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Increasing flood exposure in the Netherlands: implications for risk financing

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Abstract. The effectiveness of disaster risk management and financing mechanisms depends on an accurate assessment of current and future hazard exposure. The increasing availability of detailed data offers policy makers and the insurance sector new opportunities to understand trends in risk, and to make informed decisions on ways to deal with these trends. In this paper we show how comprehensive property level information can be used for the assessment of exposure to flooding on a national scale, and how this information provides valuable input to discussions on possible risk financing practices. The case study used is the Netherlands, which is one of the countries most exposed to flooding globally, and which is currently undergoing a debate on strategies for the compensation of potential losses. Our results show that flood exposure has increased rapidly between 1960 and 2012, and that the growth of the building stock and its economic value in flood-prone areas has been higher than in non-flood-prone areas. We also find that property values in flood-prone areas are lower than those in non-flood-prone areas. We argue that the increase in the share of economic value located in potential flood-prone areas can have a negative effect on the feasibility of private insurance schemes in the Netherlands. The methodologies and results presented in this study are relevant for many regions around the world where the effects of rising flood exposure create a challenge for risk financing.

1 Introduction

Flooding of river and coastal systems is the most frequent and damaging natural hazard affecting countries across the globe (UNISDR, 2011), with average annual economic losses in excess of USD 40 billion per year between 1980 and 2012 (Munich Re, 2013). For many world regions, research suggests that the main driver of increases in observed flood losses over the past few decades is increased physical and economic exposure (i.e. the assets and values located in flood-prone areas), due to the growth of population and wealth in flood-prone areas (e.g. Field et al., 2012; Bouwer, 2013; Hallegatte et al., 2013; Jongman et al., 2014). The increasing costs of flood disasters have large negative economic and political consequences in many countries (Bouwer et al., 2007; Mechler et al., 2010), and challenge the public and private sectors to develop robust insurance systems and risk reduction mechanisms (Mills, 2005; Michel-Kerjan and Kunreuther, 2011; van Renssen, 2013; Jongman et al., 2014). A growing base of detailed data on past trends and future projections are available to support decisions on the implementation of these instruments.

The accuracy of flood hazard information has improved greatly over time, with climate change projections (e.g. Lawrence et al., 2013) and inundation models (e.g. Neal et al., 2013) becoming progressively more detailed. Several studies (e.g. Apel et al., 2009; Aerts et al., 2013) have shown that these detailed hazard models can be combined successfully with detailed building-level exposure data, to provide valuable flood risk estimates on a local scale. Because of the limited data availability and the high computing power required, these comprehensive analyses have thus far not been extended beyond the level of cities or small regions. In many countries, however, decisions on disaster risk reduction and risk financing are made on both a national (Meyer et al., 2013) and international (van Renssen, 2013) level, on the basis of expected risk trends in addition to estimates of current risks. For these decisions, policy makers have so far relied on relatively coarse risk analyses using aggregated land-cover

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information, representing the predominant land cover type or population density in a certain area (e.g. Bouwer et al., 2007; Nicholls et al., 2008; De Moel et al., 2011; Te Linde et al., 2011; Jongman et al., 2012a; Poussin et al., 2012; Rojas et al., 2013; Koks et al., 2014). Since using aggregated land-use data for risk assessment leads to substantial uncertainty (De Moel and Aerts, 2011; Jongman et al., 2012b), and because disaster risk insurance policies are often linked to individual properties (e.g. Mills, 2005), these projections are limited in their ability to support risk financing decisions.

In this paper we show how detailed property level data can be used to improve the understanding of trends in flood exposure on a national level, and how this knowledge can be used to inform public and private risk financing decisions. We demonstrate this for the Netherlands, a country that faces high flood exposure and is currently debating important changes in its risk financing policies. We use a newly released data set covering 8.9 million individual properties to present a trend analysis of physical and economic flood exposure for the period 1960–2012. The main goals of this study are to estimate trends in the physical and economic exposure to flooding using detailed property level data; and to show how these findings can enhance decision making on flood risk financing on a national scale. In addition, we address the opportunities offered by the increasing availability of detailed exposure data sets compared to more aggregated information in disaster risk assessment throughout the analysis.

2 Flood risk management in the Netherlands

2.1 Flood risk and flood protection

The Netherlands has been subject to flooding throughout its existence. A major event in 1953 resulted in the loss of 1835 lives, after a strong storm surge breached coastal defences. In 1993 and 1995, exceptionally high water levels in the Meuse and Rhine led to flooding of unembanked areas and the evacuation of 250 000 people. Over time, upgrades of flood protection measures have been implemented in several steps. The current safety levels, measured in terms of the occurrence probability of floods the defences are designed to withstand, range from 1/250 to 1/11 250 years along the main rivers, and 1/4000 to 1/10 000 years along the coasts (Wesselink et al., 2013). Flood protection standards are generally higher in areas with high population density and potential losses (Kind, 2013). In comparison, protection levels up to 1/100 years are typical in most other developed countries (Wesselink et al., 2013). As a result of the high protection standards provided, population growth and economic progression has been able to continue, making the Netherlands one of the countries with the highest potential exposure to flooding globally (Jongman et al., 2012a). Currently, an estimated six million people are living in flood-prone areas, producing one-third of the country's GDP (CBS, 2009). A recent evaluation of 3767 km of dikes, dams, and dunes, however, showed that an estimated third of all embankments do not meet their nominal protection standards, and might have failure probabilities 10 times higher than designed (Atsma, 2011). In addition to this, an estimated 115 000 people are currently living in so-called outer dike areas, which are the areas between the water and the embankments and which are thus more prone to flooding (De Graaf and Van de Veerdonk, 2012).

2.2 Current risk financing practice

The 1953 and 1993/1995 floods, as well as several smaller local events in recent years, have shown that flooding remains a threat, highlighting the need for a system to manage and finance damage should a flood occur. There are various systems in use across Europe to finance potential flood losses, ranging from fully private insurance systems (e.g. United Kingdom) to public–private partnerships (e.g. France) and fully public schemes (e.g. Switzerland) (Paudel, 2012). In the Netherlands, ex post compensation payments to cover flood losses follow a legal arrangement, and are financed by the government from general tax revenues (De Vries, 1998). This means that all tax payers contribute to flood losses relative to their tax burden, irrespective of their location of residence. The main disadvantages of the current system are that people are not incentivised to undertake precautionary measures (Clark, 1998; Pearce and Smale, 2005; Botzen et al., 2009a) and that the guidelines for compensation payments are ambiguous and depend on political will (Botzen and Van den Bergh, 2008; Van Vliet, 2012; Van Vliet and Aerts, 2014). Under the current guidelines, compensation only applies if the government classifies the specific event as a "disaster", in which case officially only people living in embanked areas will be compensated (De Vries, 1998; De Moel et al., 2013). However, multiple studies have shown that flood hazard is poorly communicated. Some people living in outer dike areas do so in government-constructed neighbourhoods, and are often not aware of the hazard they face or the different compensation rules that in theory apply to their properties (De Boer et al., 2012). These people cannot be expected to have taken precautionary measures and, even though the national government is officially not accountable for damages when a flood occurs, it still provides compensation in many cases (Van Vliet and Aerts, 2014).

2.3 Private flood insurance

Private insurance with risk-based premiums can be efficient in its capacities to share the losses and incentivise risk reduction (Adam, 2013; Botzen, 2013). A variety of different flood insurance schemes are in use throughout Europe. These include private insurance systems, public–private partnerships and full public compensation schemes. For a discussion on these different practices, see Botzen (2013); Schwarze et al. (2011); and Paudel (2012). Even though offering flood insurance contracts is allowed by the Dutch government, such products were not offered for decades until the year 2012, when an optional private flood insurance scheme was launched[1]. This flood insurance, however, was criticised for its expensive premiums in high-risk areas, and its limited payouts per property (EUR 75 000 maximum). At the end of 2012, the Dutch Insurance Alliance presented a new plan for a compulsory national flood insurance scheme, which would be imposed as an added tax of "a few Euros" upon the contents insurance of every household starting as of 1 January 2014[2]. The total maximum possible payout under this scheme has been proposed at EUR 5 billion which, according to the Insurance Alliance, should be enough to cover all property damage up to EUR 250 000. Critics say that the damage of an event in the Netherlands could easily reach a multiple of the proposed EUR 5 billion and that the maximum payout per household under current impact scenarios could be as low as EUR 12 500[3]. In June 2013, the national Consumer and Market Authority (ACM) gave negative advice with regard to such a mandatory insurance scheme, because the scheme would not allow sufficient competition between market players. An official decision has not yet been taken by early 2014.

2.4 Assessing flood exposure

With economic growth expected to continue, climate change potentially leading to more extreme water levels, and the maintenance standard of protection barriers being questioned, the question of to what extent Dutch population and assets are exposed to flooding is increasingly relevant for redesigning risk financing policies. Historical trends in flood exposure are important for understanding the current risk and anticipating what might happen in the future. Van der Klis et al. (2011) present trends in risk for the period 1950–2005, using economic growth figures to adjust current flood risk estimates backwards over time, but do not account for spatial variations in risk patterns. De Moel et al. (2011) present a method that does have a spatial component, and estimate trends in exposure between 1900 and 2000 (as well as projections up to 2100) using historical, current and projected land-use maps. An important limitation of this method is that the aggregated land-use classes inadequately allow for varying density and use of buildings across the country, which might lead to significant estimation errors (Jongman et al., 2012b). In addition, these previous exposure analyses could not be linked to individual properties, while risk financing schemes are largely based on property level contracts. In this paper we analyse trends in flood exposure using property level data, and demonstrate relevant information for risk management that can be extracted from these data.

3 Methods and data

We analysed trends in flood exposure in the Netherlands using property level data. First, we divided the Netherlands into five distinctive flood hazard zones. Second, we combined different spatial databases into one national data set of properties, their use and characteristics, and an estimate of their value. Finally, we analysed the trends in flood exposure over time, as well as the distribution of property values in the defined hazard zones. Each of these steps is described in the following sections.

3.1 Flood hazard zones

The majority of the flood-prone areas in the Netherlands are divided into 95 *dike rings*, protected by embankments designed to withstand water levels expected to occur every 250 to 10 000 years. There is also development in the outer dike areas, located between the dike and the water bodies. Some of the dike rings and outer dike areas have experienced flooding in past decades, such as during the 1953 coastal flooding, and the 1993 and 1995 Meuse floods in the southeastern province of Limburg.

For this study we have split the Netherlands into five distinctive flood hazard zones:

1. outer dike;
2. 1953 flooded;
3. 1993/1995 flooded and evacuated;
4. protected flood-prone; and
5. non-flood-prone (Table 1; Fig. 1).

Both the 1953 flooded areas and the 1993/1995 flooded and evacuated areas have previously experienced flood events, which could have affected trends in flood exposure after those events. Protected flood-prone areas are potentially subject to flooding but have not been affected in recent times. These protected flood-prone areas are based on the Risicokaart Nederland (Risk map of the Netherlands). This aggregated flood depth map, published in 2008, represents the

[1] Overstromingsschade na 59 jaar weer verzekerbaar ("Flood risk insurable once again after 59 years"). Press release, http://www.eigenhuis.nl/actueel/pers/2012/overstromingsschade-woning-verzekerbaar/ (in Dutch) (2013).

[2] Collectieve dekking van overstromingsrisico ("Collective coverage of flood risk"). Press release, https://www.verzekeraars.nl/actueel/nieuwsberichten/paginas/collectieve-dekking-van-overstromingsrisico-.aspx (in Dutch) (2012).

[3] Vrijwillige en concurrerende overstromingsverzekering in plaats van verzekeraarscartel ("Voluntary and competitive flood insurance instead of insurance cartel"). Press release, http://www.eigenhuis.nl/actueel/pers/2013/379909-vrijwillige-overstromingsverzekeringen-verzekeraarskartel/ (in Dutch) (2013).

Table 1. Overview of the hazard zones and their sources as used in this study.

ID	Name	Description	Source
	Flood hazard zones used in this study		
1	Outer dike	Areas located between flood defences and major rivers	Constructed by the authors using the spatial locations of embankments and rivers
2	1993/1995 flooded and evacuated	Areas flooded or evacuated during the 1993 and/or 1995 floods	Rijkswaterstaat Limburg; for details see Ward et al. (2011)
3	1953 flooded	Areas flooded during the 1953 flood	Constructed by the authors based based on Deltawerken*
4	Protected flood-prone	Areas prone to flooding but protected by flood defences	Based on the publicly available Risicokaart ("Risk Map") (De Moel et al., 2011; Waterdienst, 2008). Excludes potentially flood-prone areas in Limburg.
5	Non-flood-prone	Areas not prone to flooding.	Constructed by the authors, consisting of all areas not part of any of the other categories

* Constructed based on visual data available at: http://www.deltawerken.com/25 (last access: March 2013).

most recent information of the potential maximum flood inundation levels in the Netherlands (Wouters and Holterman, 2007; Waterdienst, 2008). There is a degree of overlap between hazard zones 1, 2 and 3 (Table 1), which results from the fact that some areas that are classified as "outer dike" were also flooded in 1953 or 1993/1995. In areas where that is the case, the area was assigned to the hazard zone with the highest potential hazard (e.g. areas evacuated in 1995 that are also protected by dikes are assigned to hazard zone 2). The reasoning is that we aimed to list the areas from expected high to low perceived flood hazard, and identify differences in exposure trends and property values amongst these areas. We assumed the flood hazard zones to have stayed constant over the period of analysis, meaning that any change in flood exposure results from the change in property stock within these given zones.

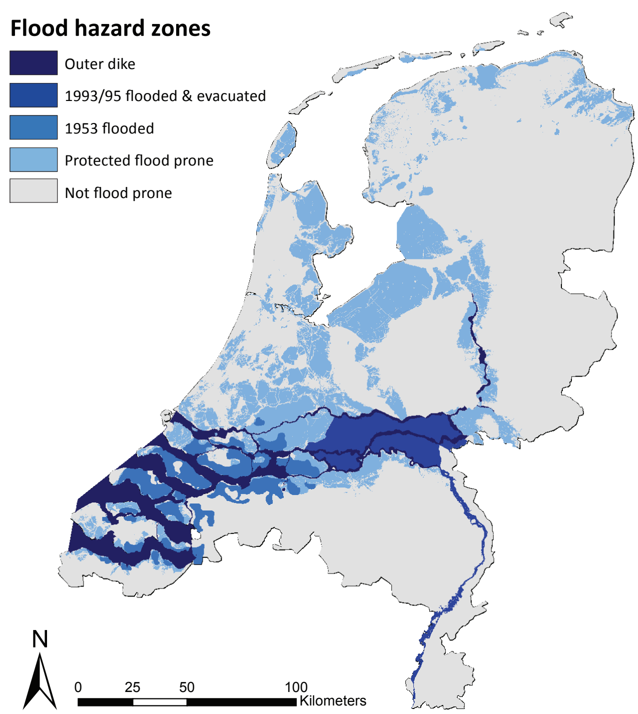

Figure 1. Map of the flood hazard zones. Note that there is a slight overlap between some of the hazard zones, in which case the area is assigned to the hazard zone with the lowest number (see Table 1).

3.2 Exposure data

3.2.1 Property data

Since the approval of the 2008 national law "Basisadministratie Adressen en Gebouwen" (BAG; Registration of Addresses and Buildings), Dutch municipalities are responsible for the collection of specified attributes of all of their buildings, and store these in a common database. The resulting database includes various indicators at the level of buildings, as well as individual addresses within those buildings, for the entire country. For over 8.9 million individual addresses, the database lists several factors, including: the use (e.g. residential/commercial), the surface area (defined as the total floor space of the property), and the year of construction. Recent open data initiatives of the Dutch government have led to the national aggregation and public distribution of a selection of the BAG database. While municipalities are still the official source holder of the data, it is now nationally distributed by the national real estate organisation Kadaster[4]. The data are free for government and non-profit organisations. For this study we used a spatially explicit version of the database, containing geographical coordinates for each of the registered addresses. From this point on, we refer to the addresses as "properties".

[4]Database available at: http://www.kadaster.nl.

3.2.2 Real estate values

In addition to the number of properties potentially exposed to flooding, we have also estimated their economic value using national property value data. The estimated value of properties is used for various taxation purposes in the Netherlands. Since 1994, municipalities have been responsible for assessing and registering the value of all properties in their jurisdiction. This so-called WOZ (*Wet Waardering Onroerende* Zaken, "Law Valuation Real Estate") value is estimated using a combination of methods, based on: the selling price of similar properties in the vicinity; the value of the underlying land corrected for investments; the expected future rental payments; and/or the estimated future cash flows of the organisation occupying the property (Waarderingskamer, 2005). The WOZ values are market values, and are thus similar to the sale price of the properties, excluding contents. The availability of these detailed property market values has two main advantages for this study. First, the market values are strongly related to potential damage and thus potential insurance claims (Bin et al., 2008; Botzen et al., 2009b). Market values are a good proxy for potential damages, because people who can afford an expensive house, tend to have more expensive interiors and possessions (e.g. expensive floors and electronics) as well. However, this relationship is not perfect and the use of market values has some limitations (see Sect. 3.3.3). The second advantage of using market values, is due the fact these values partly result from location preferences of buyers, and may therefore reflect their perception of flood risk (Bosker et al., 2013). For our analysis, we used a spatial data set with average property values per hectare for the year 2011[5]. Values are available for most hectare plots in the Netherlands, except for the areas where too few data points are available to make a reasonable estimate and for plots with fewer than 10 residents, where average property values could be traced back to individual properties.

3.3 Analysis

3.3.1 Exposure assessment

We constructed and combined data sets on flood hazard zones, individual properties and real estate values in order to estimate property values in hazard zones and identify trends in exposure between 1950 and 2012. The first step in this process was to convert the hazard zone and real estate value areas into raster grids with cells of 100 m × 100 m. Then, we spatially linked these grids with the property point data and created one data set by assigning a hazard ID to each of the 8.9 million addresses, corresponding to the five flood hazard zones. Subsequently, we overlaid the property data with the data set of average economic property values, and assigned an average value to each of the properties where data were available. Finally, we analysed the stock of properties located in the various flood hazard zones and estimated the physical and economic exposure for each year and property use. In this analysis we assumed that properties were constructed in the building year specified in the property data and that no properties have been demolished or replaced. In addition, we estimated trends in exposed economic value using the estimated property value for 2011, assuming that relative property values are geographically distributed similarly between 1960 and 2011.

[5]Database available at: http://www.cbs.nl/nl-NL/menu/themas/dossiers/nederland-regionaal/publicaties/geografische-data/archief/2013/2013-kaart-vierkanten-art.htm (2013).

3.3.2 Property value distribution

The high spatial resolution of property level data allows for the analysis of the distribution of property values across the different flood hazard zones. Information on the value distribution can be important for risk financing strategies. In many private insurance schemes, including the national compulsory scheme being considered for implementation in the Netherlands, both the premiums and expected payouts are linked to the value of the property and contents. If properties in exposed areas are, on average, of higher value than those in non-flood-prone areas, this imposes an additional financing risk on the insurer, and vice versa. We used the property level data to assess the distribution of residential property values across the defined flood hazard zones. Within each hazard zone, we derived value distributions both on the basis of the total economic values for each individual property, as well as the average value per square metre of floor space. We then analysed the frequency distribution of property values across the hazard zones. Finally, we applied a non-parametric two-sample Mann–Whitney U test (Lehmann, 2006) to test whether the computed median property values in flood-prone areas are significantly different from the median property values in non-flood-prone areas.

3.3.3 Assumptions and limitations

In carrying out the analyses, a number of assumptions were made. First, we used the available construction year to estimate the total number of properties located within a given hazard zone in a given year. In doing so we assumed that no old properties have been removed or replaced by newer ones, which means that we might underestimate the property stock in the earlier years for areas where replacement did occur. Second, we assume the hazard zones to have remained constant over time. In reality, artificial changes to river beds, land subsidence, and climate change might have slightly altered potential inundation areas over time (Bouwer et al., 2010). Third, we estimated trends in exposed economic value using the estimated property value for 2011, assuming that relative property values are geographically distributed similarly between 1960 and 2011. In reality the property value in some areas may have increased more than in others, leading to overestimation or underestimation of economic exposure in certain areas. Fourth, the property values represent market values of properties. Although these are directly linked to potential damages and compensation payments (Botzen et al., 2009b; Bin et al., 2008), this relationship does not always hold. The actual financial risk also depends on other factors, including specific content value and repair costs. Thus, some expensive houses may not have higher repair costs than cheaper houses after a flood, and market values may not be an accurate representation of financial risk in those cases. For this reason we largely focus on relative trends in risk rather than absolute estimates, since risk changes are known to be less uncertain than absolute monetary values (Bubeck et al., 2011). Finally, not all data are available for all properties. This especially applies to the property values that, for privacy and statistical reasons, are obtained for only 80.8 % (7 197 683) of the properties used in this analysis. We based our analysis on these available data.

4 Results and discussion

We discuss the results of the analysis in three parts. In Sect. 4.1 we present an analysis of trends in physical and economic flood exposure. In Sect. 4.2 we examine the distribution of property values across the different flood hazard zones. In Sect. 4.3 we discuss the implications of the findings for risk financing in the Netherlands.

4.1 Floodplain development in the Netherlands

4.1.1 Physical exposure

We constructed an index for each hazard zone to analyse the relative changes in exposure between 1960 and 2012. The results show that the total number of properties in the Netherlands has increased by 216 % during this period, which equals an annual average growth of approximately 2.3 %. In 2012, an estimated 2.3 million properties were located in flood-prone areas, compared to 6.5 million in the rest of the country (Fig. 2). On a national level, we found that the growth of property stock in flood-prone areas has been larger than growth in non-flood-prone areas. This is in line with earlier findings of De Moel et al. (2011), who used historical geographical maps to show that urban expansion rates in flood plains are greater than urban expansion rates in non-flood-prone areas. This trend, however, is not visible in all regions. In Austria for example, asset growth in flood-prone areas has been slower than in areas not prone to flooding (Cammerer and Thieken, 2013). A possible explanation could be that the higher flood protection standards, and thus lower flood probabilities, in the Netherlands have resulted in a stronger sense of safety and thus relatively more development in flood-prone areas (the so-called “levee effect”, see Di Baldassarre et al., 2009; Lane et al., 2011; Husby et al., 2014).

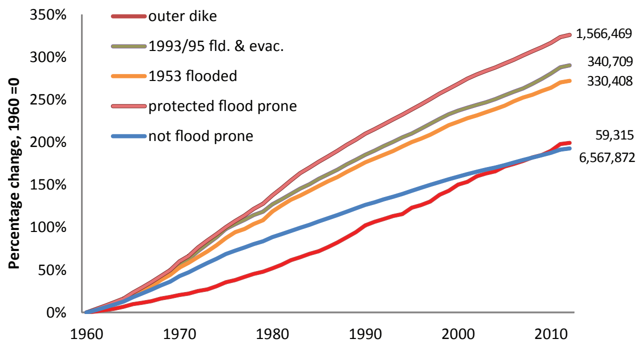

Figure 2. Relative changes in the number of exposed properties per hazard zone, between 1960 and 2012. The absolute labels present the count of properties in each hazard zone in 2012.

The largest relative increase in the number of exposed properties between 1960 and 2012 is found in protected flood-prone zones (326 %), whilst the increase in non-flood-prone areas over the same period is only 193 % (albeit from a higher baseline). Outer dike areas still host only a small share of the total property stock, although they have experienced the highest relative growth rate of all hazard zones since the 1970s. The total surface area of all properties in all flood-prone areas has increased by 328 % since the 1960s, compared to 208 % in non-flood-prone areas. The share of the surface area of properties located in flood-prone areas, as a percentage of the national total, increased from an estimated 20 % in 1960 to over 26 % in 2012. Figure 2 shows that the relative increase in surface area in protected flood-prone areas was higher than the relative increase in the areas affected by the 1953 and 1993/1995 floods over the period of analysis. A likely explanation is a difference in economic activity and population growth between these areas. Protected flood-prone zones host a number of expansion areas around major urban centres, while the 1953 and 1993/1995 areas are largely characterised by lower population densities and levels of economic activity.

Using historical land-cover maps, De Moel et al. (2011) found an increase in exposed urban area in the Netherlands of around 150 % in the period 1960–2010, which is more than 50 % lower than our estimates. To assess the effect of using property level data instead of aggregated land-use data, we compared changes in urban land cover from the data used by De Moel et al. (2011) to our property level results for the period 1960–2010. The results (Fig. 3) show several patterns. First, we see that increases in urban area in flood-prone areas have been higher than in non-flood-prone areas, both when computed using property data and surface area data. Second, the figure clearly shows that the total property surface area located in flood-prone areas is increasing continuously, even while the total area classified as “urban” in the aggregated data set stabilises. This is because the aggregated land-use data only account limitedly for changes in property density

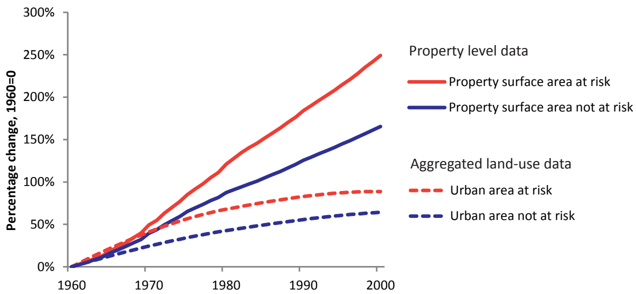

Figure 3. Comparison of trends in property surface area, estimated using the property level database, and aggregated data on historical urban land-cover (Knol et al., 2004). The figure shows that while the total urban area has stabilised over time, the property area at risk shows a continuous increase. This demonstrates that risk analysis using aggregated land-use information does not account for increases in urban *density* and thus might underestimate trends in exposure.

in areas already classified as urban, and can therefore significantly underestimate the true exposure (Jongman et al., 2012b). This emphasises that property level data provide a more realistic representation of trends in exposure, and that risk assessment can benefit greatly from the use of this information.

4.1.2 Economic exposure

We combined the property data with a data set on estimated current property values in order to estimate the economic value of exposed properties. The total estimated value of the properties with available data in flood-prone areas is EUR 409 billion at 2011 property prices, which represents 25 % of the total value of all properties. Of the total property value in hazard zones, 68 % are located in general protected areas, 16 and 14 % in areas affected by the 1993/1995 and 1953 floods respectively, and 2 % in outer dike areas. Since 1960, the total value of the property stock (in 2011 prices) has increased by 329 %, which is almost exactly the same as the relative increase in surface area and property count. This indicates that the current value of properties is not directly related to the construction year of that unit. The breakdown in exposed property values over the different hazard zones also shows a pattern very similar to that in Fig. 2. The largest relative growth in exposed economic value between 1960 and 2012 is seen in general protected flood-prone areas (350 %), the 1953 flooded areas (301 %) and the 1993/1995 affected zones (297 %). The increase in non-flood-prone areas is 187 %, although in absolute terms this still represents the largest share of increased economic exposure.

The growth of property value in outer dike areas totalled 197 % over 1960–2012, which is low compared to the other hazard zones. However, the results show that the rate of exposure in outer dike areas increases after 1970 (similar to Fig. 2). All other identified zones show a decline in the rate of exposure growth, which means that the share of assets located in high risk outer dike areas is increasing. A large share of the increase can be explained by expanding commercial and industrial areas in outer dike areas. About 27 % of the growth in the number of outer dike properties and their value is a result of increases in industrial, commercial and "other" properties, with the other 73 % resulting from an increase in the number of residential properties. In the other hazard zones, the increase in the number of residential properties accounts for 85–88 % of the total increase. Across all property uses and hazard zones, the share of total property value located in flood-prone areas relative to the total value increased from 18 % in 1960 to over 25 % in 2012. This trend has mainly been driven by the relatively strong increase of residential value in flood-prone areas compared to non-flood-prone areas. The total value of properties with industrial, office or other uses has also increased strongly in flood-prone areas but at a slower pace than the growth in residential property stock.

As a percentage of Dutch GDP, the total exposed property value fluctuated from 77 % in 1960 to 89 % in the mid-1980s and back to 73 % in 2011. This fluctuation indicates that exposure has been growing more rapidly than economic growth in some periods while being in line with growth in other time periods. This confirms conclusions from studies on global (e.g. Jongman et al., 2012a), European (e.g. Barredo, 2009) and national (e.g. Husby et al., 2014) scales, which find that the growth of population and assets in flood-prone areas can often be higher than average national growth. This trend is likely to be caused by the water-side location of many important cities, which generally see a stronger growth than rural areas as countries become more urbanised. In the Netherlands, this is represented by the extensive growth of the agglomeration of Rotterdam, most of which is located in flood-prone areas.

4.2 Property value distribution

The property level data not only allow for analysing the trends in exposure across flood hazard zones, but also for assessing possible differences in property values across these regions. Figure 4 shows the relative distribution of economic values of residential properties per hazard zone. The figure illustrates that property values in all hazard zones are negatively skewed (i.e. the distributions have a long tail to the right). The median property values range from EUR 184 000 (outer dike) to EUR 216 000 (1953 flooded). Outer dike property values show a distribution with more values in lower ranges, compared to the other hazard zones. On the other hand, non-flood-prone areas host more properties with very high values: in non-flood-prone areas about 0.3 % of the properties have a value of EUR 750 000 or higher, compared to only 0.001 % (outer dike) to 0.02 % (protected flood-prone) for the properties in the other hazard zones.

Table 2. Results of a two-sample non-parametric Mann–Whitney U test of property (WOZ) values for residential properties. The table shows relative and absolute differences of the median property values of each hazard zone, with the median property values of non-flood-prone areas. The p values are all beyond the 99 % confidence interval.

	Property value per square metre			Total property value		
	Median difference with non-flood-prone			Median difference with non-flood-prone		
Hazard zone	Relative	Absolute	p value	Relative	Absolute	p value
Outer dike	−6 %	EUR −121	2.6×10^{-26}	−12 %	EUR −25 000	0
1953 flooded	−1 %	EUR −23	2.1×10^{-3}	3 %	EUR 7000	6.6×10^{-10}
1993/1995 flooded and evacuated	−4 %	EUR −74	2.7×10^{-16}	−6 %	EUR −12 000	5.6×10^{-45}
Protected flood-prone	−2 %	EUR −35	2.5×10^{-3}	−5 %	EUR −11 000	5.9×10^{-30}

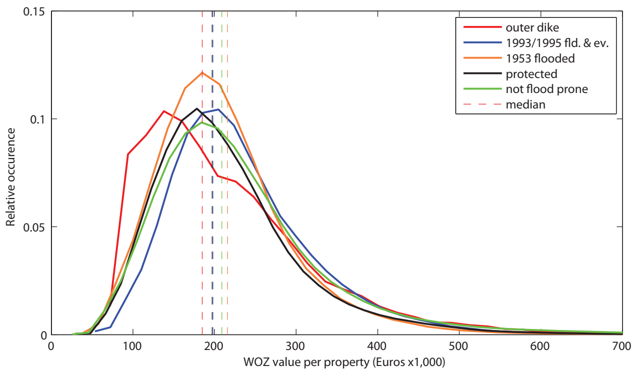

Figure 4. Frequency distribution of property (WOZ) values per square metre for residential properties, split into the five hazard zones. The dashed lines represent the median values.

Part of the difference in property values could be attributed to variation in the size of the properties under analysis. We used the available surface area of floor space per property data to control for this, and analysed the value per square metre of residential properties across the country. The distribution of property values per square metre is similar to the pattern illustrated in Fig. 4. The median varies from EUR 1895 (outer dike) to EUR 2031 (non-flood-prone). Non-flood-prone areas host a large share of properties with higher values per square metre compared to the other areas and consequently have the highest median value per square metre. To judge whether or not the property values in the different hazard zones follow the same distribution, we conducted a non-parametric two-sample Mann–Whitney U test (Lehmann, 2006). The results of this test (Table 2) show that the median residential property values in all hazard zones are significantly lower than the median residential property value in non-flood-prone areas. The p values are very low and stay well beyond 99 % significance level even when we remove high property values (> EUR 500 000) from the sample. This is consistent with earlier findings of Bosker et al. (2013), who also found a significant difference in residential house prices in some flood-prone areas of the Netherlands. Different processes could be underlying this outcome. Visual inspection of the data shows that many of the properties with high values are located in non-flood-prone areas of the cities of Amsterdam, the Hague and Utrecht. The fact that many of the centres of larger cities, which are often characterised by relatively high property prices, are located on higher ground seems to contribute to the findings.

4.3 Implications for flood risk financing

The practice of flood risk financing in the Netherlands is currently at a turning point, as private insurance schemes are being implemented after 60 years of public compensation. The results in Sect. 4.1 show that much has changed in flood exposure during this period. The number of properties in potentially flood-prone areas has increased by more than 300 %. The value of properties is directly linked to premiums and potential damages (e.g. Botzen et al., 2009b). While the data indicate a lower average property value in flood-prone areas compared to non-flood-prone areas, the total value of exposed properties has increased about threefold in absolute terms, as well as on an average per capita basis. As a percentage of GDP, the value of properties in flood-prone areas has fluctuated between 70 and 90 % (with no clear trend) under the influence of urban expansion and GDP development. As a percentage of the total national property value, the exposure has grown from 18 % in 1960 to 25 % in 2012. Given that the design standards of flood protection have stayed relatively constant over the decades, this has important implications for the financing of flood risk.

For a fully public flood damage compensation scheme, like the one The Netherlands has known since 1960, the increase in relative value at risk means that the expected compensation costs in constant prices have risen sharply over the decades, both in absolute and per capita terms. A given flood event in 2012 would lead to substantially higher losses per taxpayer than was the case in 1960, assuming that the government also provides compensation to residents in outer dike areas. To account for this, larger budgets need to be reserved to cover possible losses in the case of a flood event. Since the exposure as a percentage of GDP has not increased, but rather fluctuated over the decades, the financial capacity of the government to cope with the increasing exposure (Mechler et al., 2006) does not seem to have changed much.

The results of our analyses provide mixed signals for the feasibility of the proposed private insurance scheme operating under the solidarity principle. On the positive side, we have shown that median property values in flood-prone areas are lower than those in non-flood-prone areas. With both the premiums and expected compensation payments linked to property and content values, this will have a small positive effect on the long-term balance sheet of insurance companies. However, this fact is contrasted by the continuing increase in the relative value at risk, due to the larger growth of property value in flood-prone areas compared to non-flood-prone areas. Over time, this will lead to increasing expected payouts relative to the number of clients. This means that the total financial risk is growing and premiums would have to rise accordingly. In addition, financial regulations will require the insurer to keep an increasing amount of capital, or access to more reinsurance funds, to reduce the risk of insolvency (Jongman et al., 2014). Under the European Union Solvency II Directive, which has come into effect from 1 January 2014, insurers are obliged to keep a capital stock sufficient to cover all claims they expect to face with a probability up to 99.5 % (European Commission, 2008). As an increasing share of the total property stock is located in flood-prone areas, the loss with a 99.5 % probability is increasing relative to the number of clients. Insurance companies will consequently need to hold more capital stock, either by increasing their own capacity or through reinsurance. This changing environment could in time deteriorate the profitability of insurance companies in the solidarity-based insurance market.

In addition, the uncertainty in the current safety level offered by flood protection measures (Atsma, 2011), already has implications for current insurance premiums[3]. Future premiums may fluctuate strongly as more information on the state of the embankments becomes available. In the United Kingdom, similar concerns have led to a “gentlemen’s agreement” between government and the insurance sector, in which the government agreed to keep investing in flood protection to secure affordable insurance for everyone at risk (Surminski and Eldridge, 2014). In the Netherlands too, the government will have an important role in maintaining an affordable flood risk financing system in the Netherlands, either in a public or private insurance system.

5 Conclusions

In this study we presented trends in flood exposure on a national scale for the Netherlands, which were estimated using a detailed property level data set, and compared the results to the use of aggregated data. The results show that exposure to flooding has increased by over 300 % in the last 50 years, both in terms of the number of properties and their estimated current value. We also show that median property values in flood-prone areas are significantly lower than those in non-flood-prone areas. In spite of the lower property values in flood-prone areas, we show that the total economic value of properties in flood-prone regions has been growing faster than the national average. This leads to a continuing increase of the relative property value at risk, which could negatively influence the feasibility of private insurance schemes that may be introduced in the Netherlands. Finally, our study highlights the benefits of using property level data instead of aggregated land-use information for disaster risk assessment. While aggregated land-use data can depict trends in urban expansion, they fail to accurately represent increases in property density in built-up areas. We show that trends in urban expansion have stabilised over the past decades, while the increase in property density is continuing at a stable rate. Therefore, the results of our study show steeper trends in increasing flood exposure than previous efforts based on aggregated information.

We have also identified a number of limitations to the methodology developed in this study (see Sect. 3.3.3). The trend analysis is conducted on a national scale, whereby a stable hazard level is assumed and market values of properties are used as a proxy for financial losses. Future research should focus on improving the understanding of the drivers of these risk trends on a national and sub-national level, and on the accurate assessment of the effects of these trends on the affordability of insurance premiums.

The results presented here can contribute to risk assessment and disaster financing policies in many countries, such as the United States and the United Kingdom, where important reforms in national flood insurance programmes have been agreed upon and will be implemented over the course of the next few years.

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