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A preliminary assessment of exposure

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The impacts of climate change on cultural heritage in the Netherlands: A preliminary assessment of exposure

Report

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Front cover: Kinderdijk, South Holland, The Netherlands (photograph credit: Sandra Fatorić, 2019)

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Background

Cultural heritage provides a wide range of economic, socio-cultural and environmental benefits for current and future generations. Globally, scientific evidence shows that climate change is adversely affecting diverse tangible and intangible cultural heritage [1; 2; 3]. Yet, in the Netherlands, there is a need for a greater understanding of the cultural heritage *vulnerability* to climate change hazards. Understanding the vulnerability of cultural heritage to climate change hazards is of paramount importance to inform and guide proactive climate change adaptation planning and to reduce the potential damage or loss of heritage [4; 5; 6].

The **aim** of this study is to **evaluate and visualise the potential exposure of nationally significant cultural heritage** (national monuments or *Rijksmonumenten*) **to multiple climate change hazards in the Netherlands**. The climate change hazards assessed in this study include coastal and river flooding, urban pluvial flooding, drought and heat. The assessment is presented in a series of tables, graphs and maps for ease of use. Importantly, the presented exposure of monuments to climate change hazards **is not a measure of actual risk or impact**, but the **first scan of different levels of exposure of monuments to climate change hazards** using a scientific database of Climate Impact Atlas.

Methodology

National monuments data collection

This assessment includes 63,389 national monuments, which are divided into 13 categories and listed in the national register as of July 1, 2019. Spatial data for these monuments were provided by the Cultural Heritage Agency *(Rijksdienst voor het Cultureel Erfgoed)*. The initial 13 categories of national monuments were first validated for the accuracy and then grouped into the eight categories as shown in Table 1.

Table 1. Categories of national monuments in the Netherlands

Monument category	Number of monuments
1. Houses and housing complexes	31661
2. Agricultural buildings and mills	9948
3. Buildings with various functions Include 5 sub-categories: Administrative, legal and government buildings; Commercial buildings, storage and transport buildings; Buildings used for sport, recreation, association and hospitality; Buildings used for culture, health and science; Funeral homes (centres) and cemeteries	5716
4. Castles, stately homes (estates) and parks	5538
5. Religious buildings	4367
6. Defence works, military buildings and civil engineering works Include 2 sub-categories: Defence works and military buildings; Civil engineering works	3458
7. Archaeological sites	1464
8. Other historic objects	1237

Climate change hazards data collection

We sourced data on four primary climate change hazards – coastal and river flooding, urban pluvial flooding, drought and heat from **Climate Impact Atlas** *(Klimaateffectatlas)*. It provides an indication of the potential risks of coastal and river flooding, urban pluvial flooding, drought and heat in the Netherlands. Climate Impact Atlas is considered as a reliable source of climate change data and is used by the Dutch government in national climate adaptation policy responses [4; 5].

Each of the primary hazards has a sub-set of hazards. Because this assessment evaluates monument-scale exposure, it was not possible to include in the analysis all sub-hazards. Therefore, the following subset of each primary hazard was chosen (after discussions with climate change policy expert) for evaluation:

- **Coastal and river flooding**: (1) Failure of flood defences, (2) Localised flood probability
- **Urban pluvial flooding**: (1) Extreme rainfall events, (2) Intense rainfall days, (3) Subsurface soil compaction
- **Drought**: (1) Deterioration of timber pile foundations, (2) Subsidence
- **Heat**: (1) Tropical days, (2) Longest series of consecutive days with maximum temperature ≥25°C

Data analysis

We used **Quantum Geographical Information Systems** (QGIS) to analyse exposure, which is directly dependent on the **location** of monuments and **mapped hazard data** (e.g., whether the area near the monument experiences the hazard). In this study, the exposure to the hazard is considered to equally affect all monuments within the hazard area.

Vulnerability: Probability of loss of cultural heritage (and associated values) due to climate variability or change [7]. Vulnerability can be assessed as a combination of exposure, sensitivity and adaptive capacity [8].

Exposure: Heritage asset's presence in a place that could be adversely affected by a climate change hazard/impact [7; 8].

Sensitivity: Degree to which the heritage asset could be affected by its exposure [7; 8].

Adaptive capacity: In the heritage field, adaptive capacity is interrelated with human's adaptive capacity because typically heritage asset does not have a capacity to adjust on its own [7].

Coastal and river flooding | Failure of flood defences

Description

The Netherlands has about 3500 km of primary flood defences and about 14,000 km of regional flood defences [9].

Figure 2 shows the number of monuments per province that can be currently flooded from the failure of all primary flood defences, all regional flood defences and in all unprotected areas outside dyke-rings. Note that these flooding scenarios cannot all occur simultaneously, and the safety standards differ per area. The safety standards of primary flood defences vary between 1/1250 and 1/10,000 per year. This means that there is a chance of failure once every 1250 or 10,000 years. The safety standards for regional flood defences are lower, between 1/10 and 1/1000 per year, while for the areas outside dyke-rings are 1/1000 per year [9].

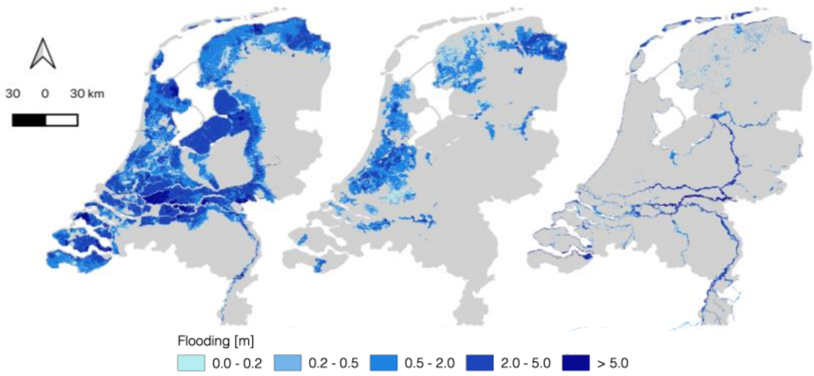

Figure 1. Flooding from failure of all primary flood defences (left), all regional defences (middle) and in all areas outside dyke-rings (right). Source: Climate Impact Atlas, 2020.

Results

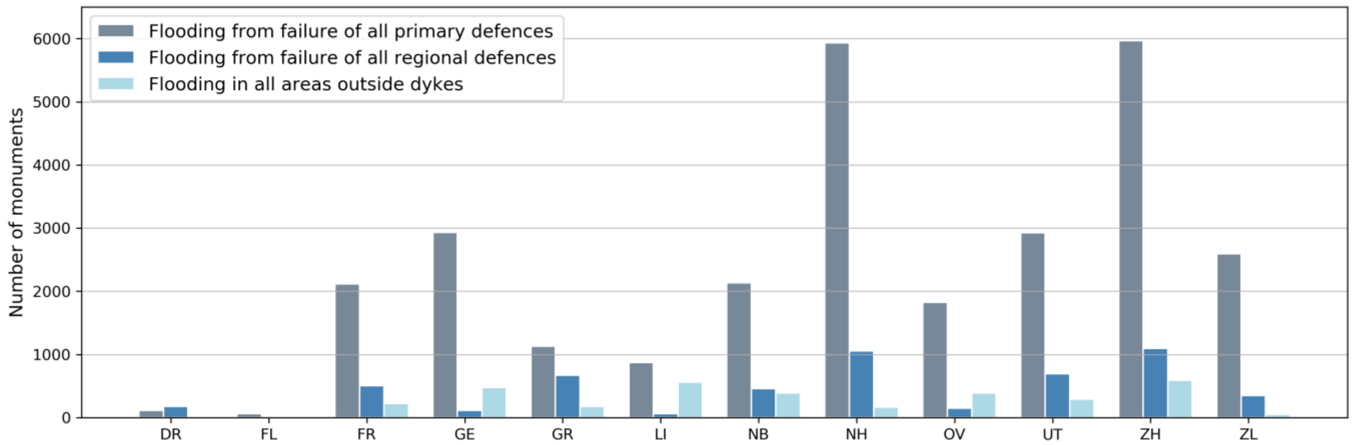

Figure 2. Number of monuments potentially exposed to flooding from the failure of all primary and regional flood defences and in all areas outside dykes. Note that this Figure shows only the extent of flooding, while the water depths are shown in Figure 5.

Table 2. Number of monuments per province potentially exposed to flooding from the failure of all primary and secondary flood defences and in all areas outside dykes

	Failure of all primary flood defences		Failure of all secondary flood defences		Flooding in areas outside dykes	
	#	%	#	%	#	%
Drenthe (DR)	115	8	179	13	22	2
Flevoland (FL)	60	55	7	6	17	16
Friesland (FR)	2115	49	502	12	225	5
Gelderland (GE)	2934	45	112	2	478	7
Groningen (GR)	1132	41	672	24	175	6
Limburg (LI)	869	16	63	1	562	10
North Brabant (NB)	2135	36	460	8	387	7
North Holland (NH)	5936	42	1057	7	164	1
Overijssel (OV)	1827	45	146	4	392	10
Utrecht (UT)	2926	51	691	12	290	5
South Holland (ZH)	5971	65	1095	12	593	6
Zeeland (ZE)	2595	69	350	9	53	1
TOTAL	28615	45	5334	8	3358	5

As shown in Table 2, about 28,615 or 45% of all national monuments can be flooded in case of all primary defence failures and 5334 (8%) of all monuments can be flooded if all regional defences fail. Similarly, 3358 (5%) of all monuments can be flooded in unprotected areas outside dyke-rings. The provinces that can experience the largest number of flooded monuments due to failure in primary defences are South Holland (5971 monuments or 65% of provincial monuments), followed by North Holland (5936, 42%) and Gelderland (2934, 45%). In case of secondary defence failure, the largest number of monuments that are exposed to flooding are in South Holland (1095, 12% of provincial monuments), North Holland (1057, 7%) and Utrecht (691, 12%). Monuments in South Holland (593, 6%), Limburg (562, 10%) and Gelderland (478, 7%) can be the most exposed to flooding outside dyke-rings.

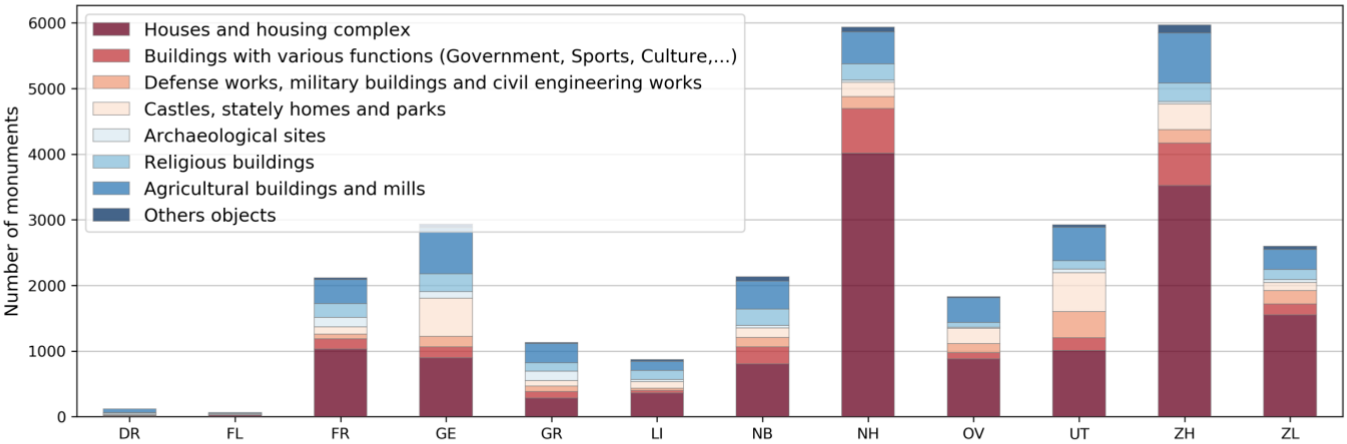

Figure 3. Categories of monuments potentially exposed to flooding from the failure of all primary flood defences.

Table 3. Categories of monuments per province potentially exposed to flooding from the failure of all primary flood defences

Failure of primary flood defences								
	Houses and housing complex	Agricultural buildings and mills	Castles, estates and parks	Buildings with various functions	Religious buildings	Defence works, military build. and civil engineer. works	Archaeological sites	Other objects
	#	#	#	#	#	#	#	#
Drenthe (DR)	9	55	9	10	7	2	23	/
Flevoland (FL)	23	12	/	3	5	2	15	/
Friesland (FR)	1033	368	113	150	206	73	146	26
Gelderland (GE)	898	700	583	164	273	162	97	57
Groningen (GR)	285	291	81	97	126	85	147	20
Limburg (LI)	363	143	101	39	135	32	32	24
North Brabant (NB)	801	429	145	265	248	140	39	68
North Holland (NH)	4012	487	215	684	247	181	38	72
Overijssel (OV)	883	376	230	95	72	138	18	15
Utrecht (UT)	1008	509	590	193	126	401	57	42
South Holland (ZH)	3521	767	398	650	280	201	32	122
Zeeland (ZL)	1553	303	122	165	152	202	48	50
TOTAL	14389	4440	2587	2515	1877	1619	692	496
%	50	16	9	9	7	6	2	2

Regarding the monument categories (Table 3), houses and housing complexes (14,389) represent half of all monuments that can be flooded if there would be a complete primary defence failure. Specifically, in 10 provinces houses and housing complexes are located in areas potentially exposed to flooding from the failure of all primary flood defences (exceptions are Drenthe and Groningen). Agricultural buildings and mills (4440, 16%) and castles, estates and parks (2587, 9%) can also experience flooding due to failure in primary defences.

Coastal and river flooding | Localised flood probability

Description

To understand the impact that flooding can have on national monuments in the Netherlands, not only is important to know potential areas prone to flooding but also the probable frequency of flooding. Insights into the probability of a water depth can help to evaluate the feasibility and affordability of flood mitigation measures.

Figure 4 shows the localised flood probability for 2050 considering a minimum water depth of 20 and 200cm. The maps are generated examining the probability (chance) of a flood event and the distribution (extent) of that flood probability over the different water depths. The flooding probabilities are based on the safety standards or maximal acceptable failure probabilities of flood defences.

Figure 5 shows the number of monuments per province that can be exposed to minimum water depths of 20, 50 and 200cm in 2050 under high probability scenario or once every 30 years (also called 30-year return period; 1/30 pe year).

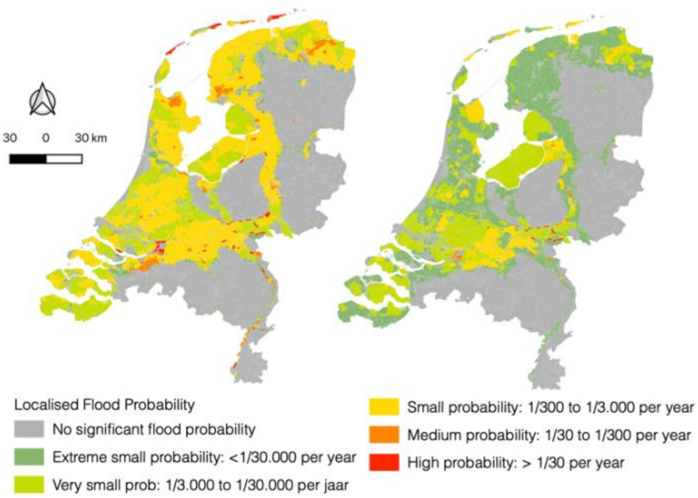

Figure 4. Probabilities to experience minimum water depth of 20cm (left) and water depth of 200cm (right) in 2050. Source: Climate Impact Atlas, 2020.

Results

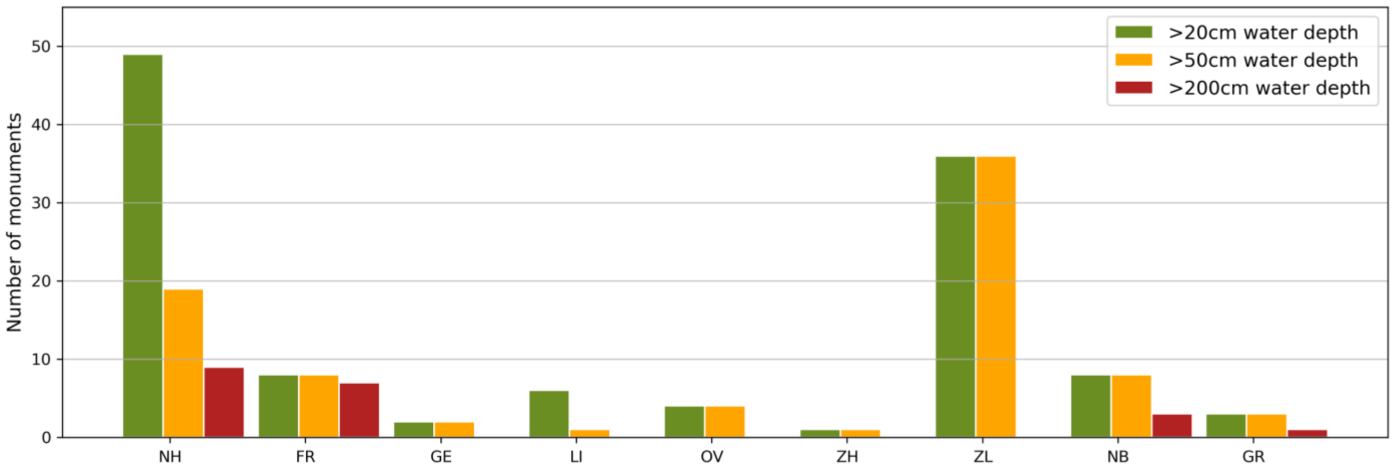

Figure 5. Number of monuments potentially exposed to minimum water depths of 20, 50 and 200cm during the 30-year return period (high probability).

Table 4. Number of monuments potentially exposed to minimum water depths of 20, 50 and 200cm during the 30-year return period (high probability)

High probability						
	>20cm		>50cm		>200cm	
	#	%	#	%	#	%
Friesland (FR)	8	0.18	8	0.18	7	0.16
Gelderland (GE)	2	0.03	2	0.03	/	/
Groningen (GR)	3	0.11	3	0.11	1	0.04
Limburg (LI)	6	0.11	1	0.02	/	/
North Brabant (NB)	8	0.13	8	0.13	3	0.05
North Holland (NH)	49	0.35	19	0.13	9	0.06
Overijssel (OV)	4	0.10	4	0.10	/	/
South Holland (ZH)	1	0.01	1	0.01	/	/
Zeeland (ZL)	36	0.96	36	0.96	/	/
TOTAL	117	0.18	82	0.13	20	0.03

As shown in Table 4, less than 1% of all national monuments can be exposed to a minimum water depth of 20, 50 and 200cm combined under a high probability scenario (or once in 30 years on average). Two provinces where the monuments can be the most exposed if the water reaches a depth of at least 20 and 50cm are Zeeland (combined 72 monuments, 1.92% of all provincial monuments) and North Holland (combined 68 monuments, 0.65%). The most exposed monuments to a water depth of 200cm and larger are located in North Holland (9) and Friesland (7). Monuments in three provinces, Drenthe, Utrecht and Flevoland are likely not exposed to a water depth of 20 and 200cm under the high probability scenario.

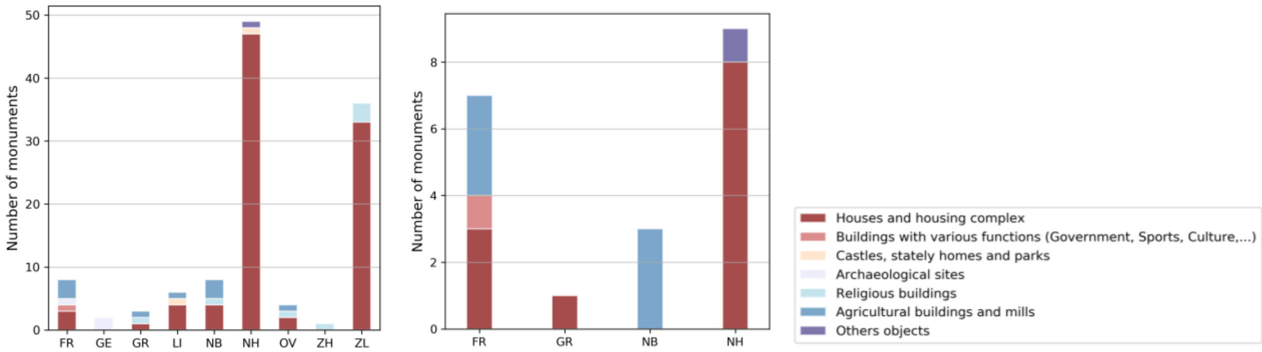

Figure 6. Categories of monuments potentially exposed to minimum water depth of 20cm (left) and 200cm (right) during the 30-year return period (high probability).

Table 5. Categories of monuments per province potentially exposed to a minimum water depth of 20cm during the 30-year return period (high probability)

>20cm under high probability							
	Houses and housing complex	Agricultural buildings and mills	Religious buildings	Archaeological sites	Castles, estates and parks	Buildings with various functions	Other objects
	#	#	#	#	#	#	#
Friesland (FR)	3	3	/	1	/	1	/
Gelderland (GE)	/	/	/	2	/	/	/
Groningen (GR)	1	1	1	/	/	/	/
Limburg (LI)	4	1	/	/	1	/	/
North Brabant (NB)	4	3	1	/	/	/	/
North Holland (NH)	47	/	/	/	1	/	1
Overijssel (OV)	2	1	1	/	/	/	/
South Holland (ZH)	/	/	1	/	/	/	/
Zeeland (ZL)	33	/	3	/	/	/	/
TOTAL	94	9	7	3	2	1	1
%	80	8	6	3	2	1	1

Table 5 shows that houses and housing complexes under a high probability scenario (or once in 30 years on average) represent 80% (94) of all monuments potentially exposed to a minimum 20cm of water depth, followed by the agricultural buildings and mills (9, 8%) and religious buildings (7, 6%). A monument category defence works, military buildings and civil engineering works is likely not exposed to the water depths of 20 and 200cm under high probability scenario.

Urban pluvial flooding | Extreme rainfall events

Description

Figure 7 shows the maximum water depth that can currently occur in a place as a result of short-term extreme rainfall events. In the modelling, 70mm and 140mm of rainfall in 2 hours were used. The extreme rainfall event of 70mm is likely to occur once every 100 years, while the rainfall event of 140mm is likely to occur once every 1000 years (also called return periods). These maps, developed by Deltares, are part of the Preliminary Flood Risk Assessment within the scope of the EU Floods Directive.

Figure 8 shows the number of monuments per province that can be currently exposed to maximum water depth larger than 20cm for the 100-year and 1000-year return periods.

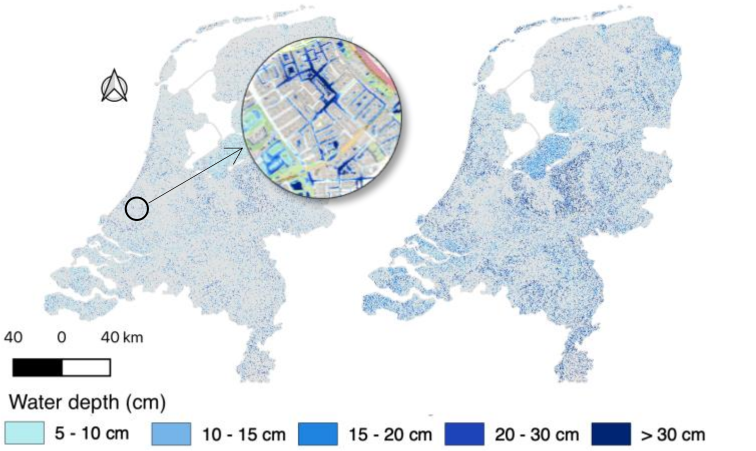

Figure 7. Maximum water depths for the 100-year extreme rainfall event (left) and 1000-year extreme rainfall event (right). Source: Climate Impact Atlas, 2020.

Results

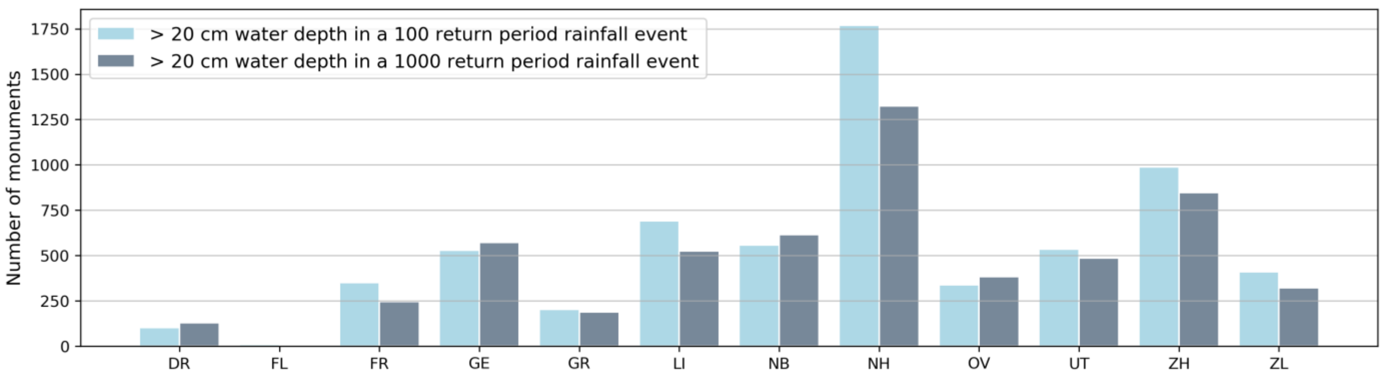

Figure 8. Number of monuments potentially exposed to maximum water depth larger than 20cm during the 100-year and 1000-year return periods.

Table 6. Number of monuments per province potentially exposed to maximum water depth larger than 20cm during the 100-year and 1000-year return periods

Maximum water depth >20cm				
	100-year return period		1000-year return period	
	#	%	#	%
Drenthe (DR)	103	7.51	128	9.33
Flevoland (FL)	10	9.17	8	7.34
Friesland (FR)	351	8.09	245	5.65
Gelderland (GE)	528	8.04	572	8.70
Groningen (GR)	203	7.33	188	6.79
Limburg (LI)	691	12.68	525	9.63
North Brabant (NB)	558	9.40	616	10.38
North Holland (NH)	1770	12.54	1324	9.38
Overijssel (OV)	339	8.37	383	9.46
Utrecht (UT)	536	9.37	486	8.50
South Holland (ZH)	989	26.39	846	22.57
Zeeland (ZL)	409	4.44	321	3.49
TOTAL	6487	10.23	5642	8.90

Table 6 shows that about 10% of all national monuments can experience a maximum water depth of 20cm and larger due to extreme rainfall events once every 100 years and nearly 9% of all monuments can experience the same water depth once every 1000 years. The provinces where the monuments are the most exposed to water depth greater than 20cm and which can occur once every 100 years are North Holland (1770 monuments, 12.5% of all provincial monuments) and South Holland (989, 26%), followed by Limburg (691, 13%). Similarly, the most exposed monuments to a water depth of 20cm and larger that can occur once every 1000 years are located in North Holland (1324, 9%), South Holland (846, 22.5%) and Limburg (525, 10%). These provinces have a large number of monuments in urban areas where paved and narrow streets can exacerbate the accumulation of water under short-term but heavy periods of rainfall.

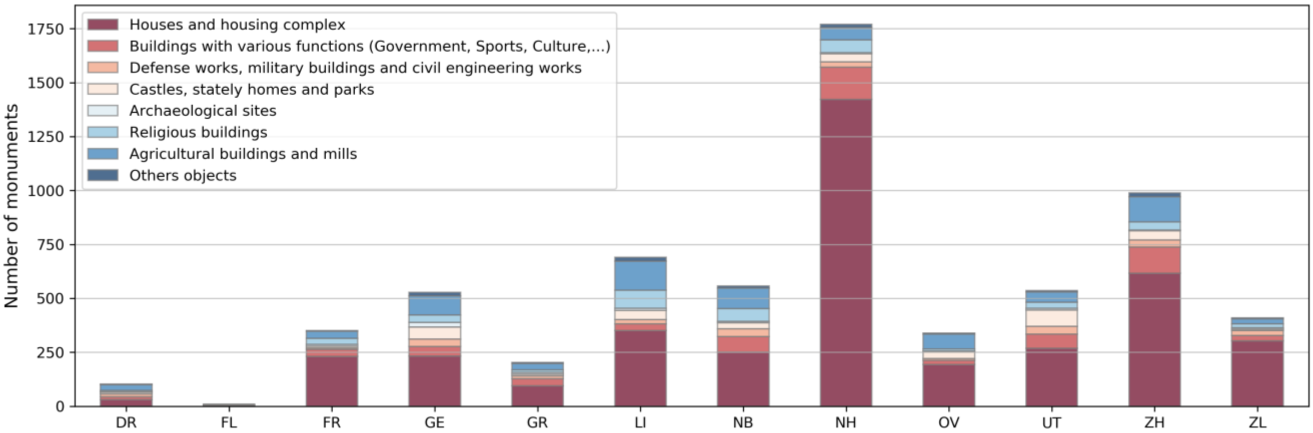

Figure 9. Categories of monuments potentially exposed to maximum water depth larger than 20cm during the 100-year return period.

Table 7. Categories of monuments per province potentially exposed to maximum water depth larger than 20cm during the 100-year return period

Maximum water depth >20cm for the 100-year return period								
	Houses and housing complex	Agricultural buildings and mills	Buildings with various functions	Religious buildings	Castles, estates and parks	Defence works, military build. and civil engineer. works	Other objects	Archaeological sites
	#	#	#	#	#	#	#	#
Drenthe (DR)	30	27	13	5	8	14	3	3
Flevoland (FL)	4	1	1	/	/	1	/	3
Friesland (FR)	231	33	33	27	7	7	4	9
Gelderland (GE)	233	88	44	34	55	35	17	22
Groningen (GR)	95	29	33	12	7	13	5	9
Limburg (LI)	350	135	32	83	43	20	19	9
North Brabant (NB)	251	94	71	60	27	37	11	7
North Holland (NH)	1423	57	148	59	38	25	15	5
Overijssel (OV)	193	69	20	10	33	8	5	1
Utrecht (UT)	268	48	66	28	76	36	6	8
South Holland (ZH)	616	117	122	37	44	32	18	3
Zeeland (ZL)	303	23	24	17	8	23	5	6
TOTAL	3997	721	607	372	346	251	108	85
%	62	11	9	6	5	4	2	1

As shown in Table 7, from a total of 6487 monuments that are potentially exposed to water depth larger than 20cm due to extreme rainfall (100-year return period), nearly two-thirds of the monuments are houses and housing complexes (3997, 62% of all monuments). Other categories that can be the most affected by water depth larger than 20cm are agricultural buildings and mills (721, 12%), buildings with various functions (607, 9%) and religious buildings (372, 6%).

Urban pluvial flooding | Intense rainfall days

Description

Intense rainfall (days with more than 25mm of rain) can lead to local accumulations of water or surface flooding (runoff; the water that does not infiltrate into the soil layer typically in urban areas). This is an important indicator for pluvial flooding which can be determined using land-use and soil characteristics. Figure 10 shows the number of days per year where more than 25mm of precipitation is expected to occur by 2050. This map was generated based on the climate scenario WH, developed by the Royal Netherlands Meteorological Institute, KNMI [10]. The WH scenario assumes a rise in temperatures of 2°C and the largest number of days with intense rainfall.

Figure 11 shows the number of monuments per province that can be exposed to 4-6 intense rainfall days per year by 2050.

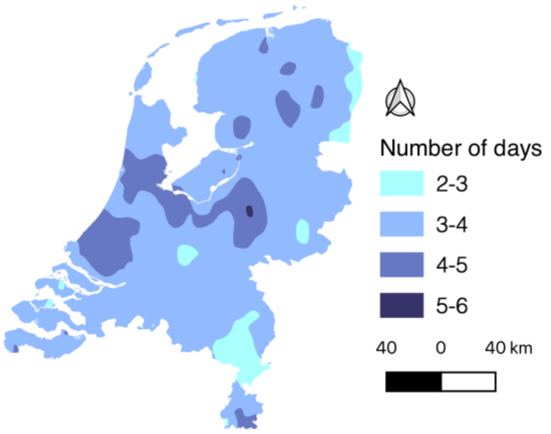

Figure 10. Number of intense rainfall days by 2050. Source: Climate Impact Atlas, 2020.

Results

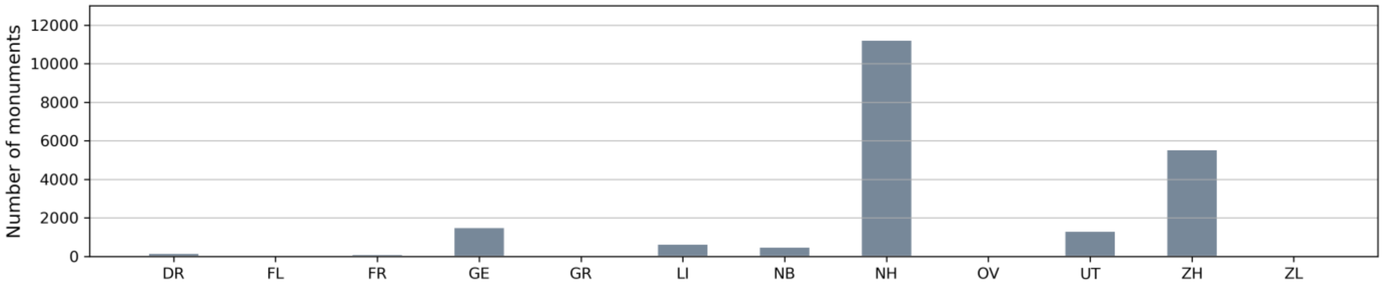

Figure 11. Number of monuments potentially exposed to 4-6 intense rainfall days by 2050.

Table 8. Number of monuments per province potentially exposed to 4-6 intense rainfall days by 2050

4-6 intense rainfall days		
	#	%
Drenthe (DR)	165	12
Flevoland (FL)	9	8
Friesland (FR)	106	2
Gelderland (GE)	1507	23
Groningen (GR)	7	0.25
Limburg (LI)	649	12
North Brabant (NB)	497	8
North Holland (NH)	11220	79
Overijssel (OV)	78	2
Utrecht (UT)	1322	23
South Holland (ZH)	5551	60
Zeeland (ZE)	8	0.21
TOTAL	21119	33

Table 8 shows that around 33% of national monuments in the Netherlands can be exposed to multiple days (4-6) of intense rainfall events by 2050, which increases the risk of surface flooding. The monuments which can be exposed to the largest surface flooding are located in North Holland (11,220, 79% of all provincial monuments) and South Holland (5551, 66%), followed by the province of Gelderland (1507, 23%).

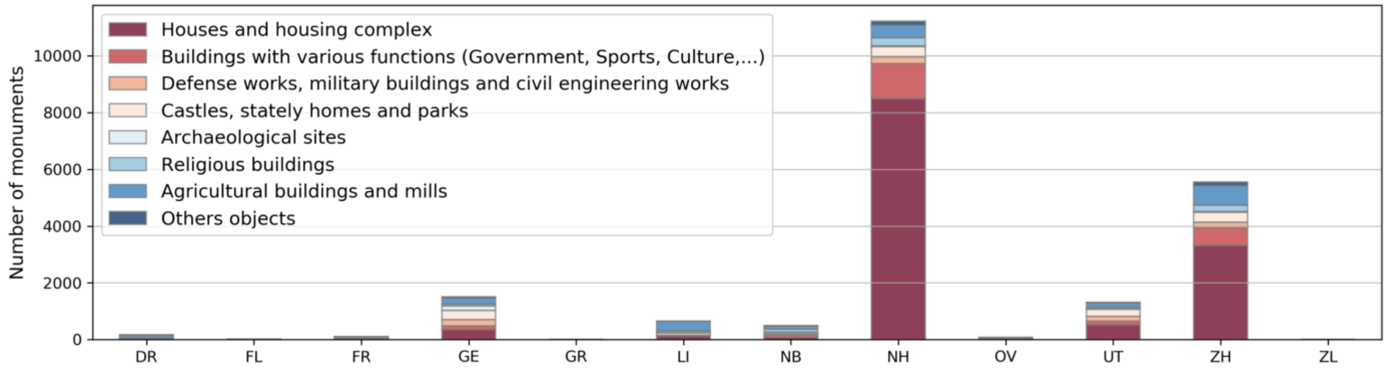

Figure 12. Categories of monuments potentially exposed to 4-6 intense rainfall days by 2050.

Table 9. Number of categories of monuments per province potentially exposed to 4-6 intense rainfall days by 2050

4-6 intense rainfall days								
	Houses and housing complex	Buildings with various functions	Agricultural buildings and mills	Castles, estates and parks	Defence works, military build. and civil engineer. works	Religious buildings	Other objects	Archaeological sites
	#	#	#	#	#	#	#	#
Drenthe (DR)	20	11	80	19	/	17	4	14
Flevoland (FL)	1	/	/	/	/	/	/	8
Friesland (FR)	30	14	19	24	6	8	3	2
Gelderland (GE)	351	129	206	318	226	69	53	155
Groningen (GR)	/	3	1	1	1	1	/	/
Limburg (LI)	133	19	321	78	8	55	16	19
North Brabant (NB)	82	76	112	50	49	95	22	11
North Holland (NH)	8487	1239	443	366	233	288	135	29
Overijssel (OV)	58	4	8	/	3	5	/	/
Utrecht (UT)	517	131	146	248	175	59	27	19
South Holland (ZH)	3313	634	686	355	187	233	124	19
Zeeland (ZL)	1	1	/	1	1	1	3	/
TOTAL	12993	2261	2022	1460	889	831	387	276
%	62	11	10	7	4	4	2	1

Regarding the monument categories (Table 9), houses and housing complexes (12,993) represent nearly two-thirds of all monuments that can be exposed to multiple days of intense rainfall events, followed by the buildings with various functions (2261, 11%) and agricultural buildings and mills (2022, 10%). In half of all provinces, houses and housing complexes are found to be the most exposed monument category to the potential multiple days of intense rainfall.

Urban pluvial flooding | Subsurface soil compaction

Description

Figure 13 shows a current risk of subsurface soil compaction. Subsurface compaction decreases the infiltration capacity, soil permeability and moisture storage capacity which can increase the risk of surface flooding. The risk map was generated using information on the soil type and properties, the fluctuation between the average highest and lowest groundwater level and the land use types [11].

Figure 14 shows the number of monuments per province that can be currently exposed to moderate and high subsurface soil compaction.

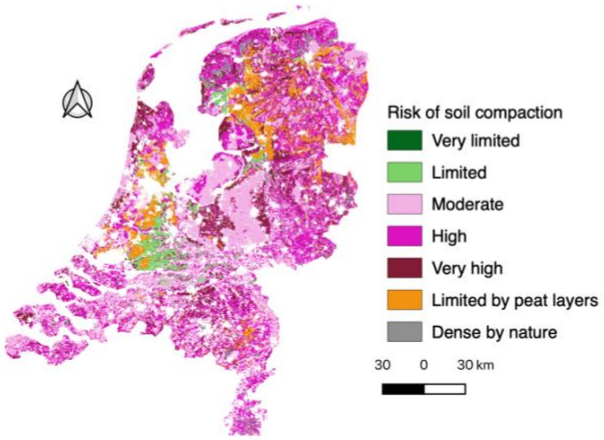

Figure 13. Current risk of subsurface soil compaction. Source: Climate Impact Atlas, 2020.

Results

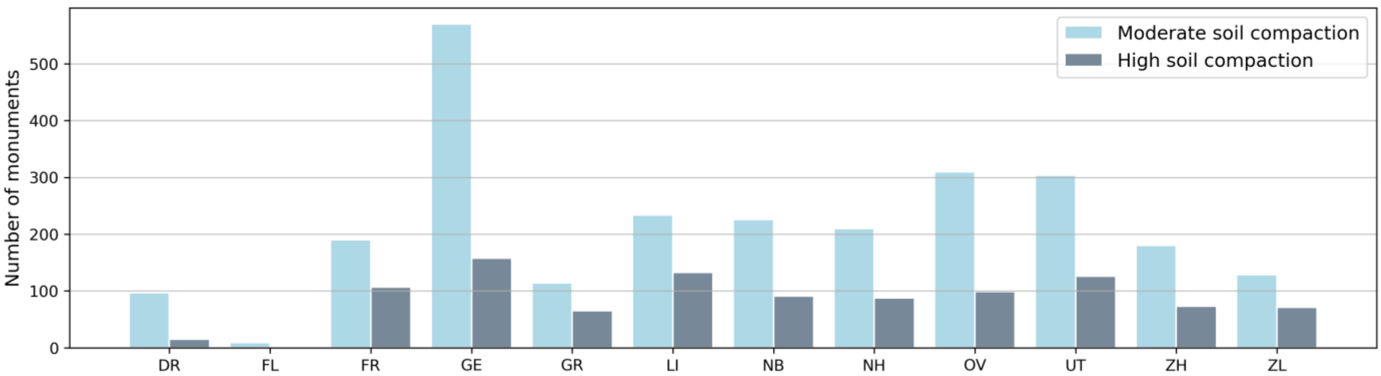

Figure 14. Number of monuments potentially exposed to moderate and high subsurface soil compaction.

Table 10. Number of monuments per province potentially exposed to moderate and high subsurface soil compaction

Risk of subsurface soil compaction				
	Moderate		High	
	#	%	#	%
Drenthe (DR)	97	7.07	15	1.09
Flevoland (FL)	9	8.26	2	1.83
Friesland (FR)	190	4.38	107	2.47
Gelderland (GE)	570	8.67	158	2.40
Groningen (GR)	114	4.12	65	2.35
Limburg (LI)	234	4.29	133	2.44
North Brabant (NB)	226	3.81	91	1.53
North Holland (NH)	210	1.49	88	0.62
Overijssel (OV)	310	7.66	99	2.45
Utrecht (UT)	304	5.31	126	2.20
South Holland (ZH)	180	1.95	73	0.79
Zeeland (ZL)	129	3.44	71	1.89
TOTAL	2573	4.06	1028	1.62

Table 10 shows that about 4% (2573) of all national monuments are located on the land prone to moderate subsurface soil compaction and nearly 2% (1028) on the land prone to high soil compaction. Gelderland and Overijssel are the provinces whose monuments can be the most affected by moderate soil compaction, with 570 (8.67% of all provincial monuments) and 304 (5.31%) monuments, respectively. Similarly, the largest number of monuments potentially prone to high risk of subsurface soil compaction is in Gelderland (158, 2.40% of all provincial monuments) and Limburg (133, 2.44%).

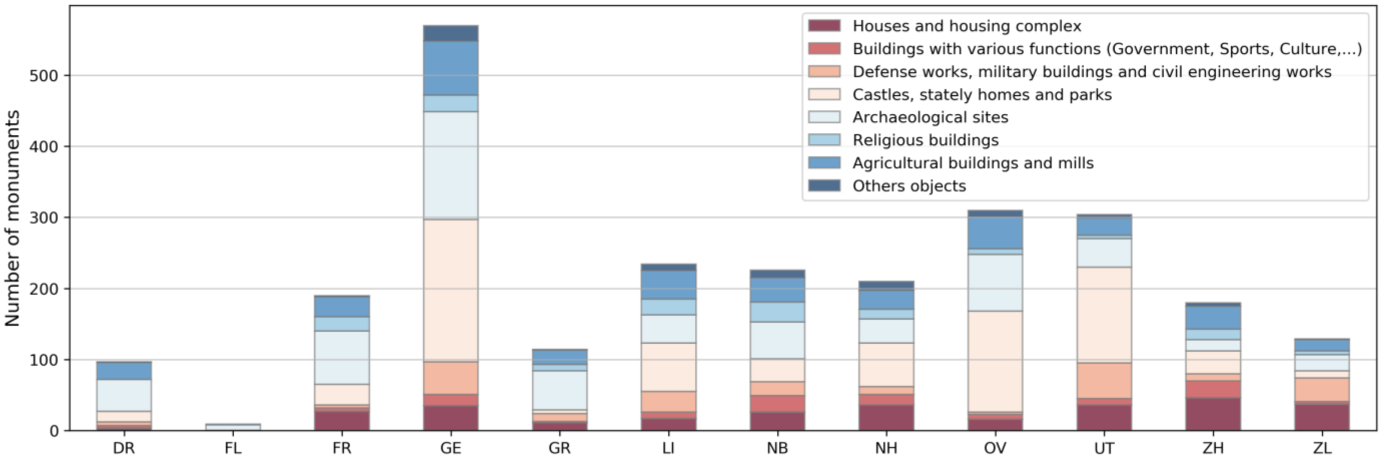

Figure 15. Categories of monuments located in areas of moderate risk of soil compaction.

Table 11. Categories of monuments located in areas of moderate risk of soil compaction

Moderate risk of soil compaction								
	Castles, estates and parks	Archaeological sites	Agricultural buildings and mills	Houses and housing complex	Defence works, military build. and civil engineer. works	Religious buildings	Buildings with various functions	Other objects
	#	#	#	#	#	#	#	#
Drenthe (DR)	15	45	24	3	5	/	4	1
Flevoland (FL)	/	8	1	/	/	/	/	/
Friesland (FR)	29	75	28	27	4	20	5	2
Gelderland (GE)	200	152	76	35	46	23	16	22
Groningen (GR)	5	55	20	11	11	9	2	1
Limburg (LI)	68	40	40	17	29	22	9	9
North Brabant (NB)	32	52	34	26	20	28	23	11
North Holland (NH)	61	34	26	36	11	14	15	13
Overijssel (OV)	142	80	45	16	3	8	7	9
Utrecht (UT)	135	40	24	36	50	5	9	5
South Holland (ZH)	32	16	32	46	10	15	24	5
Zeeland (ZL)	10	23	16	37	33	5	4	1
TOTAL	729	620	366	290	222	149	118	79
%	28	24	14	11	9	6	5	3

As shown in Table 11, from a total of 2573 monuments located in areas that are potentially at moderate risk of subsurface soil compaction, nearly a third of them are castles, estates and parks (729, 28%), followed by the archaeological sites (620, 24%) and agricultural buildings and mills (366, 14%). In five provinces, castles, estates and parks can be the most exposed monument category to the subsurface soil compaction.

Drought | Deterioration of timber pile foundations

Description

Figure 16 shows a current risk of urban areas prone to deterioration of timber pile foundations. It uses information on the construction period of buildings and the soil characteristics while excluding the effects of climate change. The deterioration of timber pile foundations is especially relevant under increasing drought scenario and associated low groundwater levels [12].

Figure 17 shows the number of monuments in urban areas that can be currently exposed to moderate and high deterioration of timber pile foundations. For this analysis, only historic buildings within the main monument categories were selected. Given the lack of information on historic buildings' foundations, exposure to this hazard is considered to equally affect all historic buildings within the hazard area regardless of their foundation type (e.g., wood, stone, concrete, steel).

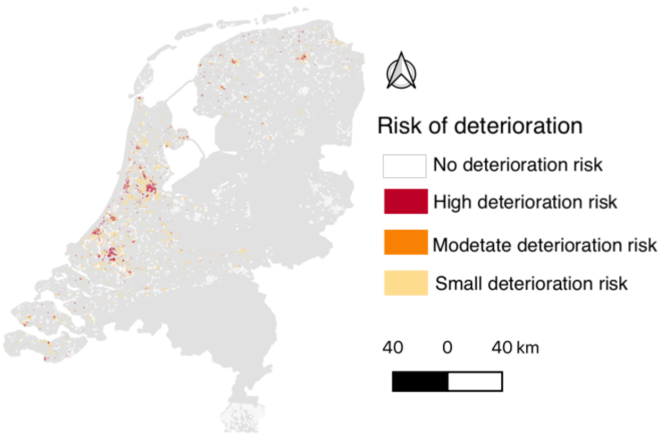

Figure 16. Current risk of deterioration of timber pile foundations. Source: Climate Impact Atlas, 2020.

Results

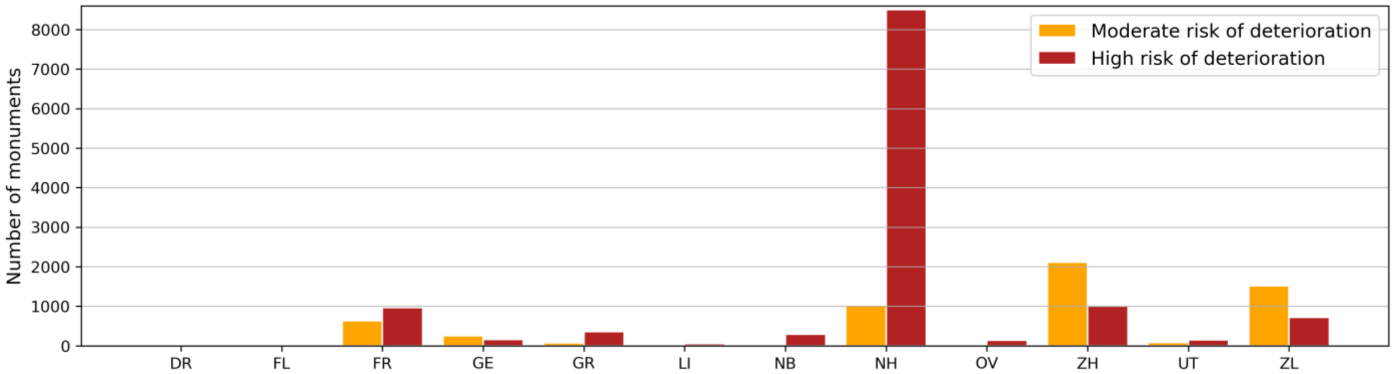

Figure 17. Number of monuments with a moderate and high risks of deterioration of timber pile foundations.

Table 12. Number of monuments per province with a moderate and high risks of deterioration of timber pile foundations

Risks of deterioration of timber pile foundations					
	Selected monuments*	Moderate		High	
	#	#	%	#	%
Drenthe (DR)	1181	6	0.51	26	2.20
Flevoland (FL)	72	1	1.39	1	1.39
Friesland (FR)	3767	632	16.78	971	25.78
Gelderland (GE)	5255	253	4.81	159	3.03
Groningen (GR)	2242	77	3.43	362	16.15
Limburg (LI)	4824	13	0.27	55	1.14
North Brabant (NB)	5099	29	0.57	296	5.81
North Holland (NH)	13193	1024	7.76	8506	64.47
Overijssel (OV)	3241	8	0.25	138	4.26
Utrecht (UT)	4510	87	1.93	151	3.35
South Holland (ZH)	8244	2113	25.63	1001	12.14
Zeeland (ZL)	3372	1514	44.90	722	21.41
TOTAL	55000	5757	11	12388	23

*Total number of monuments includes only historic buildings in each of the main monument category and excluding monuments categories (other objects, archaeological sites) and sub-categories that are not buildings (bridge, memorial, wall, border demarcation, garden and parks, military object, cemetery, waterway, street furniture, canal, road).

As shown in Table 12, about 10% of all historic buildings (as national monuments) can be affected by moderate deterioration of timber pile foundations and 23% of buildings by high deterioration. South Holland (2113, 26% of all provincial buildings) and Zeeland (1514, 45%) are the provinces with the largest numbers of historic buildings located in areas of moderate risk of foundation deterioration. In addition, North Holland (8506, 65% of all provincial buildings), South Holland (1001, 12%) and Friesland (971, 26%) are the provinces with the largest numbers of historic buildings potentially exposed to high risk of deterioration.

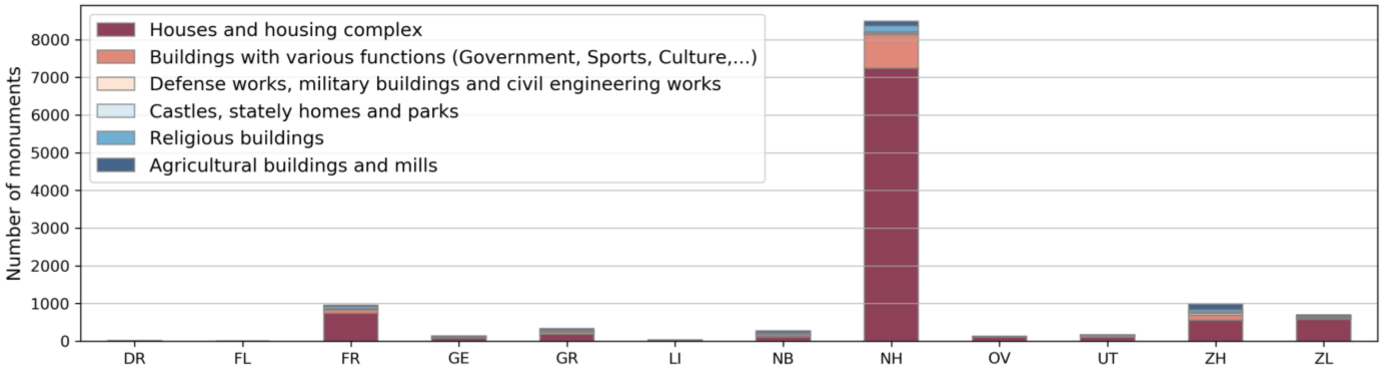

Figure 18. Categories of monuments (only buildings) with high risk of deterioration of timber pile foundations.

Table 13. Categories of monuments (only buildings) with high risk of deterioration of timber pile foundations

High risk of deterioration of timber pile foundations						
	Houses and housing complex	Buildings with various functions	Agricultural buildings and mills	Religious buildings	Defence works, military build. and civil engineer. works	Castles, estates and parks
	#	#	#	#	#	#
Drenthe (DR)	6	2	16	2	/	/
Flevoland (FL)	/	/	1	/	/	/
Friesland (FR)	742	88	61	64	10	6
Gelderland (GE)	80	13	22	22	12	10
Groningen (GR)	190	46	79	43	2	2
Limburg (LI)	23	4	21	4	/	3
North Brabant (NB)	121	35	57	31	40	12
North Holland (NH)	7234	884	172	162	26	28
Overijssel (OV)	111	3	12	9	2	1
Utrecht (UT)	105	5	21	8	6	6
South Holland (ZH)	566	134	155	65	43	38
Zeeland (ZL)	580	43	47	37	12	3
TOTAL	9758	1257	664	447	153	109
%	79	10	5	4	1	1

Table 13 shows that from a total of 12,388 historic buildings potentially located in areas of high risk of foundation deterioration, 79% of them are houses and housing complexes (9758), followed by buildings with various functions (1257, 10%) and agricultural buildings and mills (664, 5%). Houses and housing complexes are also found to be the most exposed building type to potential foundation deterioration in all 12 provinces.

Drought | Subsidence

Description

Figure 19 shows the projected rates of land subsidence or sinking of the ground (in cm) in the period 2016-2050, if no mitigation/preventive measures are taken. Areas where the subsidence is projected to be less than 3cm are not shown. In the Netherlands, subsidence is particularly concerning due to decreasing groundwater levels (drought-related) and human activities like gas extraction and water management [13].

Figure 20 shows the number of monuments per province that can be exposed to the subsidence rates of 20-40cm, 40-60cm and more than 60cm until 2050.

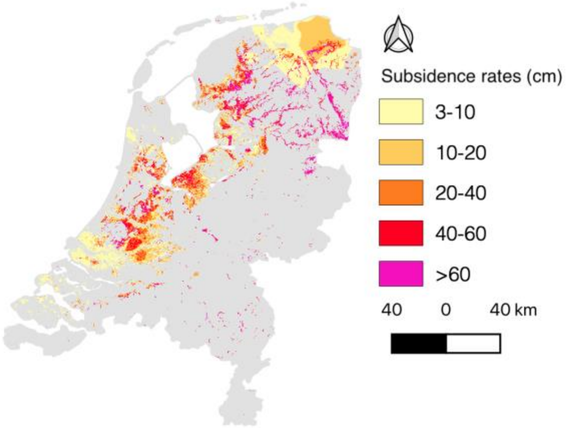

Figure 19. Subsidence rates until 2050. Source: Climate Impact Atlas, 2020.

Results

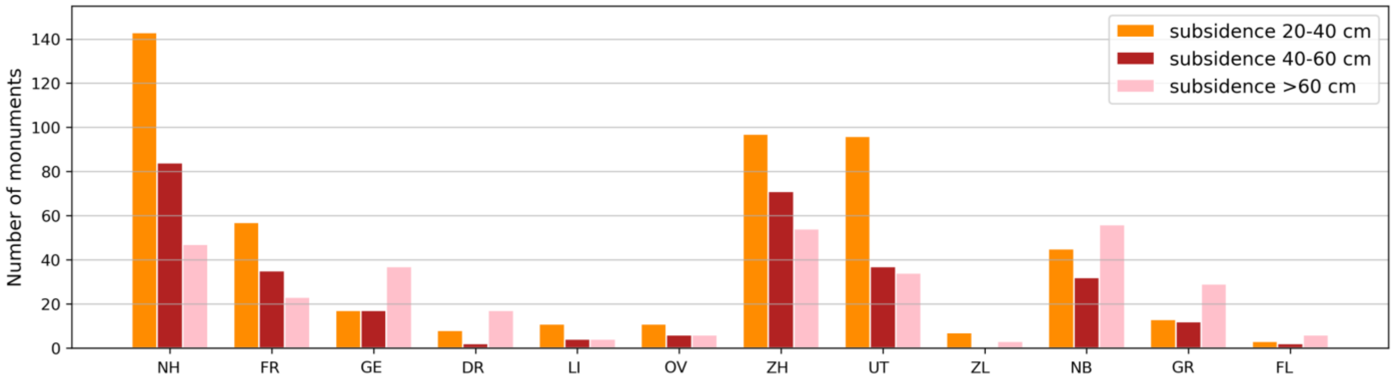

Figure 20. Number of monuments potentially exposed to subsidence rates of 20-40, 40-60 and more than 60cm in the period 2016-2050.

Table 14. Number of monuments per province potentially exposed to subsidence rates of 20-40, 40-60 and more than 60cm in the period 2016-2050

	Subsidence rates					
	20-40cm		40-60cm		>60cm	
	#	%	#	%	#	%
Drenthe (DR)	8	0.58	2	0.15	17	1.24
Flevoland (FL)	3	2.75	2	1.83	6	5.50
Friesland (FR)	57	1.31	35	0.81	23	0.53
Gelderland (GE)	17	0.26	17	0.26	37	0.56
Groningen (GR)	13	0.47	12	0.43	29	1.05
Limburg (LI)	11	0.20	4	0.07	4	0.07
North Brabant (NB)	45	0.76	32	0.54	56	0.94
North Holland (NH)	143	1.01	84	0.60	47	0.33
Overijssel (OV)	11	0.27	6	0.15	6	0.15
Utrecht (UT)	96	1.68	37	0.65	34	0.59
South Holland (ZH)	97	1.05	71	0.77	54	0.59
Zeeland (ZL)	7	0.19	0	0.00	3	0.08
TOTAL	508	0.80	302	0.48	316	0.50

Table 14 shows that nearly 2% of all national monuments can be exposed to subsidence rates of 20-60cm and more than 60cm. Among the provinces, monuments in North Holland (combined 227 monuments or 1.6% of all provincial monuments) and South Holland (combined 168, 1.9%) can experience the highest subsidence rates of between 20 and 60cm. The largest number of monuments that can be prone to subsidence of more than 60cm are located in North Brabant (56, 0.9% of all provincial monuments) and South Holland (54, 0.6%).

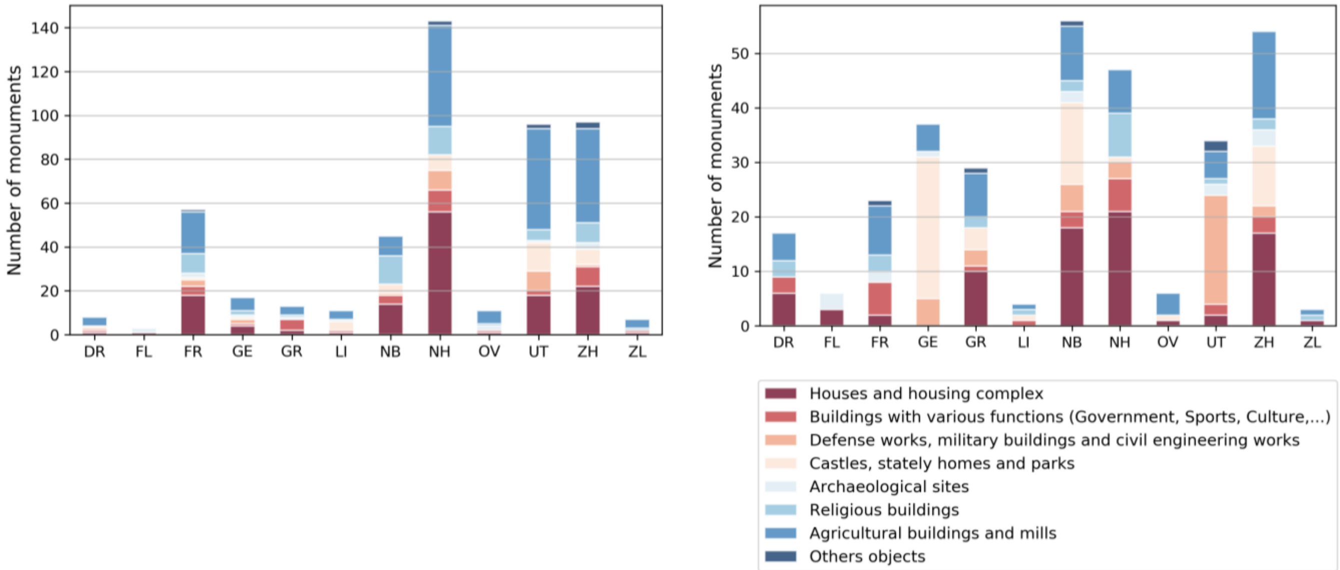

Figure 21. Categories of monuments potentially exposed to subsidence rates of 20-40cm (left) and more than 60cm (right) in the period 2016-2050.

Table 15. Categories of monuments per province potentially exposed to subsidence rate of 20-40cm in the period 2016-2050

Subsidence rate 20-40cm								
	Agricultural buildings and mills	Houses and housing complex	Religious buildings	Buildings with various functions	Castles, estates and parks	Defence works, military build. and civil engineer. works	Archaeal. sites	Other objects
	#	#	#	#	#	#	#	#
Drenthe (DR)	4	1	/	1	1	1	/	/
Flevoland (FL)	/	1	/	/	/	/	2	/
Friesland (FR)	19	18	9	4	1	3	2	1
Gelderland (GE)	6	4	2	1	1	2	1	/
Groningen (GR)	4	2	1	5	/	/	1	/
Limburg (LI)	4	1	/	1	4	/	1	/
North Brabant (NB)	9	14	13	4	4	1	/	/
North Holland (NH)	46	56	13	10	7	9	/	2
Overijssel (OV)	6	1	1	1	/	/	2	/
Utrecht (UT)	46	18	5	2	13	9	1	2
South Holland (ZH)	43	22	9	9	7	1	3	3
Zeeland (ZL)	4	1	1	1	/	/	/	/
TOTAL	191	139	54	39	38	26	13	8
%	38	27	11	8	7	5	3	2

As shown in Table 15, from a total of 508 monuments potentially prone to subsidence of 20-40cm, about a third of them are agricultural buildings and mills (191), followed by the houses and housing complexes (139, 27%) and religious buildings (54, 11%). In eight provinces, agricultural buildings and mills can be the most exposed monument category to the subsidence rate of 20-40cm until 2050.

Heat | Tropical days

Description

Figure 22 shows the average number of tropical days or days with maximum temperature (Tmax) greater than or equal to 30°C per year by 2050. For this analysis, the KNMI's WH scenario is used, which shows the largest number of tropical days [10]. While the duration of tropical days is typically associated with the public health issues, high, persistent temperature can adversely affect the monuments through physical and biochemical deterioration (e.g., facades, materials and historic fabric) [14].

Figure 23 shows the number of monuments per province that can be exposed to more than 12 tropical days by 2050.

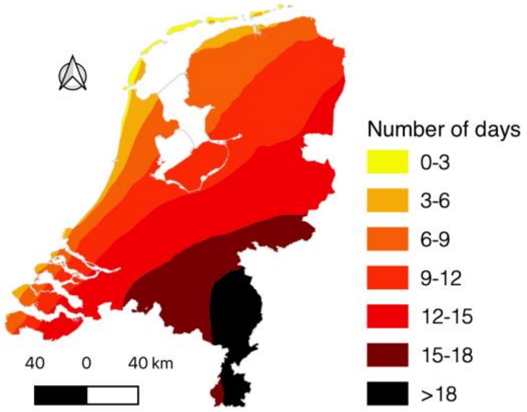

Figure 22. Number of tropical days per year by 2050. Source: Climate Impact Atlas, 2020.

Results

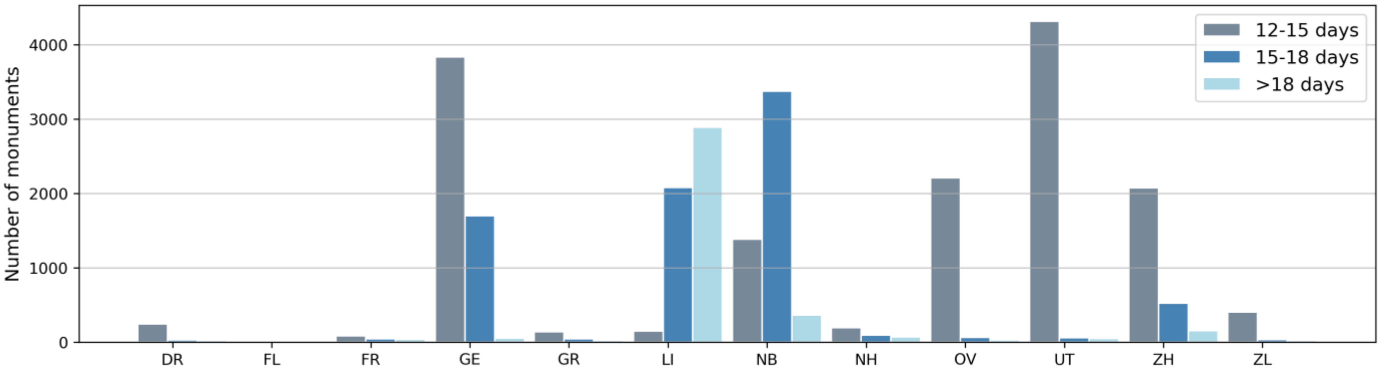

Figure 23. Number of monuments potentially exposed to 12-15, 15-18 and more than 18 tropical days by 2050.

Table 16. Number of monuments per province potentially exposed to 12-15, 15-18 and more than 18 tropical days by 2050

	Number of tropical days					
	12-15 days		15-18 days		>18 days	
	#	%	#	%	#	%
Drenthe (DR)	245	18	29	2	22	2
Flevoland (FL)	11	10	7	6	2	2
Friesland (FR)	86	2	44	1	37	1
Gelderland (GE)	3836	58	1698	26	55	1
Groningen (GR)	141	5	42	2	22	1
Limburg (LI)	150	3	2079	38	2892	53
North Brabant (NB)	1384	23	3374	57	366	6
North Holland (NH)	192	1	93	1	70	0
Overijssel (OV)	2208	55	65	2	30	1
Utrecht (UT)	4315	75	60	1	48	1
South Holland (ZH)	2075	23	525	6	156	2
Zeeland (ZL)	405	11	34	1	25	1
TOTAL	15048	24	8050	13	3725	6

Table 16 shows that nearly a quarter (15,048) of all the monuments can be exposed to 12-15 tropical days per year, while 13% (8050) of all monuments can experience 15-18 days of maximum temperature equal or higher than 30°C. About 6% (3725) of all monuments can be exposed to more than 18 tropical days. The monuments that can be exposed to the largest number of tropical days (three levels of days combined) are located in Gelderland (5589, 85% of all provincial monuments), North Brabant (5124, 86%) and Limburg (5121, 94%). However, the number of monuments that can be affected by tropical days does not only depend on the exposure to the hazard but also on other factors such as monuments' construction materials (e.g., stone, wood, steel) which are not considered in this study (see **Limitations of the study and future research needs**).

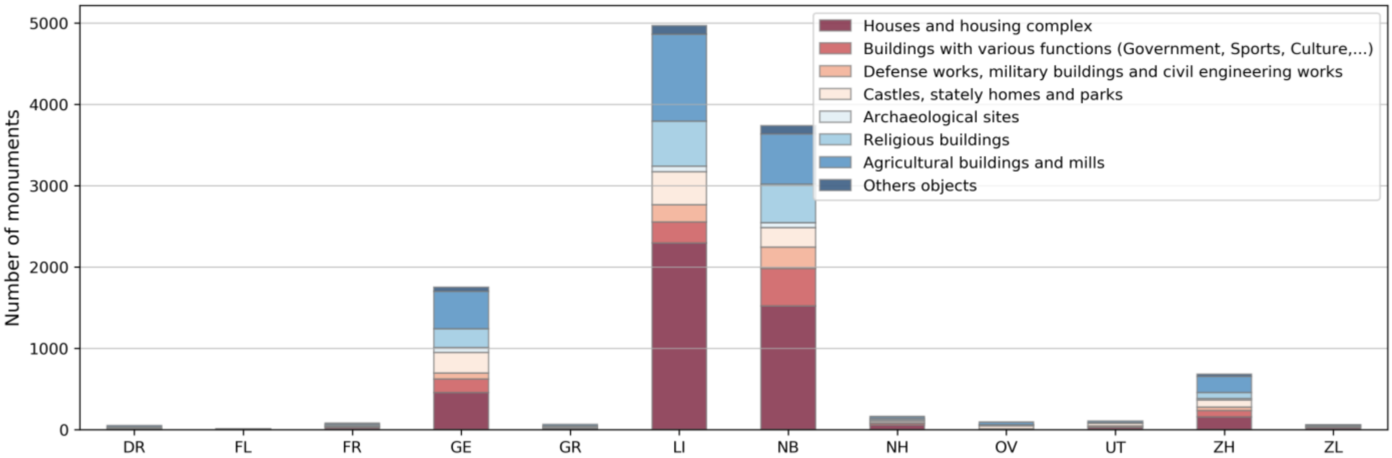

Figure 24. Categories of monuments potentially exposed to 15-18 tropical days by 2050.

Table 17. Categories of monuments per province potentially exposed to 15-18 tropical days by 2050

15-18 of tropical days								
	Houses and housing complex	Agricultural buildings and mills	Religious buildings	Castles, estates and parks	Buildings with various functions	Defence works, military build. and civil engineer. works	Other objects	Archaeal. sites
	#	#	#	#	#	#	#	#
Drenthe (DR)	5	13	9	4	5	1	/	14
Flevoland (FL)	3	1	/	/	/	2	/	3
Friesland (FR)	23	15	16	7	9	2	2	7
Gelderland (GE)	459	463	228	253	164	72	50	64
Groningen (GR)	15	17	3	3	4	1	/	21
Limburg (LI)	2296	1067	553	407	258	212	109	69
North Brabant (NB)	1520	619	477	241	461	263	101	58
North Holland (NH)	57	23	19	25	24	3	2	10
Overijssel (OV)	8	33	6	33	1	3	2	9
Utrecht (UT)	27	20	1	33	7	11	/	9
South Holland (ZH)	158	197	74	86	80	41	26	19
Zeeland (ZL)	23	10	5	6	2	3	2	8
Total	4594	2478	1391	1098	1015	614	294	291
%	39	21	12	9	9	5	2	2

Regarding the monument categories (Table 17), houses and housing complexes (4594) represent about a third of all monuments that are potentially exposed to 15-18 tropical days per year, followed by the agricultural buildings and mills (2478, 21%) and religious buildings (1391, 12%). In about two-thirds of provinces, houses and housing complexes are potentially the most exposed monument category to 15-18 tropical days per year by 2050.

Heat | Longest series of consecutive days with maximum temperature ≥25˚C

Description

Figure 25 shows the longest series of consecutive days with maximum temperature (Tmax) greater than or equal to 25°C per year in 2050. For this analysis, the KNMI's WH scenario is used, which assumes the largest number of days with Tmax ≥25°C [10]. For some monument categories (e.g., dykes, natural areas, parks, gardens, timber pile foundations of monuments) the persistence of warm periods above 25°C can cause structural damage and deterioration [14].

Figure 26 shows the number of monuments per province that can be exposed to 11-15 consecutive days with Tmax ≥25°C by 2050.

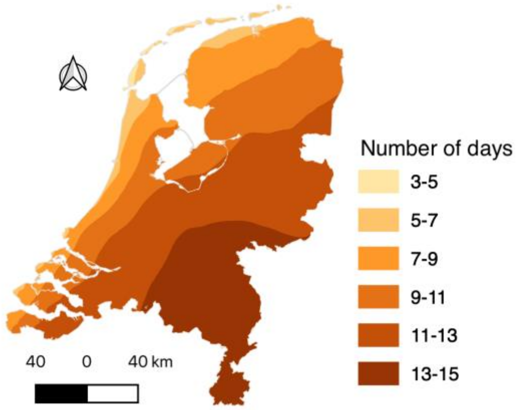

Figure 25. Number of consecutive days with Tmax ≥25°C per year by 2050. Source: Climate Impact Atlas, 2020.

Results

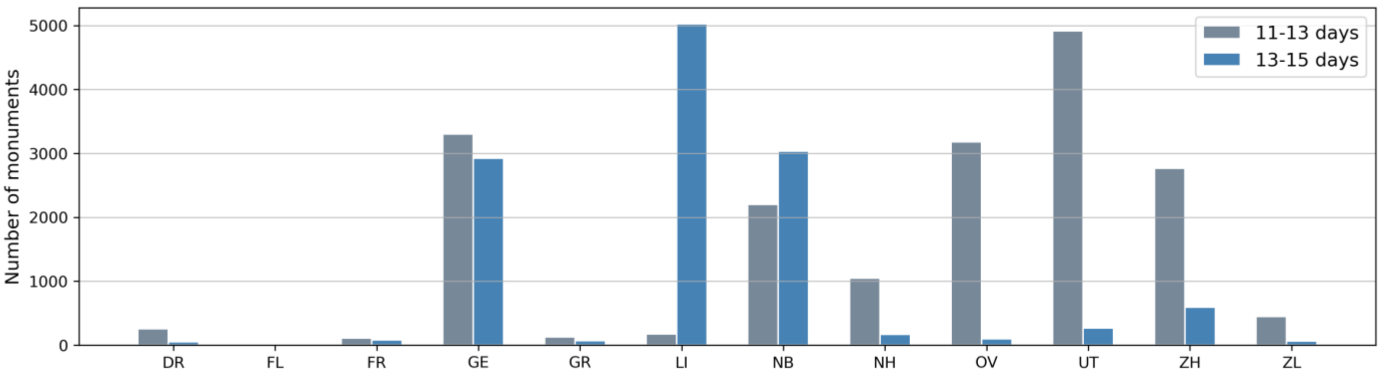

Figure 26. Number of monuments potentially exposed to 11-13 and 13-15 consecutive days with Tmax ≥25°C by 2050.

Table 18. Number of monuments per province potentially exposed to 11-13 and 13-15 consecutive days with Tmax ≥25°C by 2050

Number of consecutive days with Tmax ≥25˚C				
	11-13 days		13-15 days	
	#	%	#	%
Drenthe (DR)	256	19	53	4
Flevoland (FL)	11	10	9	8
Friesland (FR)	109	3	81	2
Gelderland (GE)	3301	50	2925	45
Groningen (GR)	130	5	68	2
Limburg (LI)	175	3	5028	92
North Brabant (NB)	2200	37	3033	51
North Holland (NH)	1047	7	167	1
Overijssel (OV)	3180	79	99	2
Utrecht (UT)	4916	86	267	5
South Holland (ZH)	2766	30	593	6
Zeeland (ZL)	446	12	65	2
TOTAL	18537	29	12388	20

Table 18 shows that nearly a third (18,537) of all national monuments can be exposed to 11-13 consecutive days with Tmax ≥25°C, while 20% (12,388) of all monuments can experience 13-15 consecutive days with Tmax ≥25°C per year by 2050. Among the provinces, monuments in Gelderland (combined 6226 monuments or 95% of all provincial monuments), followed by North Brabant (combined 5233, 88%) and Limburg (combined 5203, 95%) are potentially the most exposed to 11-15 consecutive days with Tmax ≥25°C. Note that the total number of monuments that can be affected by maximum temperature equal or higher than 25°C does not only depend on the exposure to the hazard, but also on other factors such as monuments' construction materials which are not considered in this study (see **Limitations of the study and future research needs**).

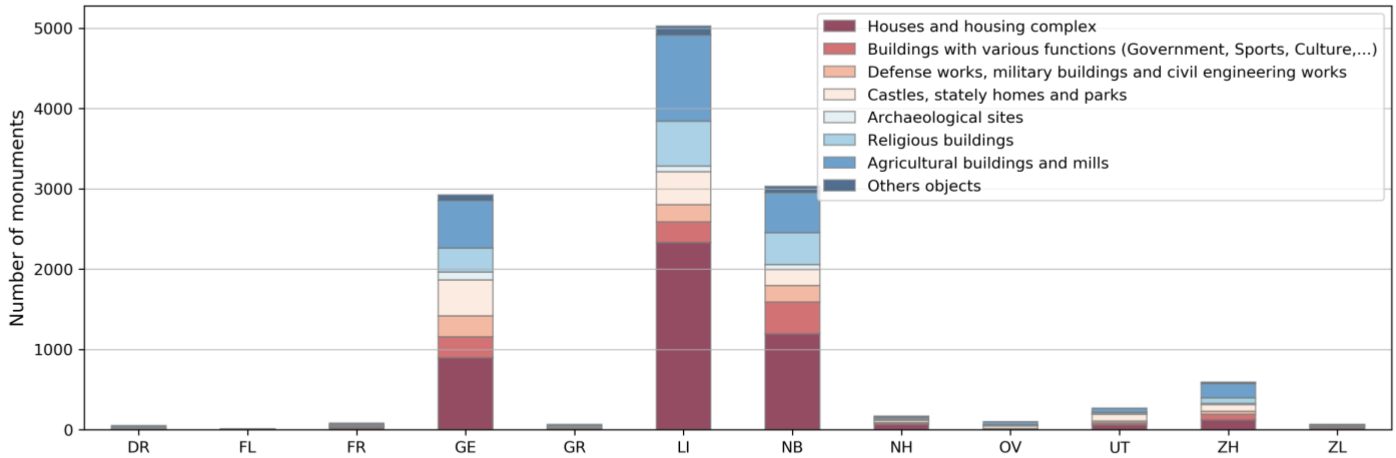

Figure 27. Categories of monuments potentially exposed to 13-15 consecutive days with Tmax ≥25°C by 2050.

Table 19. Categories of monuments per province potentially exposed to 13-15 consecutive days with Tmax ≥25°C by 2050

Consecutive 13-15 days of Tmax ≥25°C								
	Houses and housing complex	Agricultural buildings and mills	Religious buildings	Castles, estates and parks	Buildings with various functions	Defence works, military build. and civil engineer. works	Archaeal. sites	Other objects
	#	#	#	#	#	#	#	#
Drenthe (DR)	5	15	9	4	5	1	14	/
Flevoland (FL)	3	1	/	/	/	2	3	/
Friesland (FR)	26	14	15	7	8	2	7	2
Gelderland (GE)	898	588	302	446	257	263	98	73
Groningen (GR)	16	16	3	6	4	1	22	/
Limburg (LI)	2331	1075	558	410	256	215	70	113
North Brabant (NB)	1194	499	397	201	398	204	60	80
North Holland (NH)	65	22	18	25	23	3	9	2
Overijssel (OV)	9	34	6	32	2	4	10	2
Utrecht (UT)	61	49	6	87	22	23	17	2
South Holland (ZH)	121	173	70	82	69	39	18	21
Zeeland (ZL)	23	12	4	6	2	5	11	2
Total	4752	2498	1388	1306	1046	762	339	297
%	38	20	11	11	8	6	3	2

As shown in Table 19, from a total of 12,388 monuments potentially exposed to 13-15 consecutive days with Tmax ≥25°C per year, about a third of them are houses and housing complexes (4752), followed by agricultural buildings and mills (2498, 20%) and religious buildings (1388, 11%). In seven provinces, houses and housing complexes are potentially the most exposed monument category to 13-15 consecutive days with Tmax ≥25°C by 2050.

Limitations of the study and future research needs

As a preliminary assessment, this report represents a valuable step towards preparing Dutch national monuments or nationally significant cultural heritage to address current and future climate change hazards. We examined only the *exposure* (i.e., monument's presence in a place that could be adversely affected by a climate change hazard) of 63,389 national monuments to a subset of climate change hazards – coastal and river flooding, urban pluvial flooding, drought and heat.

The assessment of exposure reveals that national monuments in all 12 provinces can be already or could be further exposed to coastal and river flooding, urban pluvial flooding, drought and heat. This study also suggests which monument categories can be more exposed to specific hazards at specific locations (provinces). Importantly, while exposure can indicate monuments on which impacts can occur, exposure does not necessarily imply that monuments will be more sensitive (or affected) to the climate change hazard. Also, different hazards will have different levels of exposure for different monument categories, whereas the underlying *sensitivity* and *adaptive capacity* may not change.

Several further research needs and improvements are recommended:

- The present exposure of monuments may overestimate exposure at monument-scale due to the spatial averaging of hazards and omission of monuments' *sensitivity* and *adaptive capacity* (e.g., monument past preventive measures such as elevated monument in Friesland).
- The monument database used for the analysis identifies each monument with a node which means that some monuments such as archaeological sites or housing complexes are spatially constrained to a node. As such, while the monument's locational information may be accurate, its precision and uniformity may vary when it is used in climate change hazard analysis (e.g., some monuments may have their nodes outside of the hazard zone). Research is required to ensure additional locational accuracy of national monuments in climate change vulnerability assessments.
- Limitation of this study is also the uncertainty associated with future estimates of exposure. Climate Impact Atlas is based on the KNMI's WH scenario which in most cases shows the most forceful changes. However, we encourage cultural heritage management decisions to be made in the face of this uncertainty.
- Additional climate change hazards are relevant for evaluation of exposure, for instance, wind intensity and frequency, saltwater intrusion and sea temperature change could be examined in future research.
- Future research should analyse the *sensitivity* of monuments (i.e., the degree to which the monument could be affected by its exposure), for instance, by considering monuments' current structural condition, construction materials, state of maintenance, etc.
- Future research should analyse *adaptive capacity* of decision-makers or heritage managers, for instance, by considering past and future preventive or adaptation measures that could reduce the vulnerability of monuments to climate change. Note that monuments that are exposed to the hazard, along with preventive or adaptation measures in place, may have lower overall vulnerability to climate change.
- Future analyses should further distinguish between 13 categories of national monuments. For instance, the category of archaeological sites does not distinguish between inland, maritime and underwater archaeological sites. Each of these archaeological sites beside different exposure has its own structural/physical characteristics thus, different sensitivity (a component of vulnerability).

It is our hope that this study is the beginning of a continuing process to integrate climate change risks into cultural heritage management and conservation in the Netherlands. We hope this study will motivate the development of a holistic approach that evaluates all three components of vulnerability – exposure, sensitivity and adaptive capacity – at the national, provincial and local levels. This in turn, can guide proactive site-specific climate adaptation strategies for national monuments in the Netherlands, as well as inform potential prioritization processes for climate adaptation. We also encourage multi-level policy-makers in climate change and environmental fields to consider exposure and overall vulnerability of national monuments in their future policy-making processes.

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