Flood Risk Assessment in Ijsselmonde

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Index

Introduction

Background and study objectives

The Netherlands, a country vulnerable to flooding due to its low-lying topography, has implemented extensive flood prevention strategies. Managing flood risks primarily has historically involved technical solutions like levees and dikes (de Moel et al., 2013), but the $2.64-billion project "Room for the River" reflects further commitment to flood prevention, involving various measures such as lowering the river bed, setting back dikes, and widening channels, with the main goal of enhancing River Rhine's maximum discharge capacity (Aerts, 2018). However, across Europe, there's a growing trend towards a more comprehensive risk management strategy. This approach not only focuses on preventing floods but also prioritises tactics to minimise damage and reduce vulnerability (de Moel et al., 2013).

The focus of this report is to conduct a detailed analysis of flood risk in a specific dike ring area in the Netherlands, Ijsselmonde. It encompasses an assessment of current and potential future flood hazards, including water depth and time to inundation, and the consequent impacts on infrastructure, population, and economy. The study also considers the implications of climate change and explores spatial planning options for risk mitigation. This evaluation is crucial for evaluating the effectiveness of existing flood defence systems and for developing strategies to reduce flood risks in the context of evolving environmental conditions.

Description of the area

IJsselmonde, situated in the Rhine-Meuse delta in the Netherlands, is a 105km2 river island encircled by the Nieuwe Maas, Oude Maas, and Noord rivers in South Holland province. Positioned in a tidal river zone, IJsselmonde faces potential high water threats from river discharges and sea storm surges. The area's flood protection infrastructure comprises about 62 kilometres of dikes. The primary defence system shields roughly 13,000 hectares and serves a population of 400,000. This dike ring area includes the municipalities of Rotterdam (Zuid), Albrandswaard, Barendrecht, Ridderkerk, Heerjansdam, Zwijndrecht, and Hendrik-Ido-Ambacht, with the southern part of Rotterdam being notably economically significant (Theunissen, 2006).

The island's northern section, now part of Rotterdam, has experienced significant urban development, evolving into primarily suburban areas. The majority of the population and critical infrastructure, including three hospitals, are concentrated in this northern part of

IJsselmonde. This can be attributed, in part, to Rotterdam's status as the second largest city in the Netherlands and Ijsselmondes's proximity to the Rotterdam port, the largest port in Europe situated just outside the northern periphery of Ijsselmonde. Historically known for its agricultural productivity, only its central and southern regions retain this agricultural identity.

Critical transport routes such as the A15 and A16 highways traverse the dike ring, ensuring access to the Randstad and intersecting primary defences via tunnels. Rail connections also play a crucial role in the network, particularly due to the Randstad's accessibility and the presence of Kijfhoek, a vital rail yard for freight trains from Rotterdam's port.

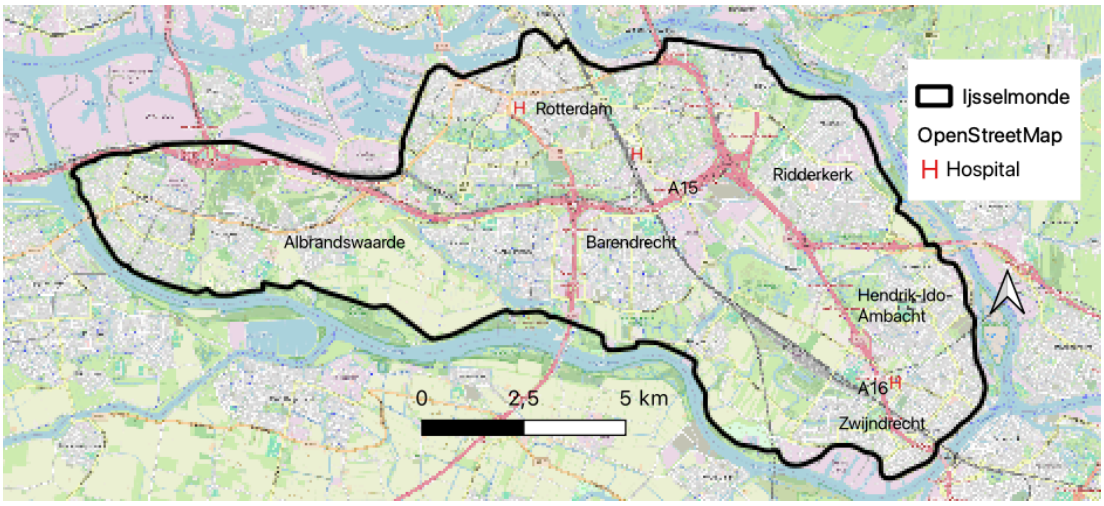

Figure 1: Ijsselmonde, its municipalities and amenities

Given its location and the recent shifts in land use, flood risk assessments for the island must consider several key factors:

- ☐ Flood Hazard Analysis: This includes examining inundation depth and time to inundation, crucial for understanding the extent and severity of flood risks in the selected area.
- ☐ Flood Impact Assessment: The analysis of how floods affect different land use types and the associated socio-economic impacts in 1990 and 2018, providing insight into the vulnerability and risk exposure of the area.
- ☐ Future Developments: This encompasses assessing the potential effects of climate change on flood risks, which is vital for long-term flood risk management and planning.

Overall, a comprehensive approach to flood risk management is essential for IJsselmonde, considering its unique geographical position and evolving land use patterns. This includes not only evaluating current risks and mitigation strategies but also planning for future changes and potential impacts on the island's diverse regions.

Methods

Data specifications and sources

Layer	Date	Resolution	Source	Format
Open Street Map	2024	N/A	Open Street Map	vector
AHN25	2002	25	Actueel hoogtebestand	raster
CLC1990	1990	93.5	Corine Land Cover	raster
CLC2018	2018	93.5	Corine Land Cover	raster
dijkringgebieden	2010	N/A	Rijkswaterstaat	vector
kruinhoogten	2010	N/A	Rijkswaterstaat	vector

Table 1: data descriptions

OpenStreetMap (OSM) is a reliable geographic data source, characterised by its community-driven, open-source model. It leverages local knowledge and diverse data inputs for map accuracy. Its self-correcting mechanism, facilitated by a global network of contributors, ensures dynamic data updating. The transparency in data modification and wide-ranging coverage, including underrepresented areas, further enhance its reliability. Despite potential variability in data quality, OSM's comprehensive and adaptable framework makes it a dependable resource for geographic information.

AHN25, part of the Actueel Hoogtebestand Nederland, is a highly precise topographical dataset featuring 25-centimetre interval elevation data, obtained using advanced LiDAR technology. Maintained by the Dutch government, it provides accurate, regularly updated topographical information, essential for applications in water management, urban planning, and environmental studies, affirming its reliability as a geographic information source. While the data set used is from 2002, the elevation is unlikely to have changed in Ijsselmonde in the last 20 years. Nevertheless, this might lead to inaccuracies in the results presented.

The **Corine Land Cover (CLC)** dataset is a highly reliable source for land use and land cover information across Europe, governed by the European Environment Agency. Created using satellite imagery, CLC offers standardised data with a resolution of 100 metres, suitable for environmental and urban planning analysis. The dataset, updated every six years, reflects changes in land cover, aiding in ecological and environmental research. The CLC dataset, spanning the years 1990 and 2018, offers a lower resolution compared to the AHN data yet remains apt for our analysis. We selected these specific years to enable a comparative assessment of flood damage across these two distinct time periods.

Rijkswaterstaat's data is reliable due to its authoritative role in Dutch infrastructure and water management, adherence to stringent accuracy standards, and expertise in handling complex environmental challenges. As a government agency, it ensures precision and accountability in data collection. The dijkring gebieden and kruinhoogten data dates back to 2010 and, although they have not undergone major reconstruction, there are frequent alterations made to strengthen and reinforce the dikes. This factor could affect the accuracy of our flood damage estimates from a dike breach, potentially leading to underestimations or overestimations in the assessment.

Conceptual method and flowcharts

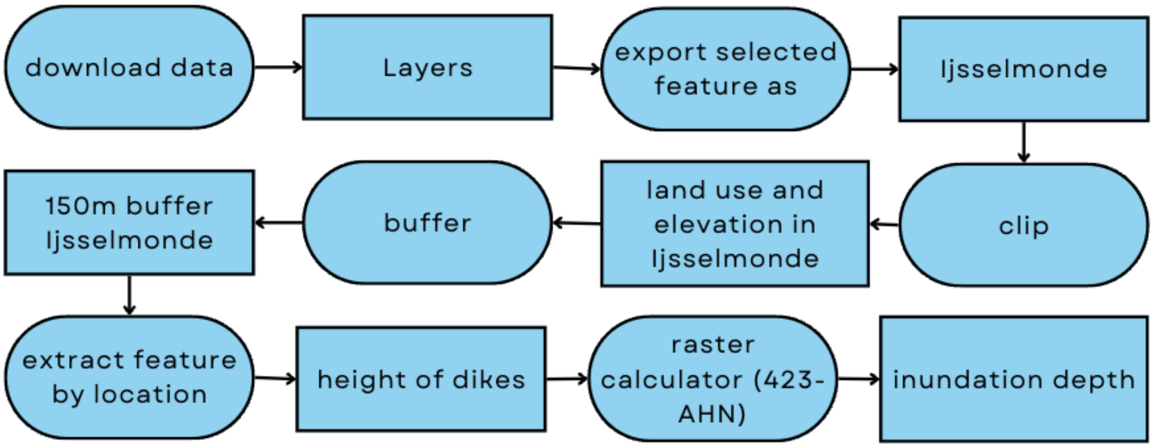

Figure 2: flowchart depicting the method for finding the inundation depth in Ijsselmonde

The first stage of the analysis was determining the inundation depths in Ijsselmonde. Figure 2 provides an overview of the steps followed.

The first step was downloading the data mentioned in table 1 and opening it on QGIS 3.34.2 . Then, the land use and elevation data was clipped to our dike ring Ijsselmonde to facilitate the analysis of the study area. A 150 metre buffer was applied around Ijsselmond to ensure that all the points representing the dike ring heights were encompassed. The measurement of 150 metres was the most adequate as it included all the points on the Ijsselmonde dike ring, but not external points irrelevant for our assessment. After extracting only the dike ring heights, it was concluded that the lowest point of the dike ring was 4.23 metres. There was still a possibility that this point was actually an outlier or incorrect data. To ensure that this was in fact the lowest point on our dike ring, we determined what and where the other lowest points on the dike ring were. These were all similar heights and in the same area so we determined that the data was correct. The inundation depth was obtained by using the raster calculator to subtract the AHN from 423 to determine the result in centimetres. This led to some of the values being negative. All these points would not be flooded and therefore were removed from the layer.

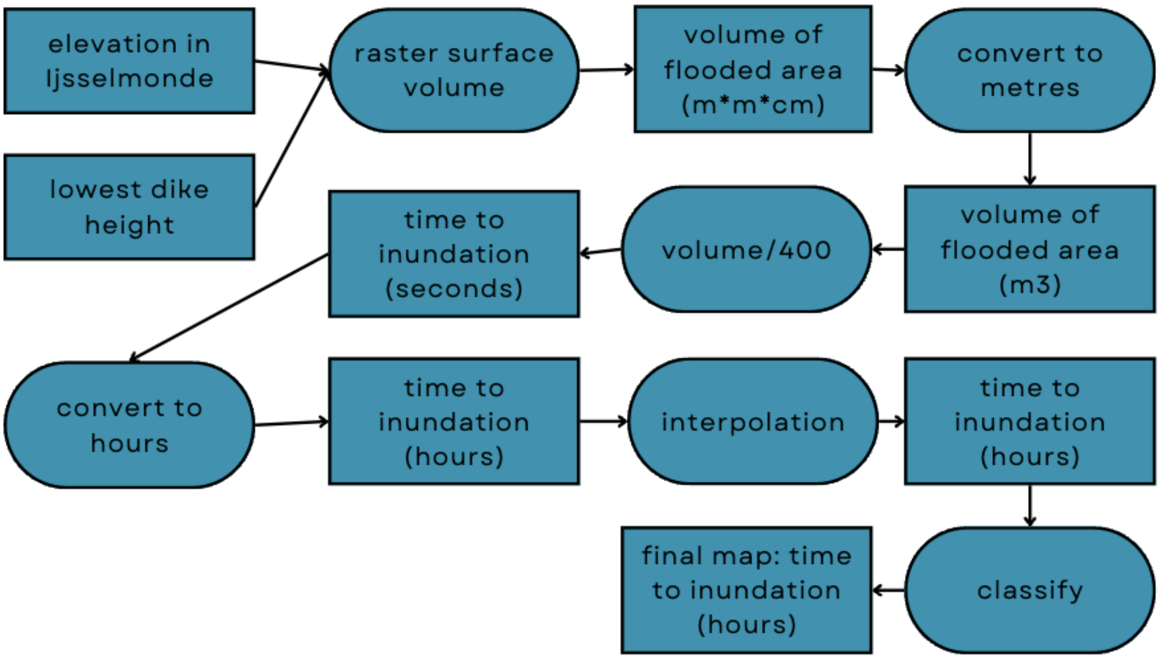

Figure 3: flowchart depicting the method used to find the time to inundation

The second stage of the analysis was determining the time to inundation in Ijsselmonde. Figure 3 provides an overview of the steps followed.

It is often useful to know how much an area will flood, but also to know how long it will take to flood, in order to take all preparatory measures, including the activation of the evacuation plan. The AHN data and the 'kruinhoogten' data allowed for the determination of the volume of flooded water, by using the raster surface volume and counting below the base level. The volume obtained was 484,312,162.50 m3. An assumption was made that the volume of water coming in through the dike breach is 400 m/s and using this we calculated the time to inundation in seconds. The result was 1,210,780.4 seconds, which converts to 333 hours. The goal was to determine how long it would take for each part of Ijsselmonde to flood. For this, 7 time periods (spanning from 1 hour to 1 week). To measure the water height after a specific amount of time following the dike breach, we used the formula Water height Y = Water height Y1 + (Specific time X − Time X1) ∗ (Height Y2 − Height Y1/ Time X2 − Time X1). After applying this to all our chosen time we classified the AHN data to correspond with the time it takes to flood, resulting in a map displaying the time to inundation.

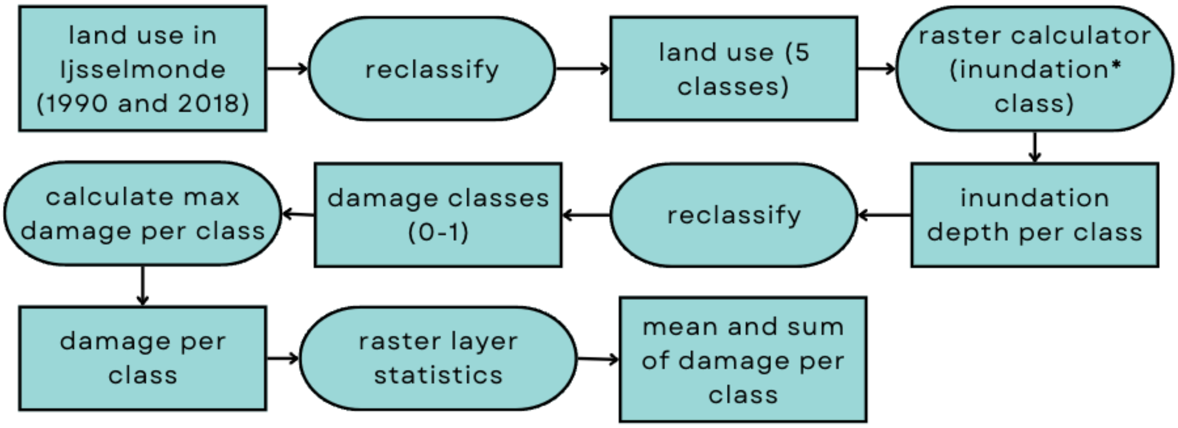

Figure 4: flowchart depicting the method to attain the flood damage per land use class in Ijsselmonde

The third stage of the analysis was determining the flood damage per land use in Ijsselmonde. Figure 4 provides an overview of the steps followed.

We first took the CLC data from 1990 and 2018 and reclassified the data into five land-use types: residential, commercial/industrial, infrastructure - roads, transport, and agriculture. We did this by using the reclassify by table function, and giving all land use that fit into the category a value of 1 and using no data for all other values. We then used the raster calculator (inundation depth*land use type) to make separate layers for the inundation depth of each land use class. However, this does not indicate the damage of each class and each land use is impacted to a greater or lesser extent. It was necessary to reclassify these layers to percent of damage from 0-1. Lastly, to determine the damage in a monetary value, the damage per class was calculated using the raster calculator and multiplying the damage class by the monetary damage per square metre determined by the European Commission (2017) and multiplying it by 625. This is because each of our raster cells was 25 square metres and we wanted to calculate the damage per square metre. It was relevant to indicate the mean and sum of the damage per land use class, using the raster layer statistics. Finally the sums of each class were added up to determine the total damage that could result from a dike breach in Ijsselmonde.

Results

<u>Hazard</u>

Water depth

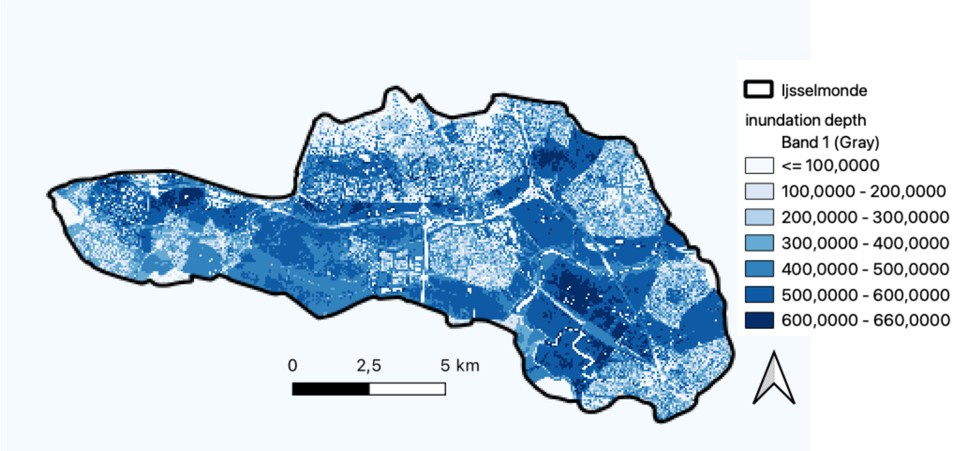

Figure 5: the inundation depth in Ijsselmonde

Figure 5 depicts the inundation depth in Ijsselmonde, which is the maximum depth the water can achieve on dry land in comparison to the terrain level. The highest inundation depths are located in the South with the maximum inundation depth being 660 centimetres.

Time to inundation

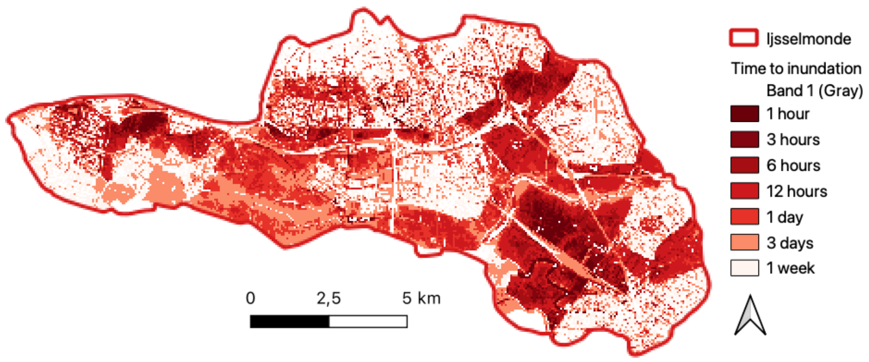

Figure 6: time to inundation in Ijsselmonde

Figure 6 shows the time it takes for areas in Ijsselmonde to flood. The areas in the South-East flood the fastest whereas the areas in the North take more time to flood allowing those in the North more time to evacuate. In figure 1 we can see that Rotterdam is in the North, which is a major city and therefore covers mostly urban land. It would therefore require major evacuation in case of a flood and therefore the fact that there is more time is important. In figure 1 we can also see that the areas that flood the fastest (figure 6) are mostly agricultural land.

Effects - damage

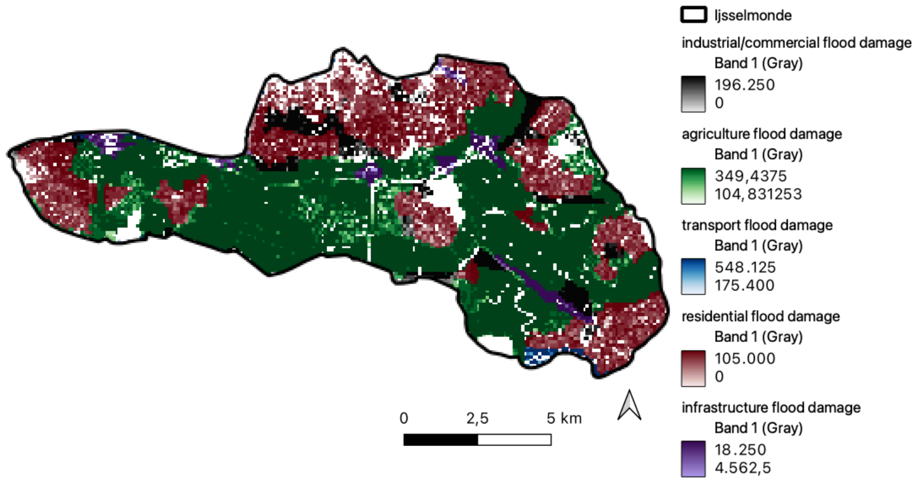

Figure 7: flood damage per land use type in 1990 (euros/m2)

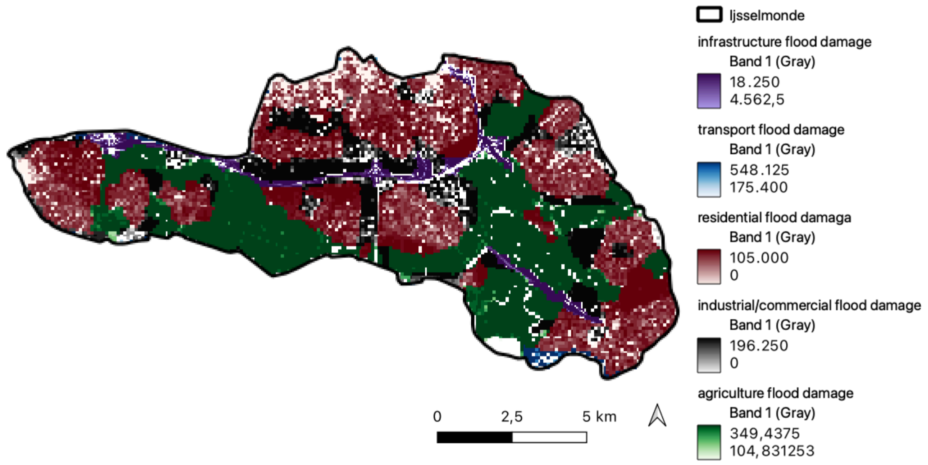

Figure 8: flood damage per land use type in 2018 (euros/m2)

In figure 7 and 8 the land use type is visible and there is a clear difference in the amount of agriculture and residential areas, depicted in green and red. Furthermore there is more infrastructure (roads) in 2018. This affects the monetary value of the flood damage.

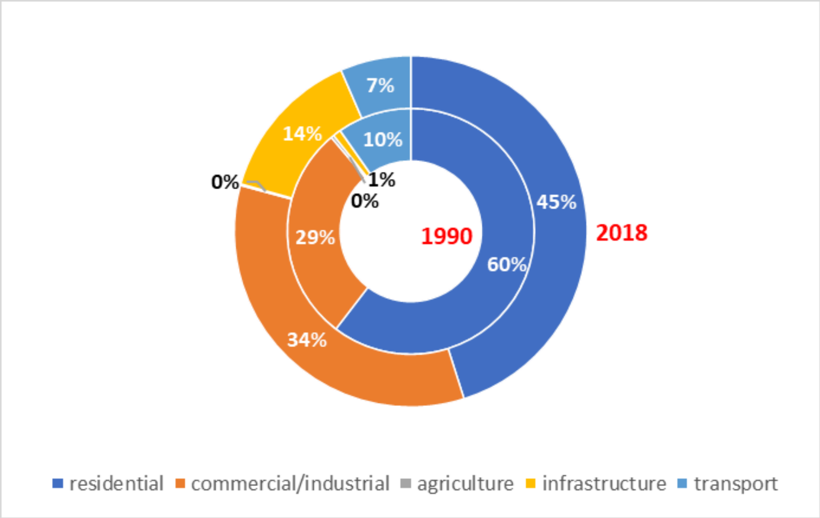

Figure 9: percentage of monetary damage per land use in 1990 and 2018

In figure 9, it is clearly represented what percentage of the flood damage cost comes from each land use type, allowing for comparisons between the 1990 and 2018. In 1990, most of the cost was associated with residential areas and that remains the highest cost in 2018, whereas there has been a large increase in infrastructure (going from 1 to 14%) and commercial/industrial areas (29 to 34%). Although agriculture covers a lot of the area in Ijsselmonde in both years, particularly in 1990 (as can be seen in figure 7), the damage cost per square metre is so low in comparison to the other land types that it is residual.

Land use type	Sum 2018	Mean 2018	Sum 1990	Mean 1990
Residential	450,000,000	78,300	319,000,000	84,300
industrial/commercial	340,000,000	174,000	150,446,232	174,937
Infrastructure - roads	141,384,210	16,585	5,543,255	16,547
transport	64,600,000	490,000	51,282,575	479,276
agriculture	1,250,000	345	2,082,647	339
Total damage	997,000,000		528,000,000	

Table 2: the sum and the mean flood damage per land use type and the total damage in 1990 and 2018 in euros/m2

To further illustrate this, it is visible that the mean flood damage cost per square metre for agriculture is 345 euros/m2 in 2018 and 339 euros/m2 in 1990, which is a lot lower than any of the other land use classes. Because a large part of Ijsselmonde was covered by agricultural land, of which a major part has now been urbanised, the total damage cost in 2018 is almost double of what it would have been in 1990 (as can be seen in table 2). Furthermore, the increase in areas associated with high damage costs (such as infrastructure, transport and industrial/commercial), the total sum of the damage has increased substantially. The highest cost in both years is associated with residential areas, which cover most of Ijsselmonde in 2018 and about half in 1990. It is also noticeable that industrial/commercial areas would also experience a lot of damage and that this has more than doubled from 1990 to 2018.

Evacuation options

In the unlikely case that the preventive measures are not insufficient and a flood does occur, it is indispensable to have a reliable evacuation plan in practice. Still, in 2009, the evacuation fraction in Ijsselmonde was 15 for people living in below river areas. This means that only 15 out of 100 of those people would be able to leave the area in case of a flood. This absolute value is critically low, but it is also low in comparison with evacuation areas from other dike rings (Maaskant et al., 2009). There is a highlighted need to structure a reliable evacuation route which prioritises evacuating the most endangered areas. These areas include Albrandswaard's agricultural and residential lands, and areas around Hendrik-Ido-Ambacht's railway and the Albert Schweitzer hospital in Zwijndrecht.

The main evacuation routes would instinctively be the railroad and the A16 going directly through the South-East of Ijsselmonde where the time to inundation is about 12 hours to 3 days (see figure 1 and 6). This means these routes are ideal for the residents to return to their places of residence to gather their belongings and exit the area. This would be particularly significant for the people living in Hendrik-Ido-Ambacht and Zwijndrecht as this is close to both the railroad and the A16 and part of these residential areas are also likely to flood quickly. Evacuating the Albert Schweitzer hospital location Zwijndrecht must be a top priority. Continuous information just be shared to safeguard the accessible points and safe routes for the speedy evacuation of potentially the entire population of 400,000.

In the event of a flood, effective crisis communication is a crucial and undeniable component of the response strategy which includes the evacuation plan. In the Netherlands, this involves coordinated communication among hydrological experts (like water boards and

Rijkswaterstaat), firefighters, police, and municipalities, facilitated by a joint call centre where representatives from each group work together permanently for efficient information exchange (van Manen, 2024). The municipalities have a significant organisational role, while hydrological experts provide essential advisory services. The police play a critical role in maintaining order, especially during evacuations, and firefighters are key in managing emergencies, such as preventing hazardous chemicals from a flooded plant from contaminating water sources. Furthermore, evacuation strategies, particularly by car, benefit from real-time information on inundation timelines, allowing for the effective use of roads, monitored and managed by the police, including the implementation of one-way traffic to expedite the evacuation process.

Discussion

Reflections on the methods

The flood risk assessment for Ijsselmonde operates under certain limitations and assumptions. It is presumed that water would enter the area at a velocity of 400 m/s in the event of a flood, yet this velocity may vary with the nature of the flood event, such as dike breaches or heavy rainfall, potentially leading to inaccuracies for different scenarios.

The analysis also assumes uniform flood damage costs for infrastructure and transport across Europe, modified by the GDP of the Netherlands to suggest a direct proportionality. This may not accurately reflect the unique economic impact within Ijsselmonde, where the mean damage cost for transport implies high expenses even for small affected areas.

Discrepancies in land use classification arose from the original Corine Land Cover layers, with certain areas designated as agricultural potentially serving other functions. This discrepancy is mitigated by the fact that the majority of the agricultural land in Ijsselmonde is non-irrigated arable land, fitting the agricultural classification, and the low damage cost associated with agriculture lessens the relative significance of this misclassification.

The assessment emphasizes the economic impact of a dike breach without addressing the actual likelihood of such an event. The condition and resilience of the dike system in Ijsselmonde, which is not deemed to be at high risk of flooding, is not factored into the analysis, potentially skewing risk perception (Theunissen, 2006).

Furthermore, the method's exclusive focus on surface water neglects the influence of groundwater, which can significantly affect flood severity. Precipitation data and climate models, essential for forecasting floods and understanding future risks associated with climate change, are also not included.

These limitations suggest the necessity for an integrated approach in future assessments, incorporating both surface and groundwater considerations, localized economic impact data, and climate projections to refine flood risk analysis for Ijsselmonde.

Future developments

Climate change

The implications of climate change for the Netherlands are profound and multifaceted, posing significant challenges for flood risk management in this low-lying country. Firstly, the anticipated rise in sea levels, projected to reach between 0.65–1.3 metres by 2100 and potentially 2–4 metres by 2200, exacerbates the risk of coastal and riverine flooding. Alongside this, changing precipitation patterns are a major concern; the wetter northern parts of Europe, including parts of the Netherlands, have experienced an increase in precipitation by 10 to 40% in the twentieth century, while some southern regions have seen decreases. This trend, characterised by more intense and frequent heavy rain events, leads to increased risks of river and flash floods, as well as local inundations. Furthermore, the increased dry periods in summer could aggravate issues such as water availability for agriculture, nature, households, and industry, as well as contribute to land subsidence. These climatic changes not only elevate the probability and potential impact of flooding but also impose additional economic burdens, especially in areas with poorer soil quality where water management costs are expected to rise significantly. The situation demands a strategic shift in the Netherlands' approach to flood risk management, necessitating innovative and integrated solutions that encompass not only enhanced physical infrastructure but also adaptive spatial planning and sustainable land use practices (Ritzema & Van Loon-Steensma, 2017).

Spatial planning options

The risk equation considers not only the hazard, but also exposure and vulnerability. This means that beyond the severity of the flood, risk is also associated with how equipped the area is to deal with it. The multilayered safety represents this division of priorities as it defines three different stages: prevention, sustainable spatial planning and disaster management. The results put forward in this report allow to draw various relevant conclusions, potentially leading to a more sustainable spatial planning in Ijsselmonde. For example, the comparison between figures 1 and 8, indicates that the residential focus points can be found in areas where the inundation depth is relatively low. This planification diminishes the flood risk of residential areas (lower exposure, even though vulnerability is high) while allowing for some losses in more agricultural areas where the inundation depth is higher, but possible damage is extremely low (very high exposure, even though vulnerability is much lower). These are important considerations in spatial planning, as they reveal the importance of positioning more valuable assets that would result in the highest damage cost in less affected areas, reducing exposure.

Interestingly, there has already been some spatial planning based on flood protection in Ijsselmonde. For example between 1996 and 2001, during the Delta Plan for Large Rivers (DGR) project, 1000 houses were demolished and the dike had to be reconstructed. Many people were allowed to return to their homes rebuilt near the dike or on a raised platform in front of the dike (Rijkswaterstaat, 2012). There is the reliance on the dike for the homes within the dike ring, however for those outside the homes were built on raised platforms to reduce exposure. We considered this a particularly relevant event as future spatial planning must accommodate the needs associated with increasing population and the transition to renewable energy, including 1 million new houses should be built in the next 7 years, and for wind and solar farms. Without further control, these may be built in areas prone to flood risk, due to lack of space(van Manen, 2024).

Conclusions

Despite Ijsselmonde's relatively low flood risk in comparison to other dike rings, a dike breach's ramifications could be significant, owing to the dense population. The flood risk is estimated at 1/4000 post-Maeslantkering, with the dike ring's failure probability at 1/1334000 annually, demanding stringent flood defences (Theunissen, 2006). The increasing frequency of extreme weather events due to climate change elevates flood risks, underscoring the need for proactive measures. Our analysis underscores the severe damage implications of a dike breach, underscoring the value of investing in secondary protection to lessen vulnerability and facilitate the safe evacuation of residents. While the Netherlands prioritises flood hazard prevention, incorporating strategies to address exposure and vulnerability, akin to practices in countries like the USA, could provide a more robust defence for areas below sea level, such as Ijsselmonde.

In Ijsselmonde, advancing spatial planning to reduce flood vulnerability is imperative. Elevating railroads could significantly improve evacuation processes, especially for non-car owners, and alleviate road congestion during floods. This promotes public transportation, aligning with sustainability goals. Building adaptation is also critical; dry-proofing strategies are recommended for areas with shallow flooding potential, effectively sealing buildings to prevent water entry for floods less than one metre deep. Conversely, wet-proofing is sensible for areas anticipating deeper floods, allowing for controlled flooding in designated home areas to protect valuable and sensitive items on higher levels. Collectively, these spatial planning and structural modifications are aimed at reducing the flood impact through strategic design and construction adaptations (The Cost of, n.d.; Wet Floodproofing, n.d.).

A comprehensive multilayer safety plan that includes these new spatial planning options would further secure Ijsselmonde from floods. Conducting a cost-benefit analysis with our damage assessment and flood probability data will guide the implementation of the most beneficial flood preventive measures for Ijsselmonde, reinforcing its resilience against the growing threat of flooding.

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The cost of dry floodproofing varies depending on the building size, depth of required protection, types of material used, and number of openings. Examples of general cost estimates can be found in FEMA publications: Homeowner's Guide to Retrofitting: Six Ways to Protect Your House from Flooding and Engineering Principles and Practices of Retrofitting Floodprone Residential Structures. (n.d.). Retrieved January 19, 2024, from https://www.edinamn.gov/DocumentCenter/View/8418/Dry-Floodproofing-PDF

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