on this approach deviate considerable from hazard maps based on local conditions (and assumptions), among others due to differences in the assumed flooding probabilities (for the JRC maps 1:100 for fluvial flooding, whereas the coastal flooding approach can practically be considered as non-stochastical, while the Dutch maps assume at least a 1:1000 return period). Still the impact of these differences on the Dutch scale exposure assessment is also substantial but less pronounced due to the fact that the ranking method is relative. On a European scale however the impact of these differences are more pronounced again if the classification is based on non-Dutch extremes. This remains to be investigated. On the other hand for the Netherlands the impact of the exposure map on the overall vulnerability assessment will most likely be limited due to its (especially on the European scale) high adaptive capacity with respect to flooding (although depending on the construction of this indicator). Still the point remains that the use of JRC maps can overestimate the exposure assessment especially in low-lying deltaic areas as the Po-valley in Italy, the Thames Estuary in the UK, the Elbe and Weser mouths and coastal plains along the North Sea in Germany, et cetera. This impact of these potential differences on the local vulnerability assessment should be investigated.

2.2 Choice of the scenario and of the climate models

Next to the sensitivity of the modeling approach, the output of the impact assessment is determined by projections on sea level rise and river discharge extremes, which largely depend on the choice of the global socio-economic scenario and on the modeling of the climate projections (see also Annex 2 of the Revised Interim Report of March 2010). Sea level rise projections are already presented in section 1 (figure 3). For the Netherlands the impact of 4 different climate scenarios (2° C or 4° C global temperature rise in 2010 and with or without change in the atmospheric circulation pattern, KNMI, 2006) on the extreme (1:1250 event) discharges of the river Rhine were estimated (figure 4, Deltares, 2011).

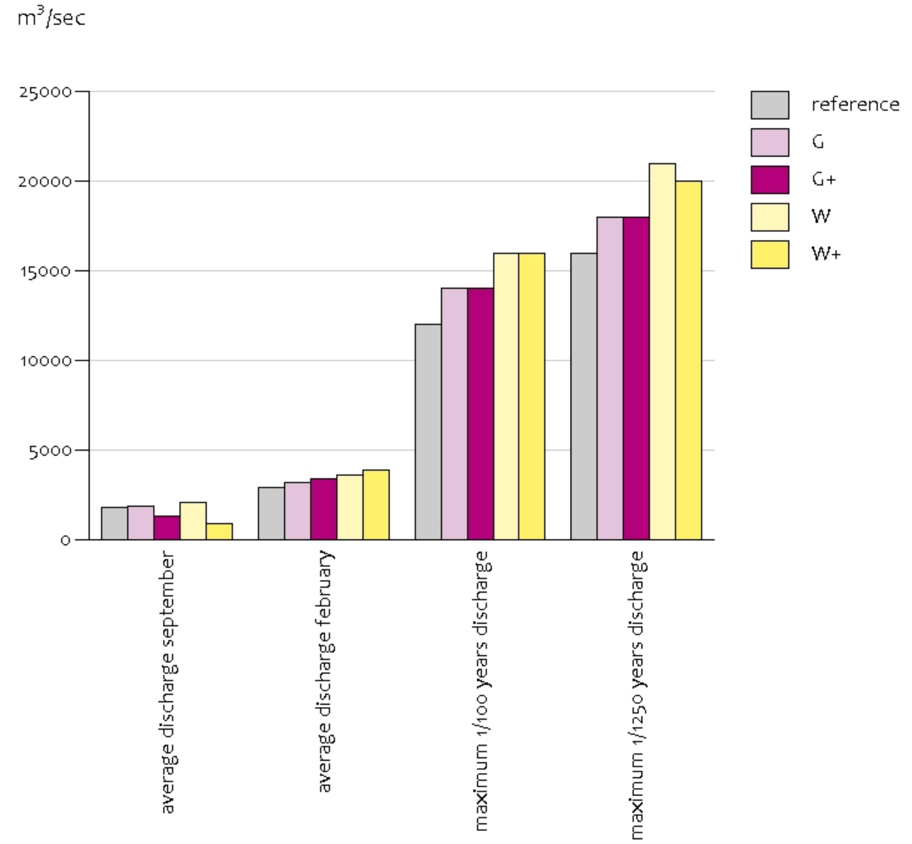


Figure 4: discharge of the river Rhine at the Dutch border (Lobith) for 4 different climate scenarios in 2100 (Deltares 2011).

JRC (Dankers and Feyen 2009) investigated the impact of four different factors on 1:100 extreme discharges of the European rivers. They used two greenhouse gas emission scenarios, two GCMs, two RCMs and three different sets of initial conditions. They concluded that the GCM was most influential on the estimated extreme discharges. The results showed three types of areas (or rivers): areas where (almost) all model runs estimated an increase of the 1:100 discharge, areas with the opposite result and finally areas where both increases as well as decreases were predicted, including the river Rhine at the Dutch border. In general their study showed the dependency of the in this case physical effects to the choice of the scenario but even more important to the atmospheric modelling approach.

At first sight the outcome of the study of Klijn et. al ((Klijn, Kwadijk et al. 2010)) and of Dankers en Feyen (2009) seem contradictionary with respect to the possible changes in extreme discharges of the river Rhine. Whereas Klijn et.al anticipate only increases, the results of Dankers and Feyen show a variable pattern with both expected increases as well as decreases. This is, however, because the two studies project the climate changes differently. Klijn and kwadijk use the knmi scenario's, that can be consisdered interpretations of the complete set of ippc ar4 climate model experiments. The knmi scenarios are not based on resutls of single climate models (see knmi reports on this), nor can they be directly associated to one or more emission scenarios. The jrc study directly uses results different global and regional climate models. Depending on the precipitation predictions of these model experiments changes in (extreme) river discharges may. Another difference is the probability of the extreme event. Klijn et. al investigated the impact of climate change on a 1:1250 event, whereas Dankers and Feyen focussed on a 1:100 event. This also may be of importance since the discharge pattern of the river Rhine is determined by a combination of snow and ice melt and rainfall/evapotranspiration. Dankers and Feyen indicated the delicate balance between anticipated decrease in snow and ice melt due to temperature rise and increase in precipitation (mainly in the winter season). If these phenomena balance at the 1:100 event level, causing both increasing as well as decreasing 1:100 discharges, depending on the choice of scenario and models, they will almost certainly not balance at the 1:1250 level which then will most likely be dominated by extreme rainfall events.

2.3 Impact methodology

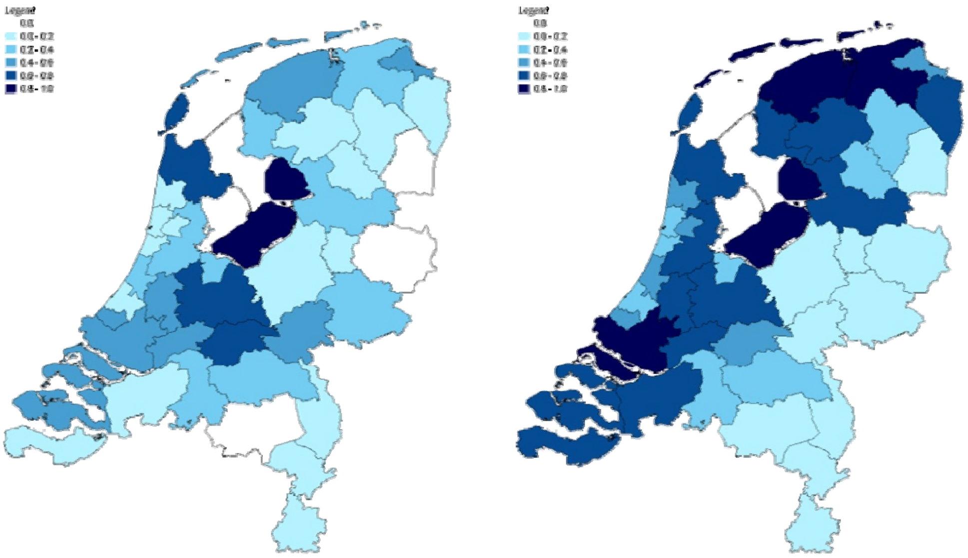
The impact analysis on nuts3 regions (the spatial level of the pan-European analysis) has been carried out both using the so called 'worst credible flood map' (WCF) and 'the Lisflood H12A2 map (Lisflood)'. In addition, the impact analysis with the WCF data has been done on two other different spatial levels (municipalities and 2 x 2 km squares). All of the indicators are collected at a very detailed spatial level (appendix 2).

Exposure

For all three spatial breakdowns (nuts3, municipalities, 2km squares) the worst credible flood map (WCF) as well as the Lisflood hazard map have been used to assess the exposure. For this purpose the JRC map for fluvial flooding was combined with the map for coastal flooding (*Barredo, J., Salamon, P., Bódis, K,* 2008.). In combining both maps, the map with the highest water depth is dominant. The WCF map contains maximum water depths for floods by river or sea (see appendix 2).

The WCF-map contains maximum water depths for flooding, irrespective of climate change. For the WCF-map the water depth classes are given. The JRC map is classified the same (see map 5). For each class of water depth the percentage area per region is calculated. Based on the water depth weights are assigned[1]. The values (weight * percentage area) are aggregated. Hence, because of the weights the total percentage of the flood prone area can sum up above 100%. In addition the score for this relative value, each region is scored for the absolute value of the flood prone area. The average of both of these scores is the final score.

Each region is scored in a range from 0 to 1 based on a continuous value[2]. The results are shown in the maps below (map 6, 7 and 8).



Map 6: Exposure to flooding for nuts3 regions based on the WCF hazard map (left) and the JRC hazard map (right).

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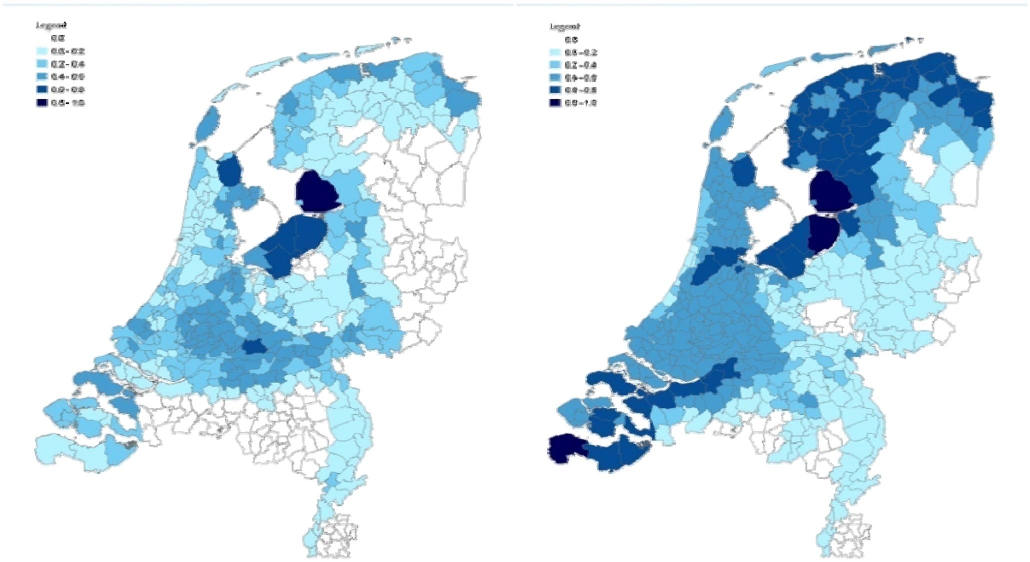
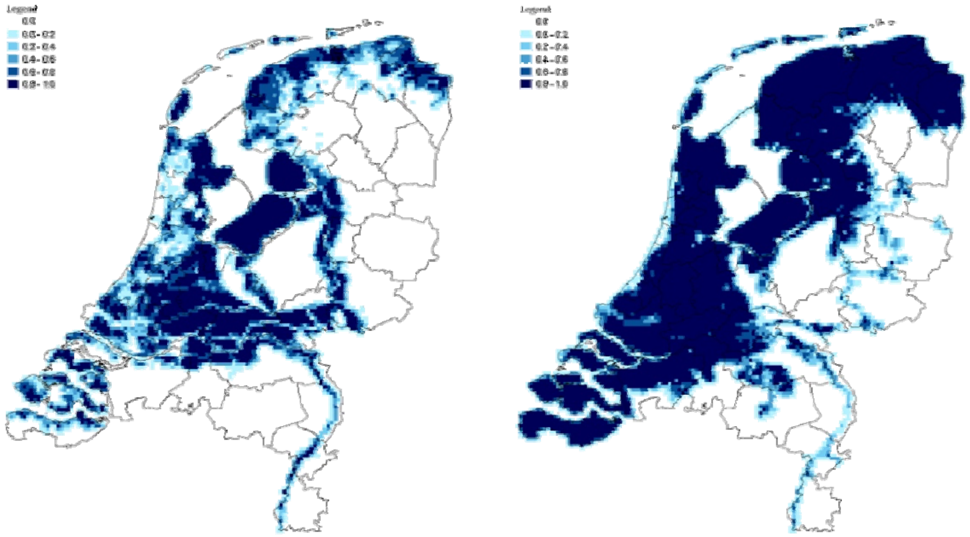
[1] 0 – 0.2 metres weight=1, 0.2 - 0,5 metres weight =2, 0.5 – 0.8 metres weight =3, 0.8 – 2.0 metres weight =4, 2.0 – 5.0 metres weight =5, > 5.0 metres weight =5

[2] rank[region-x] = (value[region-x] - MINIMUMvalue[all regions]) / (MAXIMUMvalue[all regions] - MINIMUMvalue[all regions]))



Map 7: Exposure to flooding for municipalities based on the WCF hazard map (left) and the JRC hazard map (right).



Map 8: Exposure to flooding at the 2 x 2 km squares scale based on the WCF hazard map (left) and the JRC hazard map (right).

Sensitivity

The values for the sensitivity indicators (appendix 1) are calculated in the same way the value for the exposure indicator is calculated (map 10, 11). That is: each indicator has a relative value (percentage of the indicator prone to flood; independent of water depth) and each indicator has an absolute value (the total amount of the indicator prone to flood). The final value for each indicator is the average of the relative and absolute score.

The sensitivity indicators are assigned to one of the five sensitivity dimensions. The indicators marked with a * are the selected indicators which are used to examine the sensitivity of the used method towards the choice of impact indicators. See appendix 2 for detailed information on the data.

For each dimension an aggregated average based on the individual indicators is calculated. All values are continuous between 0 and 1. Although it is possible to calculate the average by weighting the individual indicators, all are assigned the same weight.

Finally, the aggregated sensitivity score is calculated. The above mentioned aggregated scores per dimension are averaged in a weighted aggregated sensitivity score. The assigned weights are:

Physical: 0.19

Social: 0.16

Cultural: 0.10

Economic: 0.24

Environmental: 0.31

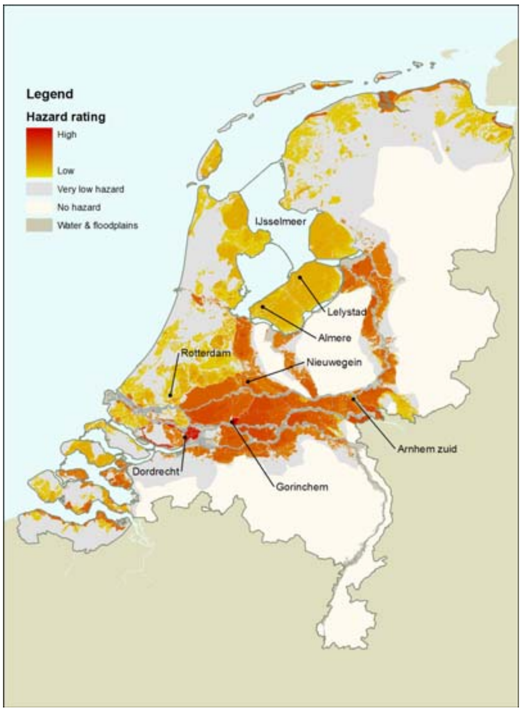
These weights were assigned according to the Delphi survey that was performed for the ESPON Climate project (see scientific report).

Impact

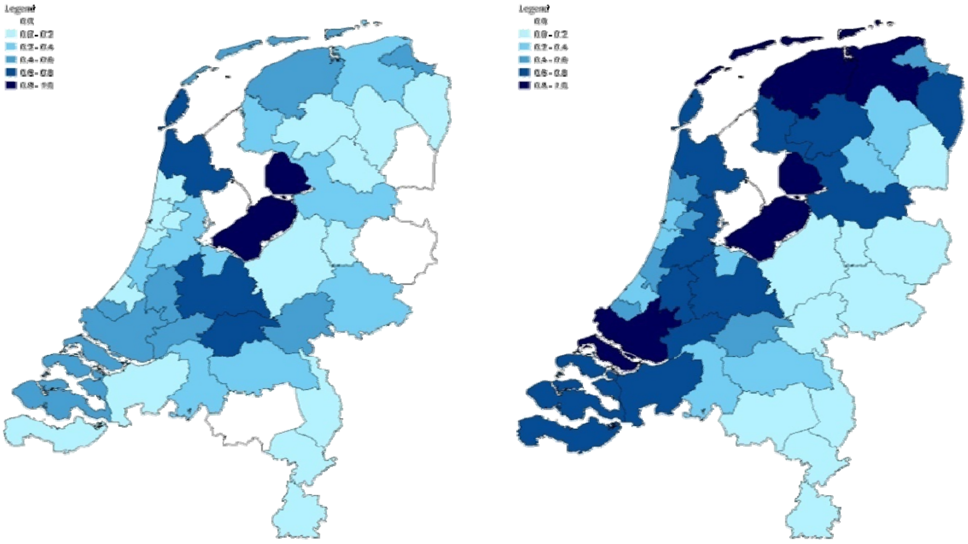
The impact is calculated by adding the exposure and the sensitivity score (map 12). Exposure and sensitivity are weighted. For each dimension, just like the sensitivity analysis, an aggregated average based on the individual indicators is calculated. The aggregated impact score is calculated exactly the same way the aggregated sensitivity score is calculated, using the same weights.

2.4 Differences as result of the use of different flood hazard assessment methodologies

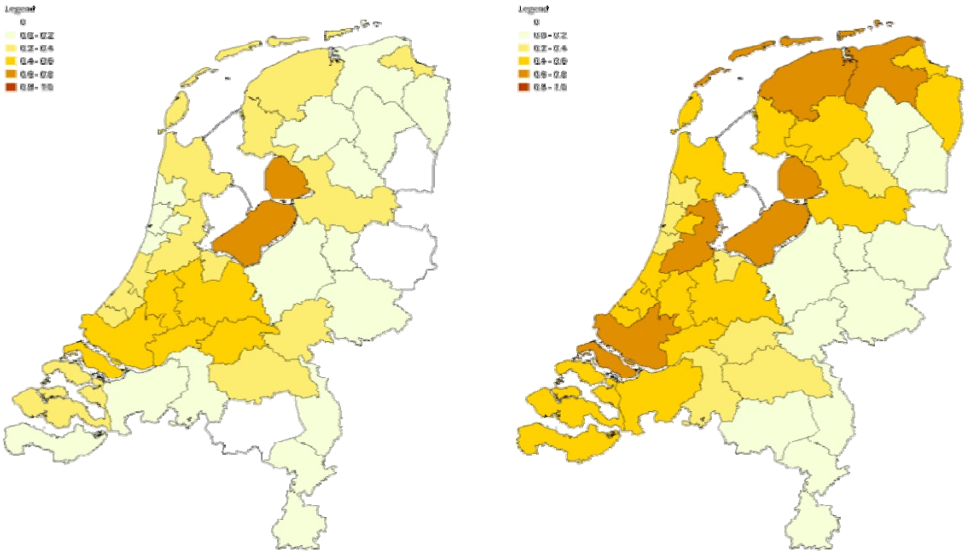
In this analysis the results of using WCF and Lisflood for the exposure maps on Nuts3 level are compared. As we saw before, the results on exposure calculations are quite different (map 6, 7 and 8). If the Lisflood map is used, more NUTS3 regions scored higher compared to the WCF flood map, especially along the coast. Only the exposure along the major rivers is higher classified when the WCF map is used. This applies, not surprisingly, also for the sensitivity and the impact maps. Although the weight on exposure between exposure and sensitivity to calculate the impact is lower, the exposure maps still are quite dominant in the method (map 10, 11 and 12). De Bruijn et al (2009) presented a risk map for the Netherlands, where risk is defined as hazard * vulnerability (map 9). (Definitions used in her study stems from the 'risk society'. 'Hazard' is comparable between both concepts, 'risk' is comparable with 'potential impacts' as defined within the framework of this study, whereas vulnerability used in the 'risk concept' is comparable with 'potential impacts to climate change' as used in this paper.) Though differently modelled, hazard is, like in our approach, based on probability of flooding and maximum water depth. Additionally the rate of water level rise is taken into account. The hazard map according to De Bruijn locates the highest ranked areas mainly in the central part of the Netherlands, where the large rivers meet the tidal waters. Since this map is also based on Dutch estimates on flooding events, it resembles the WCF hazard map to a large extent, even though De Bruijn does not take probability into account. The differences are located mostly in the south western delta (including the Rijnmond area around the port of Rotterdam) and are due to the expected rapid water level rises which are not included in the WCF map. In the same area the JRC map also shows highly hazardous areas but this is solely due to the fact that the used Diva approach assumes no flood defences.



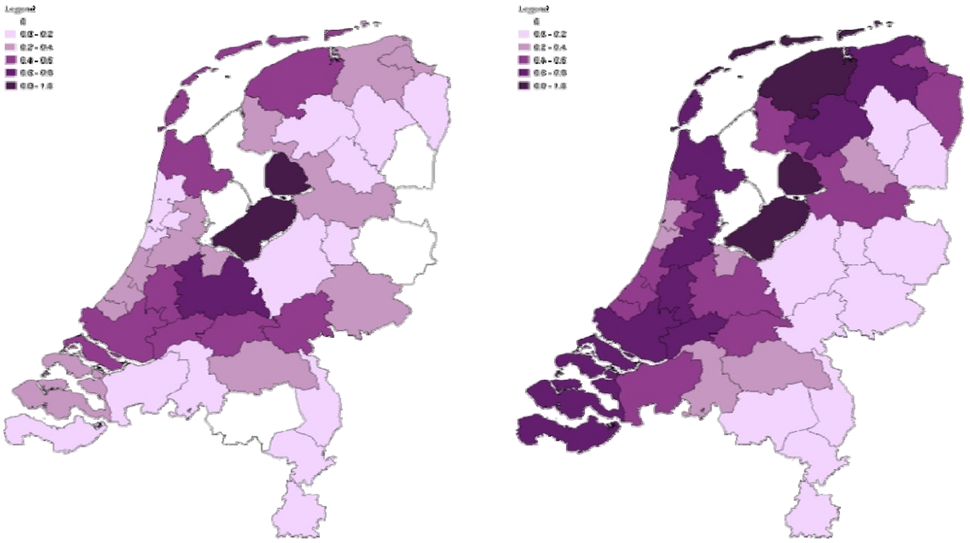
Map 9: Hazard map according to De Bruijn et al (2009).



Map 10: Exposure to flooding based on the WCF (left) and Lisflood (right) hazard map.



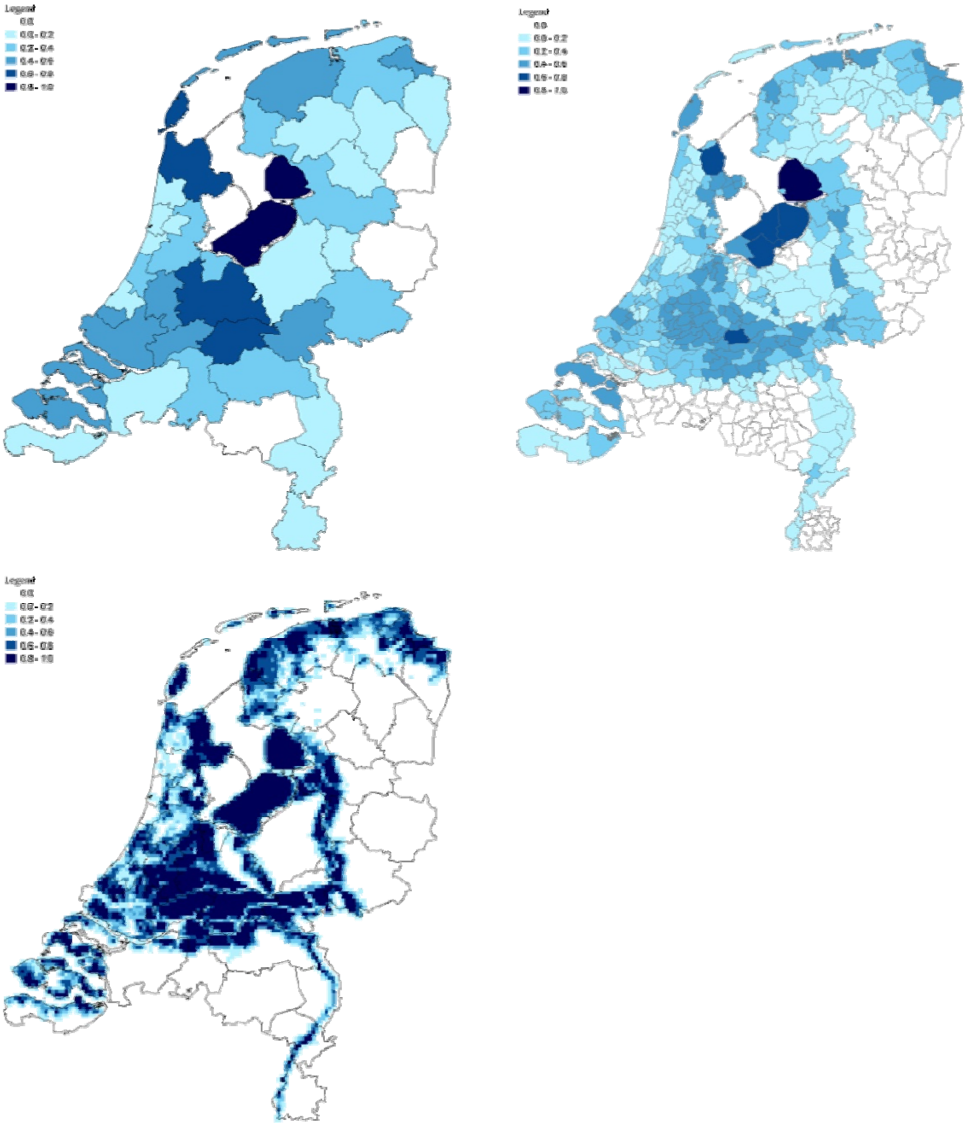
Map 11: Sensitivity to flooding based on the WCF (left) and Lisflood (right) hazard map.



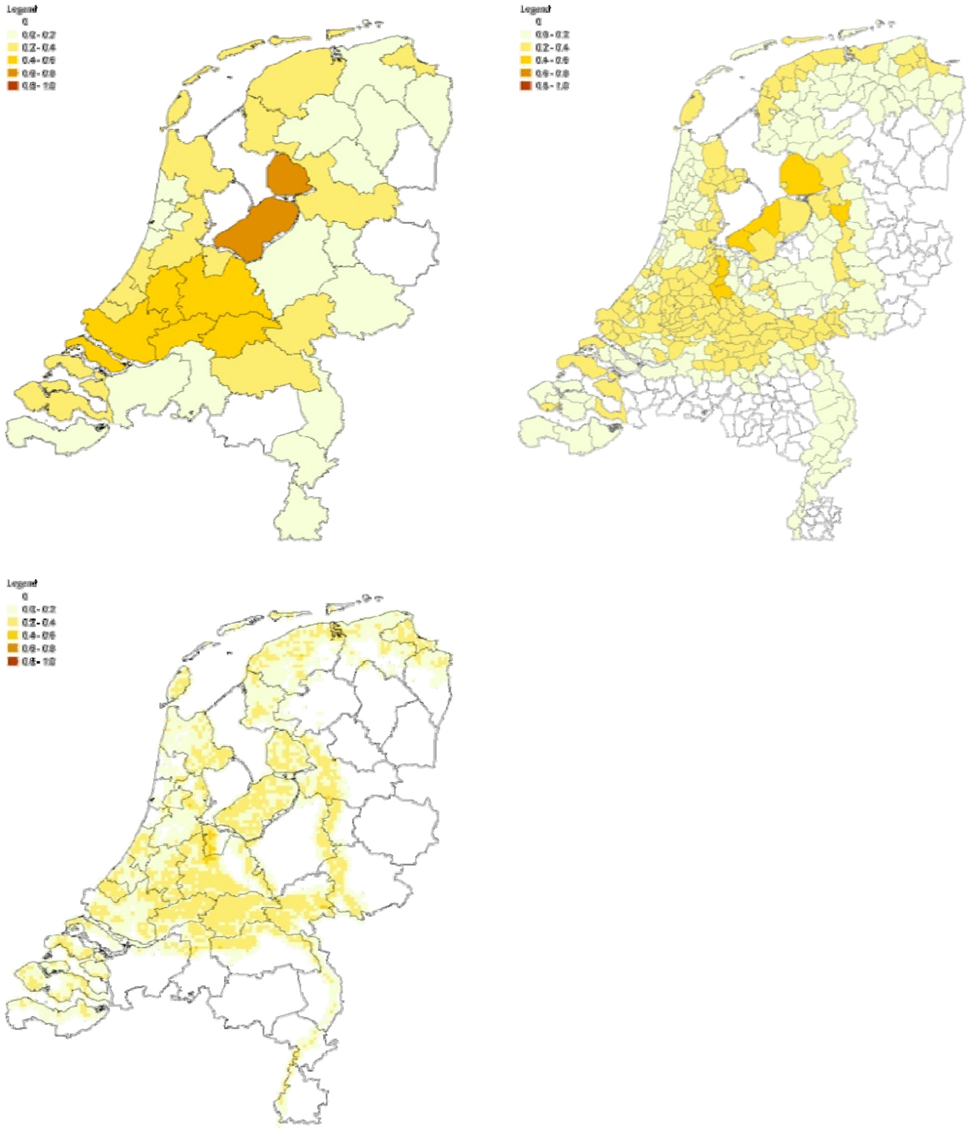
Map 12: Impact of flooding based on the WCF (left) and Lisflood (right) hazard map.

2.5 Differences as result of the spatial scale and the influence of the outliers on the impact analysis

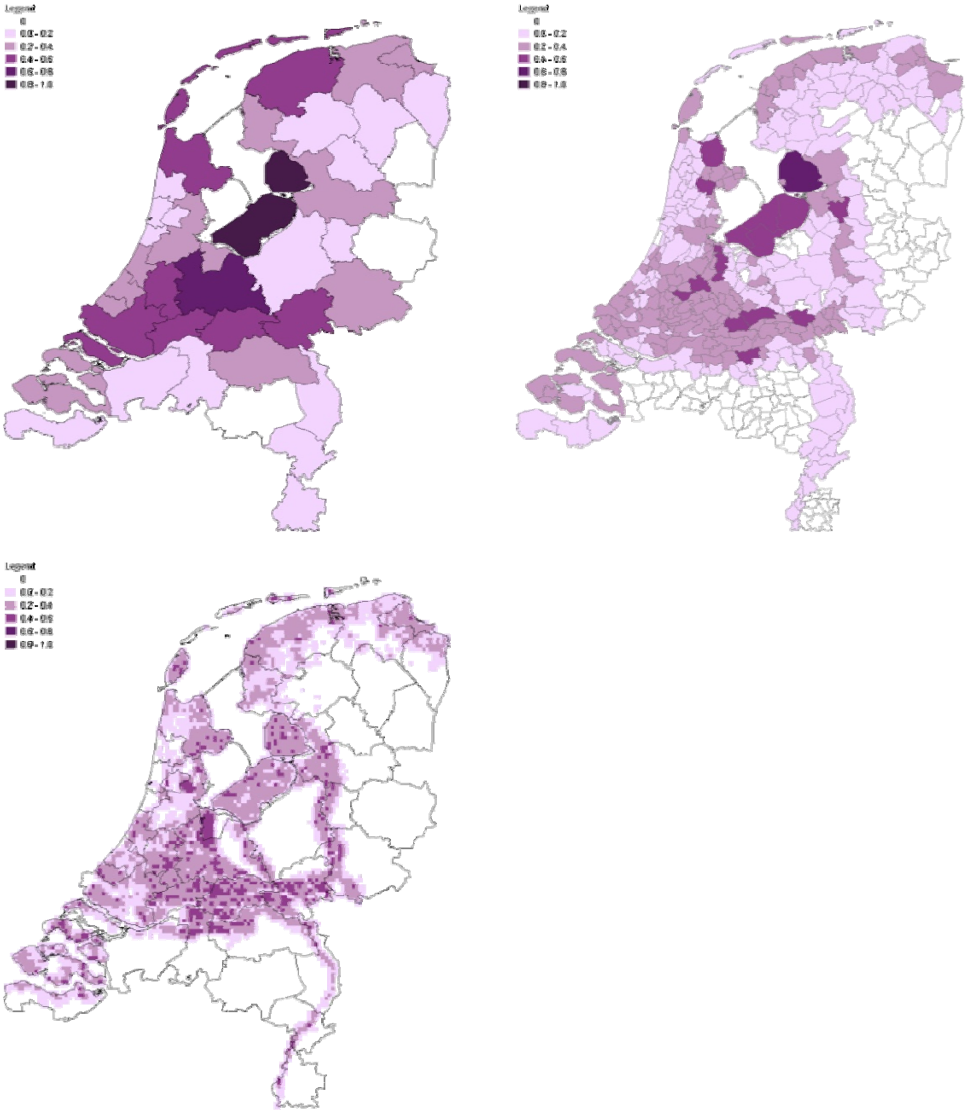
As we already saw, the more detailed the spatial level, the more the spatial extension of the exposure maps mirrors the original hazard maps (map 5, 8 and 13). By using 2 x 2 km squares the inundated area per region (cell) often is large. Therefore a lot of the inundated regions (2 x 2 km squares) are in the highest class.



Map 13: Maps of exposure for WCF on nuts3, municipalities and 2 x 2 km squares.



Map 14: Maps of sensitivity for WCF on nuts3, municipalities and 2 x 2 km squares.

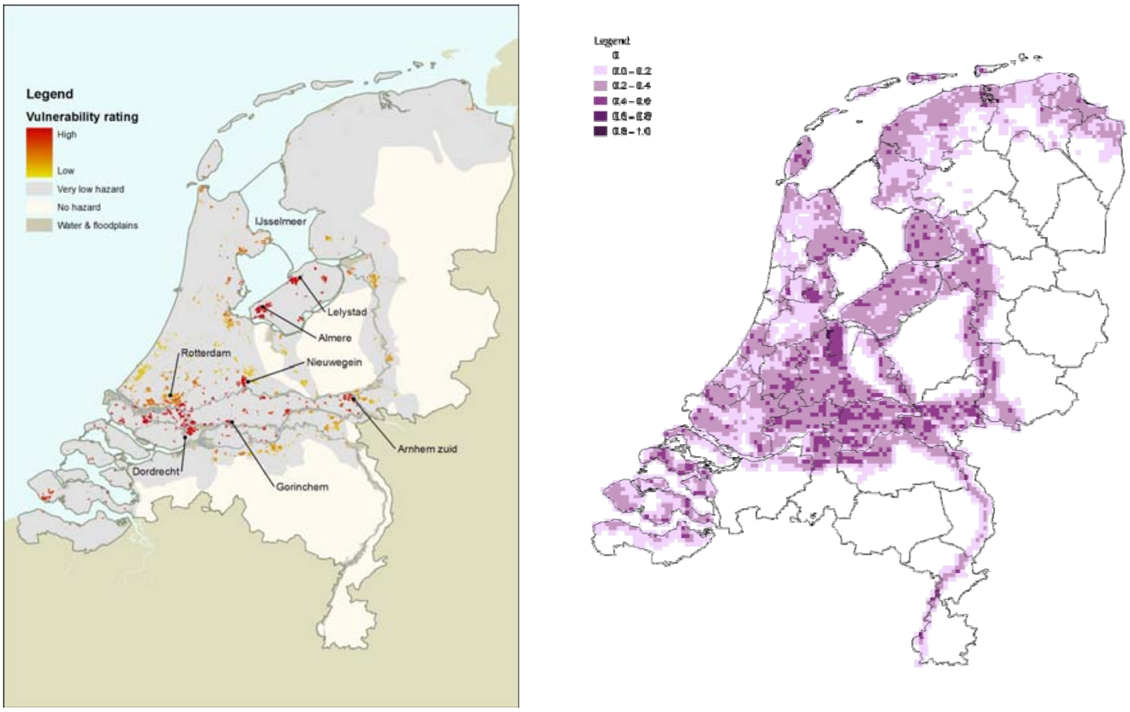


Map 15: impact for WCF on nuts3, municipalities and 2 x 2 km squares.

The results for nuts3 and municipalities do not show vulnerable places. In fact the assessment on municipalities and nuts3 is a comparison between regions. Much detail is lost by using nuts3 regions. The use of smaller regions better represents the detailed level of the underlying data (map 14 and 15).

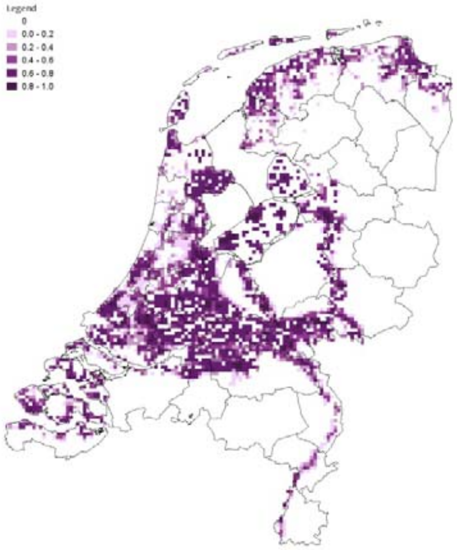
In “Risky places in the Netherlands: a first approximation for floods” (de Bruijn, 2009) a map of an overlay between hazard and vulnerability rating on a very detailed spatial level is presented (which is comparable with ‘our’ impact map). This map is completely different from the detailed 2 x 2 km square impact map that is presented above (map 15, 16 and 17).

In order to identify places with high potential impact, De Bruijn carried out the following steps (de Bruijn, 2009): The hazardous areas are defined by considering all three criteria for hazardous areas separately (floods are probable, water level rise rates are high, and water depths are large), whereas sensitive areas were identified as areas where floods occur suddenly, locations from where it is difficult to reach safe areas, and where many people live (map 16 left hand site). This map can at best be compared with the impact map at the 2 x 2 km scale produced with the WCF map, since this resembles the hazard map of De Bruijn better than the JRC map (map 16 right hand side – identical to map 15).



Map 16: Vulnerability rating map (De Bruijn, 2009) and impact map (right) using WCF hazard.

This comparison shows some remarkable differences. Due to the fact that within the approach of De Bruin only urban regions are considered to be sensitive towards flooding, her map indicates fewer locations with high risk. Yet especially the area around Rotterdam, considered as one of the most risky places in the Netherlands, and as so showing up well in her map, is hardly recognized as having a potential high impact in the impact map (map 16). De Bruijn (2009) takes into account the time available for evacuation, which is high for flooding from the main rivers (in the order of several days), but very low for coastal flooding or flooding from the large lakes (in the order of several hours). Note that this same short warning time in case of the river Rhine applies for (flash) floods in the upstream areas like the Swiss Alps. Even if our approach is solely based on housing area (map 17) this difference remains.



Map 17: Impact map 2 x 2 km squares using only housing area as impact indicator.

If the distributions of the exposure based on three different spatial scales are compared (figure 5), the relative largest number of spatial elements with extreme values (both highest as well as lowest) show up at the scale with the highest resolution (2 x 2 km). These extremes are rapidly diluted when coarser scales are applied. The distribution than depends more and more on the region with the highest exposure score, which determines the graduation. We investigated this sensitivity by leaving out the highest ranked value for each of the three different spatial scales for exposure estimates based on the WCF map as well as on the JRC maps (figure 5, 6). For the nuts3-WCF case this is the nuts3 region Flevoland (FLEV). For the nuts3-Lisflood case it is the region Noord-Friesland (NF). For the municipalities-WCF case as well as the municipalities-Lisflood case it is the municipality Noordoostpolder (NO). For the 2 x 2 km squares the regions are selected which have a score of 0.99 or higher (H).

On the nuts3 spatial level leaving out the region with the highest score, the classes with a higher score tend to be larger. Using the 2 x 2 km square regions though, the classes with a high score tend to be smaller. For the municipalities there is almost no difference. So, the sensitivity for outliers depends very much on the used spatial level. The more detailed the spatial level, the less sensitive the method is to outliers. For the high resolution maps, resetting the high sores to zero just causes a shift in the classes which is almost as big as the amount of regions that is reset to zero (figure 5, 6).

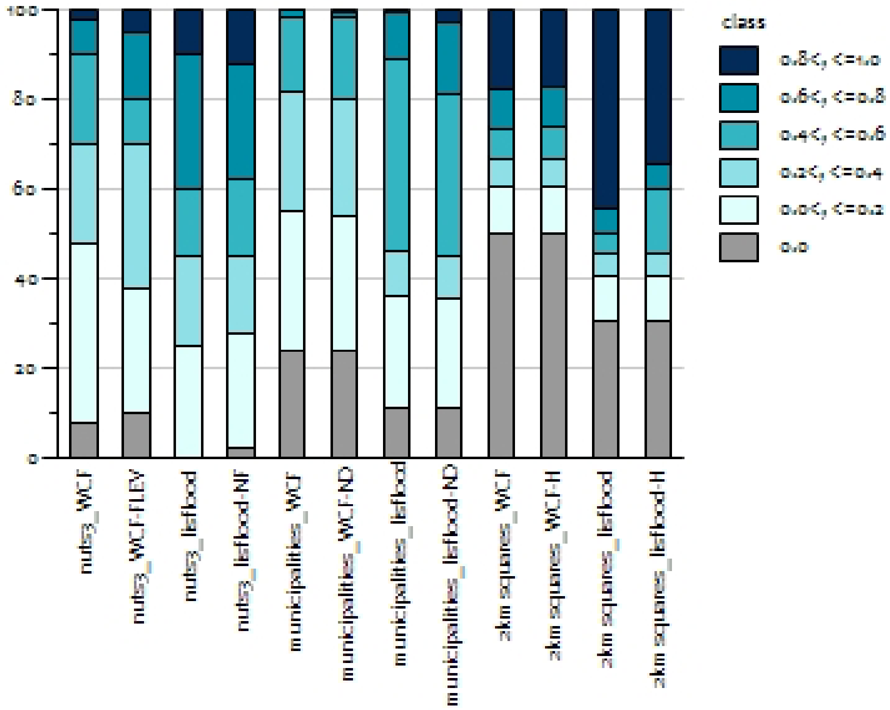


Figure 5: Distribution of exposure scores with and without highest values.

WCF: Worst Credible Flood

FLEV: region Flevoland (highest score) excluded

NF: region Noord-Friesland (highest score) excluded

NO: region Noordoostpolder (highest score) excluded

H: 2 km squares with the highest scores excluded

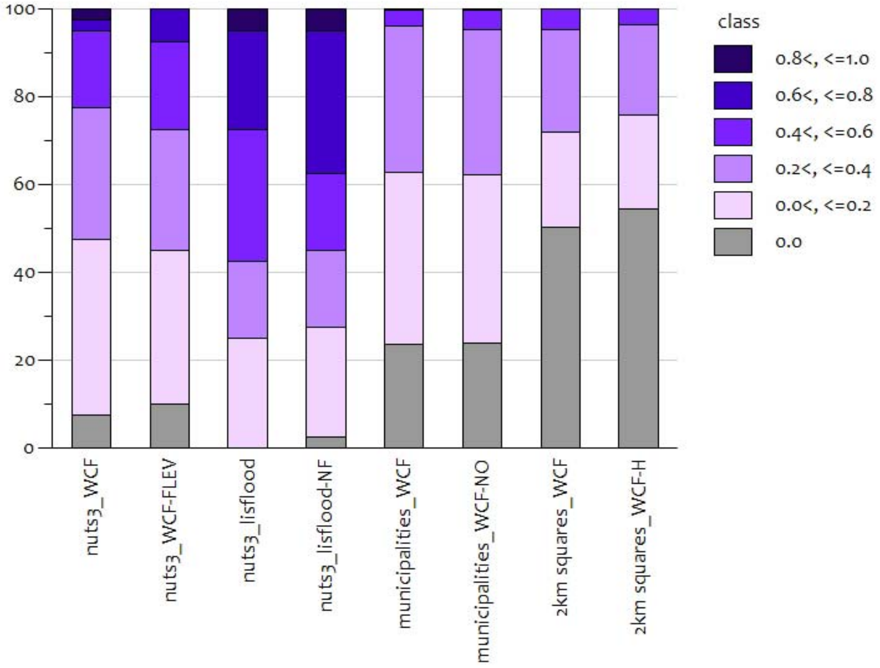


Figure 6: Distribution of impact scores with and without highest values.

WCF: Worst Credible Flood

-FLEV: region Flevoland (highest score) excluded

-NF: region Noord-Friesland (highest score) excluded

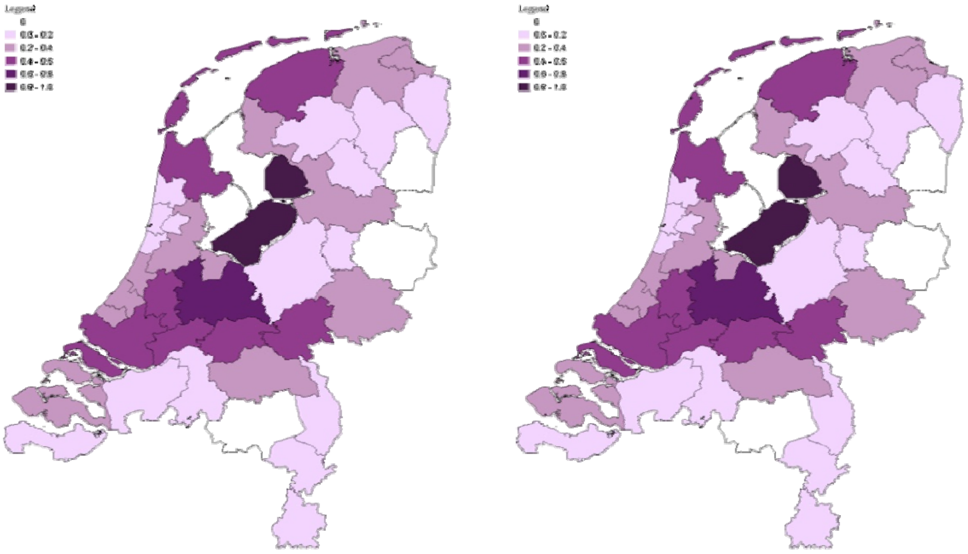
-NO: region Noordoostpolder (highest score) excluded

-H: 2 km^2 squares with the highest scores excluded

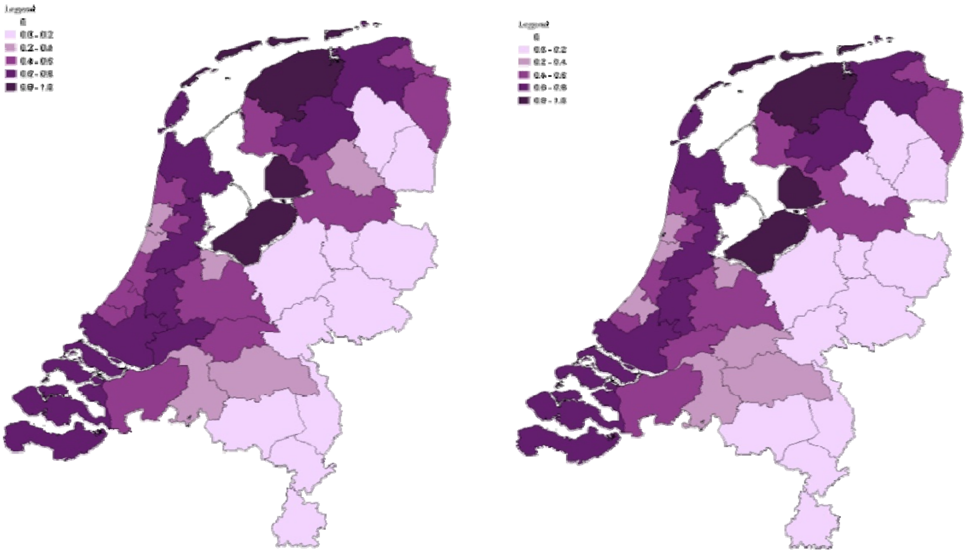
2.6 Differences as result of the sensitivity towards the choice of indicators

In this analysis the impact calculations are done with a core set of indicators. The results are compared with the results using an extended set of indicators, which we also used in all other analyses (see appendix 1).

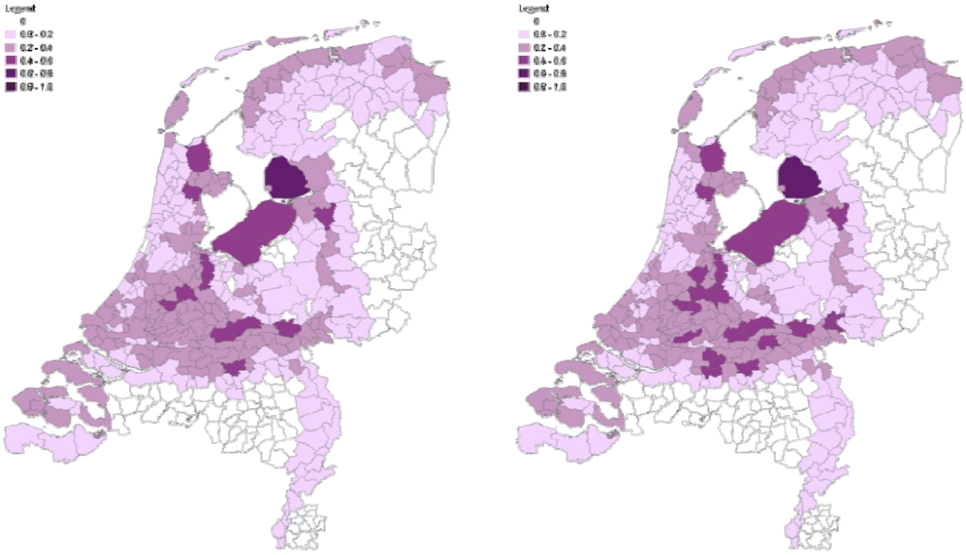
The difference between the results using all the indicators and a (core) selection of the indicators is very small. Using the Lisflood data and less sensitivity indicators on the nuts3 level, only a few regions shift to another impact class. Using the more detailed spatial levels on the WCF data, a few more regions are ranked into higher impact classes. Overall, it seems that by using a core set of sensitivity indicators instead of an extended set, the results will be more or less the same (map 18, 19, 20 and 21) (figure 7).



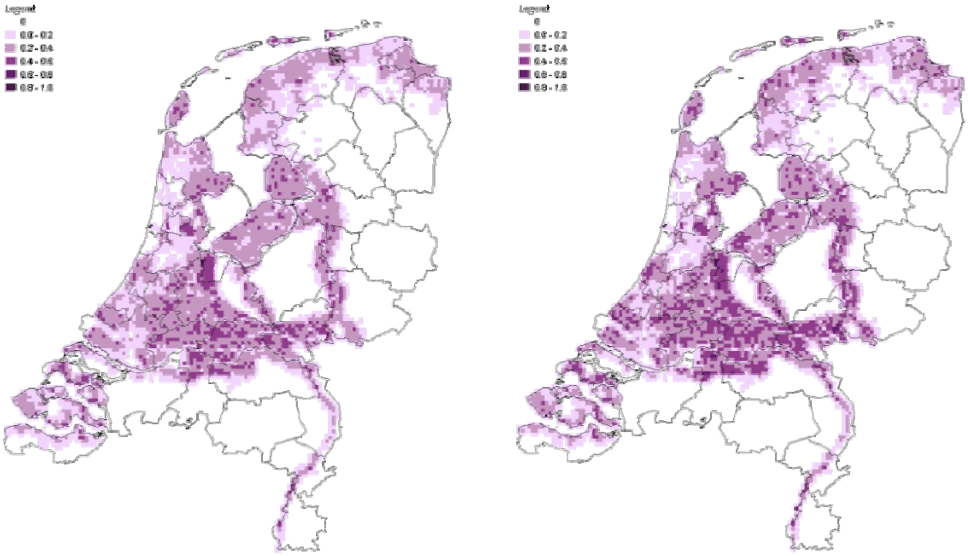
Map 18: Impact maps for WCF-nuts3 with all indicators (left) and a selection of the indicators (right).



Map 19: Impact maps for Lisflood-nuts3 with all indicators (left) and a selection of the indicators (right).



Map 20: Impact maps for WCF-municipalities with all indicators (left) and a selection of the indicators (right).



Map 21: Impact maps for WCF-2 x 2 km squares with all indicators (left) and a selection of the indicators (right).

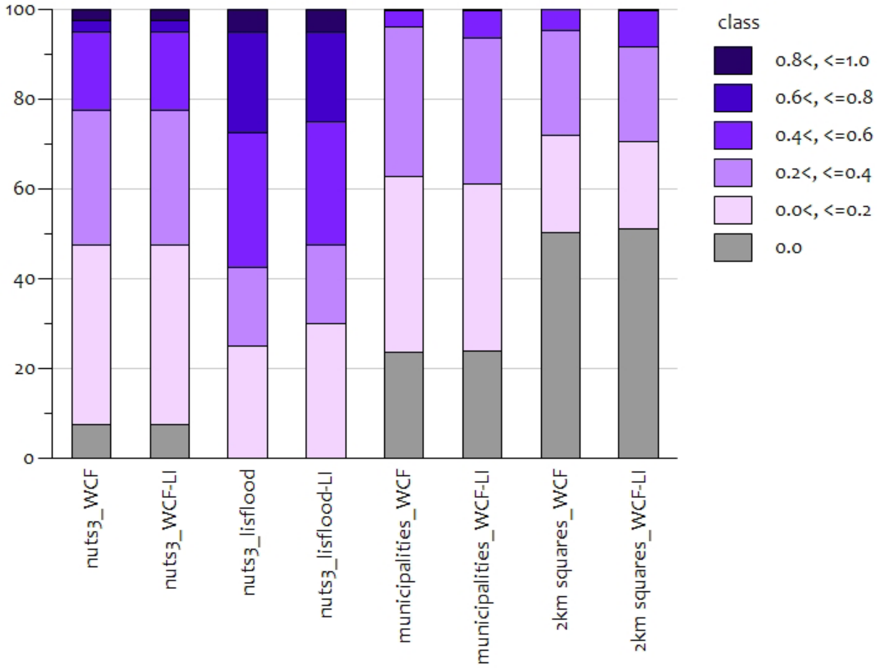


Figure 7: Impact scores with all indicators and a selection of the indicators (LI).

3. Adaptive capacity and vulnerability

To compare the adaptive capacity assessed by means of the ESPON framework with local estimates, we have to consider the climate adaptation in the Netherlands in a broader sense since the ESPON estimate is based on general features like R&D expenditure and GDP per capita.

Though climate change is expected to have many effects in the Netherlands the four most marked ones are flooding (coastal, large lakes and main rivers), water management (mainly fresh water supply but to some extend also water nuisance), heat (cities) and nature (Ligtvoet 2009). The Dutch adaptive capacity with respect to flooding and water management is high. On both issues cyclic strategies are developed and broad into action consisting of setting protection levels, among others, based on projections on future climate changes, monitoring and adapting the existing infrastructure (the flood defence system and the water supply and drainage system). These strategies are statutory (mainly embedded in the Dutch Water Law). With respect to flooding protection levels are set and funded at the national level, whereas the 26 existing Water Board Authorities are responsible for the maintenance and the adaptation. On drainage and fresh water supply, both above mentioned authorities together with the main municipalities have agreed on a National Water Action Plan. Municipalities and Water Boards are responsible for the implementation.

Adaptation policy on heat however is currently not a national issue. Individual cities are active in the field of mitigation (aiming at climate neutral cities), but rarely in the field of heat. Finally at the national scale the main goals of nature policy are the conservation of species according to the European guidelines (Natura 2000). Since the ongoing increase in mean temperature already causes a migration of species northwards (PBL, 2008) this conservation policy will be hard to sustain in the future. Adapting this policy should be done at the European level. At the national scale it is recognized that enlarging of the areas by combining the in the Netherlands often scattered pattern of small nature reserves is a good adaptive strategy anyway. Recently however the budgets for nature conservation are pruned drastically, hence only very limited funds will remain to do so.

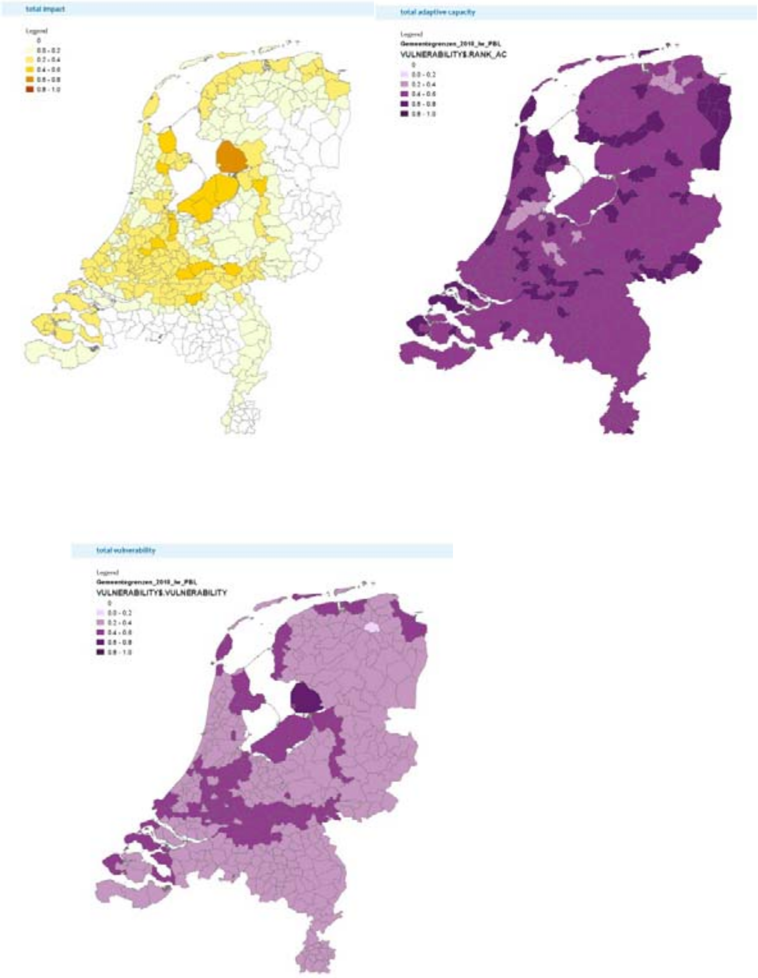
In line with the ESPON approach, for this case study the estimation of the adaptive capacity is based on the determinants of adaptive capacity as described in the ESPON climate scientific report (see scientific report). These determinants are: knowledge and awareness, technology, infrastructure, institutions and economic resources. It is assumed that access to technology and the way institutions function do not differ significantly between municipalities in the Netherlands.

Skilled and trained personnel and population can increase the adaptive capacity (see scientific report). Educational commitment and computer skills by means of percentage of inhabitants with a tertiary education, and computer use are the indicators that describe the knowledge and awareness.

Highway density is the indicator which describes the infrastructure determinant. The infrastructure supports adaptive capacity, but more important the coping capacity by means of how easily the population can be reached by emergency services or how easiliy the population can leave an emergency area on their own (see scientific report).

Economic assets play an important role in adaptive capacity. They can be used to fund and support adaptation measures and strategies (see scientific report). For the determinant ‘economic resources’ two indicators are used: the age dependency ratio and the GDP per capita. We were able to collect almost all of the data at municipal level. See appendix 1 for detailed information on the data.

Merging these indicators by averaging shows hardly any differentiation at this level. Therefore the final merging of the adaptive capacity and the potential impact into a vulnerability map on the municipal level resembles the potential impact map, but with a more smoothed pattern due to the almost uniform distribution of the adaptive capacity over the Dutch municipalities (map 22). Therefore the final classification is still to a high degree determined by the extreme exposure estimation of one single municipality (the Noordoostpolder, one of the lake IJsselmeer polders).



Map 22: Estimated potential impact (left), adaptive capacity (middle) and vulnerability (right) on the municipality scale

4. Summary and main findings

The increase of flood hazard, drought and water nuisance are recognized as the biggest challenges of the Netherlands with respect to climate change (V&W 2009). This case study focuses on flood hazard, expected to increase due to both a sea level rise as well as an increase in extreme discharges of the main rivers.

The most recent projections on sea level rise for the Netherlands cover a range of 35 to 85 centimetres for 2100 (KNMI 2006). In the case of high-end/worst-case estimates, the rise is between 130 and 150 centimetres (Deltacommissie 2008). At the end of this century the 1:1250 per year discharge of the river Rhine at the Dutch border is estimated to increase with 15-35% (Klijn, Kwadijk et al. 2010). 56% of the Dutch area, where almost 70% of the population is concentrated, is prone to flooding. Yet even in the most extreme imaginable circumstances only 34% of the area, inhabited by 37% of the Dutch population, is expected to be exposed to flooding (Kolen and Geerts 2006). Due to the more simplified DIVA approach to coastal flooding, used in the ESPON framework, the estimated hazard along the coast is fare more extensive than expected on the basis of more realistic flood models.

The sensitivity to flooding is assessed on the base of five impact dimensions:
1) physical - e.g. settlement, power plants, infrastructure
2) social – e.g. inhabitants, elderly and low educated people
3) cultural – e.g. national landscapes, historic towns and UNESCO world heritage
4) economic – e.g. jobs, livestock and farming
5) environmental – e.g. Natura 2000

The individual dimensions show different spatial sensitivity patterns. If however merged into one sensitivity indicator the spatial pattern almost fully mirrors the potential exposure pattern. The combination of exposure and sensitivity shows a potential high impact in NUTS3 regions located along the coast or close to the coastal area and, due to their expected extreme high exposure, in the Lake IJsselmeer polders. On the municipal level this pattern is more differentiated due to its higher resolution and due to the dominant effect on the classification of one single municipality (Noordoostpolder) with an estimated extreme high potential exposure.

In line with the ESPON approach, the estimation of the adaptive capacity is based on the determinants for adaptive capacity (see scientific report): a) knowledge and awareness, b) technology, c) infrastructure, d) institutions and e) economic resources on the municipal level. Merging these indicators by averaging shows hardly any differentiation at this level. Therefore the final merging of the adaptive capacity and the potential impact into a vulnerability map on the municipal level resembles the potential impact map, but with a more smoothed pattern due to the almost uniform distribution of the adaptive capacity over the Dutch municipalities. Therefore the final classification is still to a high degree determined by the extreme exposure estimation of one single municipality.

With respect to flooding the analysis shows a high sensitivity to the used hazard assessment method. Two hazard maps were compared: the Dutch scale worst credible flood map (WCF-map) and the European scale JRC-map, based on the JRC Lisflood model (A2 scenario run) for river flooding and on a DIVA approach for coastal flooding (Dankers.R. 2008) (*Barredo, J., Salamon, P., Bódis, K,* 2008.). The WCF-map contains maximum water depths for flooding, irrespective of climate change. The Lisflood map however does take into account climate change. Both maps show large differences in the estimated water depths and flood extent (among others based on differences in the flooding probability which are considered). Using the WCF-map the Netherlands appears to be less sensitive towards flooding in comparison with the JRC-map, irrespective of the used spatial scale (NUTS3 or municipalities). The DIVA approach does not take into account that the availability of water is limited in the case of a coastal flooding (mostly due to the fact that storm events take place within a limited time frame). Especially in low lying coastal areas the extent of the flooding area can be overestimated using this approach, possibly causing a biased pan-European exposure map.

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Appendix 1

Indicators

Exposure indicators:

Flood prone area by rivers and sea

Maximum water depth in the worst case scenario in six classes

Sensitivity indicators[3]:

physical:

houses

housing area*

working area*

infrastructure (road, rail, airports)*

high voltage stations

power plants

hospitals

schools (from primary to university)

High voltage centres and high voltage stations are treated in a different way. It is argued that if one of these centres or stations is exposed to flood it is sensitive in spite of the percentage of the centre that is exposed.

No distinction is made for the type of hospitals and schools.

social:

inhabitants*

elderly (households)

low educated (households)

cultural:

national landscapes

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[3] All sensitivity indicators should be read like indicator prone to flood

state monuments*

historic city and town views

archaeology areas

tentative UNESCO world heritage

UNESCO world heritage*

museums, libraries, theatres and galleries*

No distinction is made for the type of museum, libraries, theatres and galleries.

economic:

arable farming

grassland livestock

zero grazing livestock*

greenhouses*

jobs*

environmental:

nature*

natura2000*

Adaptive capacity indicators:

Educational commitment

Computer literacy

Transport

Income per capita (GDP)

Age dependency ratio

Appendix 2

The used data

Worst credible flood

Used data: risk map of the Netherlands, flood prone area.

Detailed information[4]*:*

The worst credible flood map shows the flood prone areas in the Netherlands. The map also shows the maximum water depth in the worst case scenario.

How exactly a flood takes place, depends on many factors. For many areas, computer calculations are made to show how a flood could progress. In these computer calculations assumptions are made about the location and size of a dike breach and water levels in the river or at sea. By combining the results of the calculations for each site a maximum flood depth is determined.

Lisflood H12A2

Used data: Hazard maps LISFLOOD for rivers (1:100 year flood) and hazard maps coastal flooding using 2-meter surge (1:100 year flood).

Detailed information: JRC has created separate hazard maps for coastal and fluvial flooding. The hazard maps for fluvial flooding show water depths that are supposed to result from floods with a probability of 1:100 per year (Barredo et al., 2008b). The hazard maps for coastal flooding show water depths that are supposed to result from a storm surge of 2 meter above mean sea level (Barredo et al., 2008a). (Mens, Klijn, 2009). Both maps are combined taking the maximum value from one of both.

Houses

Used data: Geomarktprofiel 2007

Detailed information: Pointdata on number of houses and inhabitants, the type and date of construction on 6-digit postal code.

Calculation: Combination (identify) with administrative areas of municipalities 2010 and the worst credible flood map which results in the number of houses per municipality that is prone to flood and the number of houses not prone to flood.

Housing area 2006

Used data: Land use survey 2006; the Land Use Base of Statistics Netherlands.

Detailed information: Land use map based on topographic map 1:10.000

Calculation: Selection on item housing area, retail, public services, socio-cultural facilities, parks and gardens. Combination (union) with administrative areas of municipalities 2010 and the worst credible flood map which results in the housing area per municipality that is prone to flood and housing area not prone to flood.

Working area 2006

Used data: Land use survey 2006; the Land Use Base of Statistics Netherlands.

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[4] source:
http://factsheet.risicokaart.nl/risicokaart/FactReportRisicoPDF.aspx?risicotype=overstroming

Detailed information: Land use map based on topographic map 1:10.000
Calculation: Selection on item working area. Combination (union) with administrative areas of municipalities 2010 and the worst credible flood map which results in the working area per municipality that is prone to flood and working area not prone to flood.

Infrastructure 2006
Used data: Land use survey 2006; the Land Use Base of Statistics Netherlands.
Detailed information: Land use map based on topographic map 1:10.000
Calculation: Selection on item road, rail, airport. Combination (union) with administrative areas of municipalities 2010 and the worst credible flood map which results in the infrastructure area per municipality that is prone to flood and infrastructure area not prone to flood.

High voltage stations 1988
Used data: Pointdata of stations (quite old)
Detailed information: doubts on quality of data
Calculation: Combination (identify) with administrative areas of municipalities 2010 and the worst credible flood map which results in the number of high voltage stations per municipality that is prone to flood and the number that is not prone to flood.

Power plants 1990
Used data: contours of power plants (quite old)
Detailed information: Very detailed contours of power plants. Checked with aerial pictures.
Calculation: Combination (union) with administrative areas of municipalities 2010 and the worst credible flood map which results in the area of power plants per municipality that is prone to flood and the area that is not prone to flood. Chosen is to use the amount of power plants prone to flood.

Hospitals 2009
Used data: Pointdata of hospitals
Detailed information: from the National institute for public health and the environment (RIVM). The data includes type of hospital and amount of beds.
Calculation: Combination (identify) with administrative areas of municipalities 2010 and the worst credible flood map which results in the number of hospitals per municipality that is prone to flood and the number that is not prone to flood.

Schools 2008 (from primary to university)
Used data: Pointdata of schools
Detailed information: key register off all educational institutes (from primary to university)
Calculation: Combination (identify) with administrative areas of municipalities 2010 and the worst credible flood map which results in the number of schools per municipality that is prone to flood and the number that is not prone to flood.

Inhabitants 2007
Used data: Geomarktprofiel 2007
Detailed information: Pointdata on number of inhabitants on 6-digit postal code.
Calculation: Combination (identify) with administrative areas of municipalities 2010 and the worst credible flood map which results in the number of inhabitants per municipality that is prone to flood and the number of inhabitants not prone to flood.

Elderly (households) 2008
Used data: Geomarktprofiel 2008
Detailed information: Pointdata on number of households and households with elderly on 6-digit postal code. Data based on questionnaire.
Calculation: Combination (identify) with administrative areas of municipalities 2010 and the worst credible flood map which results in the number of households 65+ per municipality that is prone to flood and the number of households 65+ not prone to flood.

Lower educated (households) 2008
Used data: Geomarktprofiel 2008
Detailed information: Pointdata on number of households and households with level of education on 6-digit postal code. Data based on questionnaire.
Calculation: Combination (identify) with administrative areas of municipalities 2010 and the worst credible flood map which results in the number of households with a lower level of education per municipality that is prone to flood and the number of households with a lower level of education not prone to flood.

National landscapes 2010
Used data: Definite national landscapes 2010
Detailed information: National landscapes are areas where additional government commitment is given to the conservation and development of internationally and nationally unique characteristic landscape qualities.
Calculation: Combination (union) with administrative areas of municipalities 2010 and the worst credible flood map which results in the area of national landscapes per municipality that is prone to flood and the area that is not prone to flood.

State monuments 2009
Used data: State monuments 2009
Detailed information: Pointdata with exact locations of state monuments. The dataset include only registered state monuments.
Calculation: Combination (identify) with administrative areas of municipalities 2010 and the worst credible flood map which results in the number of state monuments per municipality that is prone to flood and the number of state monuments not prone to flood.

Historic city and town views 2009
Used data: historic city and town views 2009

Detailed information: The historic city and town Map includes all areas (recent or further back) for which the procedure is launched to be designated as protected town or village view. The quality of the geometry is variable.
Calculation: Combination (union) with administrative areas of municipalities 2010 and the worst credible flood map which results in the area of historic city and town views per municipality that is prone to flood and the area that is not prone to flood.

Archaeology areas 2009
Used data: Archeological monument map 2009
Detailed information: The Archeological monument map is a digitized database of all known archaeological sites worth preserving in the Netherlands. For the analysis no distinction is made on the item archaeological quality.
Calculation: Combination (union) with administrative areas of municipalities 2010 and the worst credible flood map which results in the area of archaeology per municipality that is prone to flood and the area that is not prone to flood.

Tentative UNESCO world heritage 2010
Used data: Dutch data from the National Heritage Board
Detailed information: Properties submitted on the Tentative UNESCO List
Calculation: Combination (union) with administrative areas of municipalities 2010 and the worst credible flood map which results in the area of tentative properties that is prone to flood and the area that is not prone to flood.

UNESCO world heritage 2010
Used data: Dutch data from the National Heritage Board
Detailed information: Properties submitted on the UNESCO List
Calculation: Combination (union) with administrative areas of municipalities 2010 and the worst credible flood map which results in the area of properties that is prone to flood and the area that is not prone to flood.

Museums, libraries, theatres and galleries 2009
Used data: LISA2009
Detailed information: LISA is a database containing information on all branches in the Netherlands where paid work is done. A selection is made on sbi-codes 91021, 91011, 90041 and 91022. Locations are pointdata on 6-digit postal code.
Calculation: Combination (identify) with administrative areas of municipalities 2010 and the worst credible flood map which results in the number of museums etc. per municipality that is prone to flood and the number not prone to flood.

Arable farming 2006
Used data: Land use satellite map (LGN) 2006.
Detailed information: In the (very detailed) data the main agricultural crops are distinguished. Data are combined on topographic map 1:10.000
Calculation: Selection on item corn, potatoes, beets, cereals, bulbs, other crops. Combination (union) with administrative areas of municipalities 2010 and the

worst credible flood map which results in arable framing area per municipality that is prone to flood and area not prone to flood.

Grassland livestock 2006
Used data: Land use satellite map (LGN) 2006.
Detailed information: In the (very detailed) data the main agricultural crops are distinguished. Data are combined on topographic map 1:10.000
Calculation: Selection on item grassland farming. Combination (union) with administrative areas of municipalities 2010 and the worst credible flood map which results in grassland framing area per municipality that is prone to flood and area not prone to flood.

Zero grazing livestock 2008
Used data: pointdata with the location of zero grazing livestock farms 2008
Detailed information: Data contains 'NGE' (Nederlandse grootte-eenheid); a measure that represents the economic size of agricultural activities (1 NGE ~ €1.400).
Calculation: Combination (union) with administrative areas of municipalities 2010 and the worst credible flood map which results in zero grazing livestock NGE per municipality that is prone to flood and NGE not prone to flood.

Greenhouses 2006
Used data: Land use survey 2006; the Land Use Base of Statistics Netherlands.
Detailed information: Land use map based on topographic map 1:10.000
Calculation: Selection on item working area. Combination (union) with administrative areas of municipalities 2010 and the worst credible flood map which results in the working area per municipality that is prone to flood and working area not prone to flood.

Jobs 2009
Used data: LISA2009
Detailed information: LISA is a database containing information on all branches in the Netherlands where paid work is done. An item with jobs per branch is available. Locations are pointdata on 6-digit postal code.
Calculation: Combination (identify) with administrative areas of municipalities 2010 and the worst credible flood map which results in the number of jobs per municipality that is prone to flood and the number not prone to flood.

Educational commitment
Used data: Percentage of total labour force that is higher educated per municipality in period 2007 – 2009 (statline CBS).
Detailed information: The total labour force and the education level of the labour force are known per municipality. This data is used as a proxy for the education level of the population.
Calculation: Per municipality the percentage is calculated using the absolute labour force figures. If figures are unknown, the national average is assigned. The range is from 0% to 62%. The average is 26%. The percentages are

normalized based on the assumption that the lower the percentage higher educated labour force, the higher the contribution to the final vulnerability.

Computer literacy

Used data: Percentage of DigID owners by municipality 2009 (statline CBS).

Detailed information: DigID is a digital identity which people can use as digital login code to official sites (for instance for paying taxes) of the government (state and local). This data is used as a proxy for computer literacy.

Calculation: The percentage of DigID owners per municipality is known. The percentages are normalized based on the assumption that the lower the percentage of DigID owners, the higher the contribution to the final vulnerability.

Transport

Used data: Length of road 2010 (statline CBS).

Detailed information: The total length of roads owned by state, province or municipality where motor traffic on more than two wheels is allowed.

Calculation: The total length of roads is divided by the total population per municipality. The results are normalized based on the assumption that the lower the length of roads per inhabitant, the higher the contribution to the final vulnerability.

Income per capita (GDP)

Used data: Regional accounts, key figures 2008 (statline CBS).

Detailed information: The gross domestic product (GDP) is the result of the production activity of resident producer units. It is equal to the value added at basic prices of all business classes together. The value added (basic prices) per business class is equal to the difference between production (basic prices) and intermediate consumption (purchase). The GDP per capita GDP is divided by the average population of Netherlands or region during the reporting period (CBS).

Calculation: The figures are given per NUTS3 region. Every NUTS3 region consists of municipalities. The municipalities inherit the NUTS3 figures. The results are normalized based on the assumption that the lower the income per capita, the higher the contribution to the final vulnerability.

Age dependency ratio

Used data: Grey pressure (65 + compared to 15-64 years) [%] in 2010 (ABF, combimonitor, CBS population statistics).

Detailed information: The age dependency ratio is calculated using detailed population statistics.

Calculation: The results are normalized based on the assumption that the higher the age dependency, the higher the contribution to the final vulnerability.