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InSAR for Climate Change Geo-Resilience: Quantifying the Risks of Urban Flooding

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Abstract

Climate change in NW Europe has seen a 35% increase in the average annual precipitation over the last century and a marked increase in extreme rainfall events (European Environment Agency, 2019). Combined, these can cause localised flooding resulting in damage to buildings and agriculture. When it isn't raining, countries are experiencing long periods of drought, which, particularly in the Netherlands, has accelerated soil decomposition. The resulting runoff now exceeds the ability to store rainwater and when combined with subsidence means many houses in the Netherlands flood in a worsening recurring cycle. The task is to predict and quantify the risk.

SkyGeo works with a number of municipalities to understand which houses are at most risk and how that risk will change in the future. High resolution TerraSAR-X was processed using SkyGeo's proprietary InSAR software. The resulting data was combined with a high-resolution LIDAR digital elevation model (DEM), building contours and (in some cases) recent door sill height measurements. Using the InSAR displacement rates and DEM inputs, we made a prediction as to the number of years before the building reaches a critical level below NAP (Normal Amsterdam Level). Together with the municipalities, we defined risk thresholds based on expected damages, frequency of damages and projected door sill heights based on the settlement rates.

The result is a series of maps which the municipality uses to visualise and communicate the flooding problem to homeowners. The InSAR results help inform the 50-year projections the municipality has to make as part of the climate strategy plan.

Keywords: InSAR, Climate, Foundations, Flooding

1. Introduction

The likelihood of flooding in urban areas is high due to the high proportion of tarmacked and paved surfaces which limit water infiltration and increase runoff. Further growing urban populations and urbanisation increase the pressure on existing drainage systems, increasing the likelihood of them being overwhelmed. In the Netherlands, 40% of the population live in the 36 largest cities, and this percentage is increasing yearly (Klimaatadaptienederland, 2022).

Furthermore, climate change in NW Europe is causing an increase in both average annual precipitation and in extreme rainfall events. Both changes increase the chance of flooding. Simultaneously, periods of continuous drought occur more often. Long dry periods accelerate soil decomposition, particularly in areas of peat soil, causing subsidence (Figure 1a).

Additionally, in the Netherlands, the majority of buildings built before 1970 are built on wooden piles. If groundwater levels reduce, for example during dry summers, these wooden piles begin to rot. Buildings on shallow foundations can be affected by differential settlement of subsoil, soil movement (such as shrink and swell of clays) and due to low quality/ageing foundations. A typical cross section of the subsurface in the West Netherlands is shown in Figure 1b.

In recent years, the increase in drought summers has led to increase claims associated with foundation damage. Ownership of tackling foundation issues are complex. The homeowner is responsible for the foundation; however, they do not have influence over the major causes of damage such as subsidence and changing groundwater levels. Experts estimate that the total cost of foundation damage in the Netherlands will add up to 20 to 30 billion euros by 2050 (Kok, 2021).

The nature of foundation problems is variable across different regions and dependent on several factors including foundation type, subsurface geology and groundwater levels. This makes knowledge on the extent of foundation problems difficult to obtain. The starting point to be able to tackle the foundation problems and building damage is more data to understand the scope of the problem.

Interferometric Synthetic Aperture Radar (InSAR) is a remote sensing technique that can estimate millimetre displacements of the Earth's surface. Using this technique, settlement rates of the buildings and the surrounding ground can be estimated. The settlement rate of the building provides insight into houses with potential foundation issues that are causing subsidence. In this paper, three cases of using settlement rates of houses estimated using InSAR to quantify risks associated with climate change are shared.

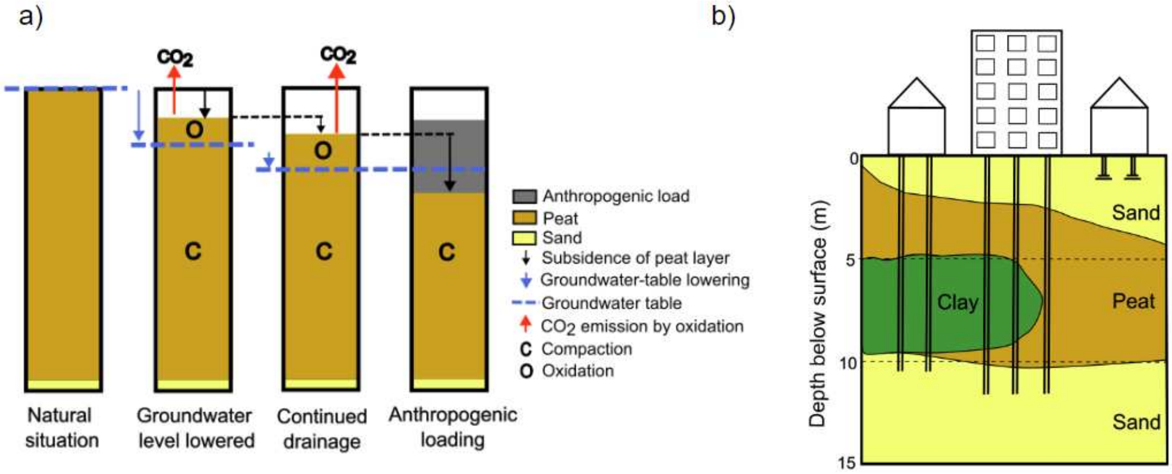

Figure 1: a) Schematic representation of the contributions of changes in groundwater level and anthropogenic loading subsidence through compaction and peat oxidation. Modified after van Asselen et al., 2018. b) Typical cross section of the Subsurface in the West Netherlands. Two houses on the left are founded on wooden piles, which typically go into the sand layer below the peat. On the right is a shallow foundation.

2. Method and data sources

The primary data source used in this investigation is InSAR. The underlying SAR data used was high resolution TerraSAR-X. The InSAR data was processed using the Persistent Scatterer Interferometry (PSI) method using SkyGeo's proprietary processing method.

A number of additional data sources were used during the InSAR processing and interpretation. A high-resolution LiDAR digital surface model for the Netherlands, Actueel Hoogtebestand Nederland (AHN), was used as an input to enable height separation of InSAR points on buildings vs those on the ground surface. Subsurface geological information was utilised from boreholes available on the Dutch Oil and Gas Portal (NLOG, n.d.). Information on the buildings, including building shapes in a GIS format containing information such as the building age were available from the Basisregistratie Adressen en Gebouwen (BAG) online portal. The BAG shapes were used to aggregate InSAR points to provide an average displacement rate per building. Weather information was also obtained from the Dutch National Meteorological Institute (KNMI).

3. Results

The results are shared through three case studies. The first on the topic of assessing flood risk in a municipality, the second on scoping the extent of foundation problems for a housing corporation and the third demonstrates the effects of drought summers on houses with shallow foundations.

3.1 Establishing buildings at highest risk of flooding in Krimpen aan den Ijssel

In 2008, municipalities were given the statutory task of taking care of groundwater as part of the new Water Act. To fulfil this task, the municipality of Krimpen aan den Ijssel formulated a groundwater care plan. As part of this, the municipality continuously monitors groundwater levels, manages interventions in the public spaces to remedy groundwater problems and is an advisor for residents with groundwater/flooding complaints.

Subsidence is a well-known problem in Krimpen aan den Ijssel. It is located between two large rivers, the Ijssel and the Maas to the east of Rotterdam. It is largely built on peat soil, interspersed with clay, underlain by sand. The variability of subsurface geology is shown in Figure 2.

The aim was to quantify the subsidence of houses in the area to understand which houses were most at risk from groundwater problems and flooding and to provide input to their groundwater care plan and long-term climate strategy. InSAR displacements were estimated from 2009 to 2020. InSAR points were then separated between those on buildings and those on the ground by applying a height threshold of 2.5 m above the AHN height. Using the building shapes from BAG, points above 2.5 m and within 1 m of a building shape were then aggregated to the building to provide an estimation of displacement per building. The output is shown in Figure 3.

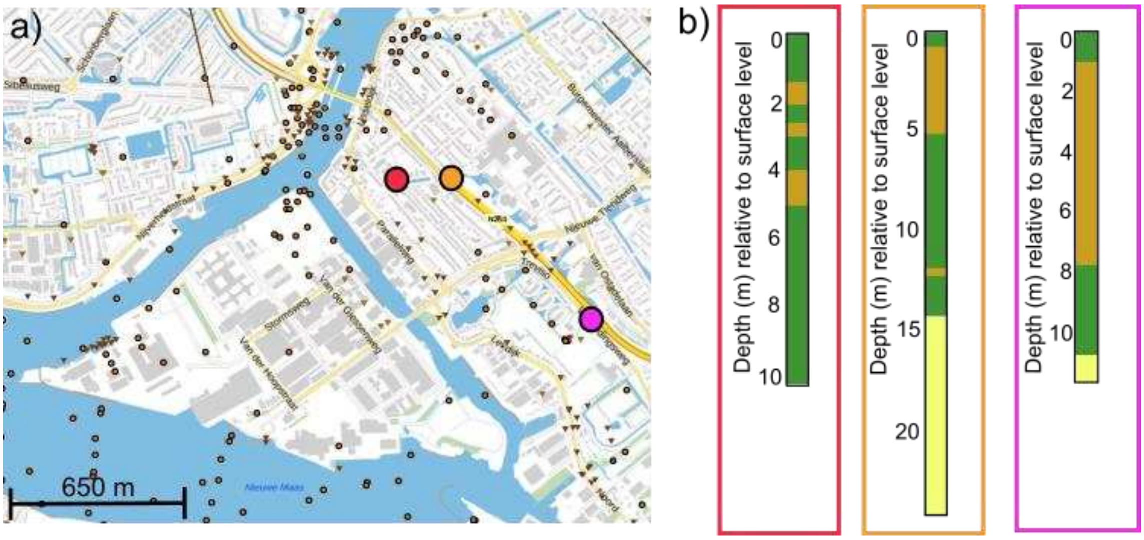

Figure 2: Three examples of boreholes in Krimpen aan den Ijssel showing the variation in peat thickness in an area less than 1 km across.

Figure 3: Average settlement rate per building, over the period 2009 to 2020, in a neighbourhood of Krimpen aan den Ijssel. Settlement rates are variable across the area, to the north-west and south-east the houses are generally stable with displacements less than 1 mm/yr. However, in the centre, there are several houses subsiding at > 5 mm/yr.

There are certain known heights, based on the knowledge of groundwater levels, where if a house falls below this level it is susceptible to flooding. These heights and the associated issues are outlined in Table 1.

Table 1: Potential issues for homeowners if the house floor level falls below the defined height.

Height (m)	Potential issue if floor level falls below the defined height
-1.10	High risk of flooding in the crawl space beneath the house
-1.40	Floor level is lower than the public space, hence rainwater from the plot no longer drains into the public areas and sewer system under gravity, making it more susceptible to flooding. Heavy rain may lead to wastewater flowing in the reverse direction from public sewer, via the sewer connection, into the home.
-1.92	The floor level is lower than the height of the overflow threshold, backwater of wastewater can flow from the public sewer, via the sewer connection, to the plot or into the home, even with low rainfall. The wastewater and rainwater cannot be drained from the plot to the public sewer under free fall and pumps are needed to drain the wastewater and rainwater from the plot to the public sewer.

With this information, the municipality has quantitative, data-based insights into locations and timings of risk. In the neighbourhood in Figure 4, approximately two thirds of the houses are already below -1.10 m NAP and have a high risk of flooding and just under one third are also below -1.4 m below NAP.

This knowledge has been used to communicate the flooding problem to homeowners, support budget allocation and provide input for climate change strategy plans.

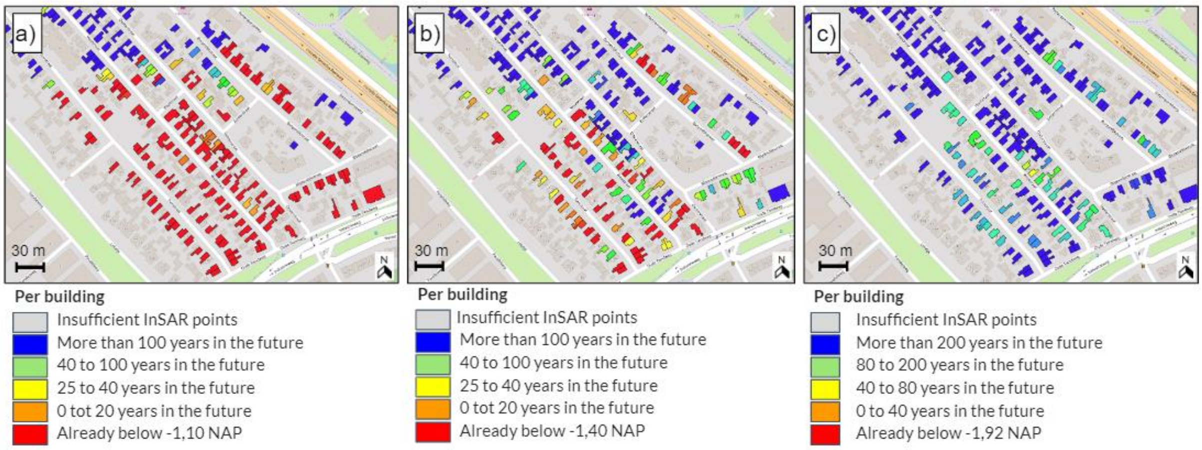

Figure 4: Number of years until a building reaches the defined height below NAP in a neighbourhood of Krimpen. a) -1.10 m, b) -1.40 m and c) -1.92 m.

3.2 Assessment of buildings with foundation damage - Ymere

Ymere is a housing corporation in the Netherlands that manages over 80,000 residences in the west of the Netherlands including homes in cities like Amsterdam, Haarlem and Almere. As part of their climate change strategy, Ymere plans to convert their buildings into a more “green” residence by improving the insulation as well as installing solar panels on rooftops. However, additional loading from solar panels and other renovation efforts can negatively impact weak foundations. Since most of the houses in the region are situated on old wooden piles, understanding the health of the foundation is critical.

Their initial approach to obtain knowledge on the state of foundations were randomised inspections based on visual surveys and communication from residents, which they then followed up with levelling campaigns. This information consequently informed their maintenance and upgrade schedules.

Since 2018, the corporation has relied primarily on SkyGeo’s InSAR based risk indicator map to plan their renovation efforts (Figure 5). The risk indicators are based on several statistical parameters that serve as proxies for foundation and building health. These parameters include anomalous horizontal motion, recent deviant displacement as compared to long term subsidence trends, and tilt of the building. These were then packaged into a risk value per building. An automated report was generated per building that contained the aggregated statistical information and the leading factor for risk.

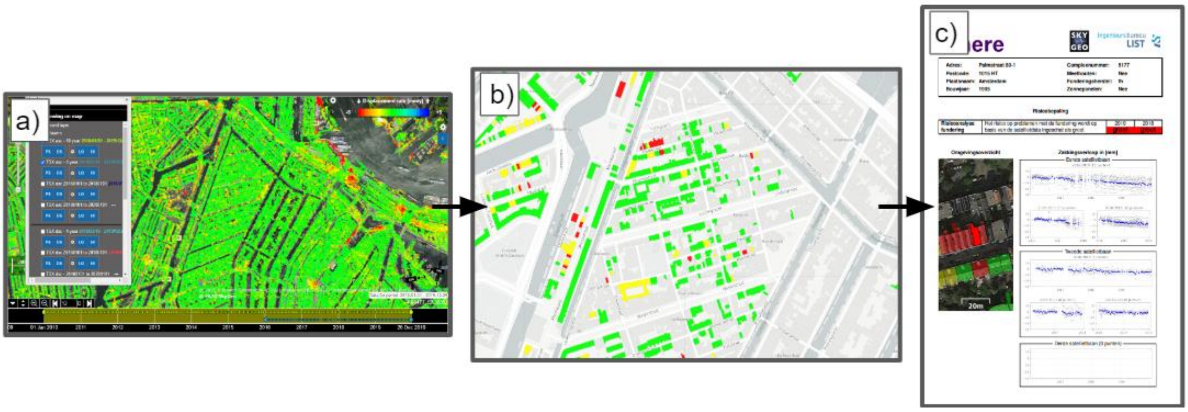

Figure 5: A summary of the approach adopted by SkyGeo to assist Ymere with foundation inspections. a) InSAR displacement map b) InSAR displacements aggregated per building c) individual building report summarising the risk *level* and key statistical parameters.

For example, in 2020, two buildings A and B (Figure 6a) to the north-west of the city of Amsterdam agreed to the CO_2 reduction pact (improved insulation) as well as to have solar panels installed on their roofs. However, Buildings A and B are state protected infrastructure and built in 1982 which makes them potentially high risk when it comes to renovations. They are both multistorey buildings with 4 four floors. Fortunately, the buildings have previously not shown any visual cracks or have ever needed any foundation repairs. But this means that there are also no measuring bolts installed and thus no historical traditional measurement information on the building. Using SkyGeo's risk map, Ymere could look back in time at the building's risk levels in the previous years.

In 2018, both Building A and Building B exhibited little to no characteristics for poor foundation health (Figure 6b). It is worth noticing however that the buildings adjacent to B seem to show concerning displacements. In 2020, however, B was graded as a building with moderate risk (Figure 6c). Thus, only building A was chosen for solar panel installation. In 2021, the risk assessment of buildings A and B indicated that building A's risk continued to be low indicating that the building was successfully transformed as per the CO2-pact.

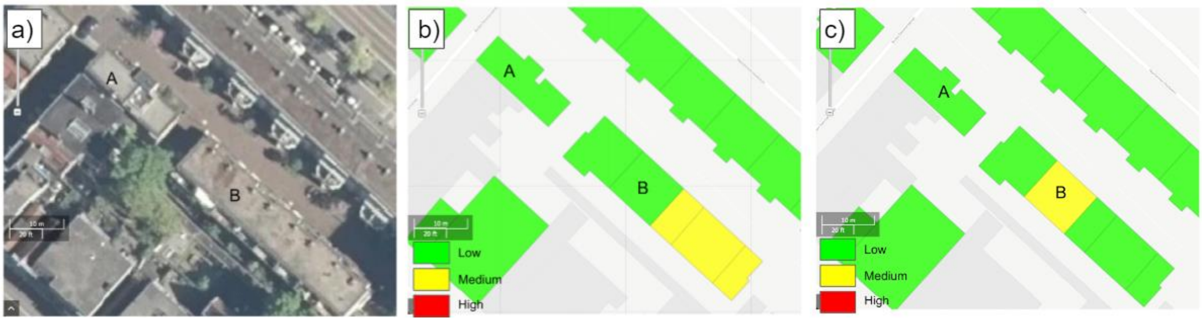

Figure 6: a) Orthophoto of the building of interest. b) Building risk map in 2018 c) Building risk map in 2020.

These risk maps are updated yearly to provide an annual picture of the status of all 80,000 buildings. This enables better informed budgeting and maintenance decisions based on quantitative data.

3.3 Effect of recent drought summers on building settlement

Increasing frequency of drought summers is an effect of climate change and of the past five summers, four are considered drier than average (KNMI, n.d.). A concern for many municipalities in the Netherlands is - what is the effect of these droughts on the infrastructure? The effects of drought are most problematic for older buildings on shallow foundations, because they are sensitive to changes in groundwater level and shrink-swell of clays. We investigated the effects of drought on a neighbourhood in the north of Rotterdam, Netherlands which was built near the end of the 1950's on shallow foundations. The geology consists of about 12 metres of soft soils (mainly clay) underlain by sand layers (similar to Figure 1).

A clear seasonal pattern is observed in the InSAR time series of these houses (Figure 7). Typically, the seasonal amplitude is about 3 mm with the peak in February and trough in September. The seasonal movement is presumably caused by fluctuations in the groundwater level and associated swelling of clays, since it peaks in winter when groundwater levels are highest.

Permanent settlement only occurs when the load in the soil increases to levels not previously encountered; this means that in years where the groundwater level remains within heights that have previously occurred no additional permanent settlement is expected. Hence in drought years, with unprecedented groundwater levels, permanent settlements are to be expected.

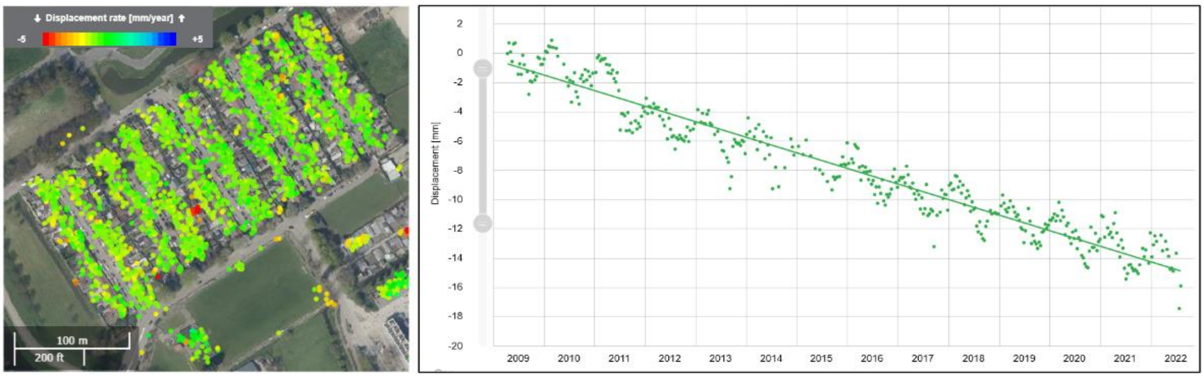

Figure 7: Left) TSX InSAR points on the buildings only over the period 2009 - 2022. Right) Time series of these building showing seasonal movement. The average linear displacement rate is approximately -1 mm/yr.

Figure 8 shows that in some years the settlement that occurs in the spring/summer is then compensated by a swell in the autumn/winter, but in others, permanent settlement is observed. Looking at a subsection of the last 13 years, between January 2014 and January 2020, two years with permanent settlement are observed in 2016 and 2018 (Figure 8). The permanent settlement is approximately 2 mm in each of those years. The two years of permanent settlement correlate with notable dry summers as reported by the Dutch National Weather Service (KNMI, n.d.). The description of the summer weather 2016 and 2018 respectively are as follows "Very warm, very sunny and on the dry side" and "Extremely warm, extremely sunny and very dry".

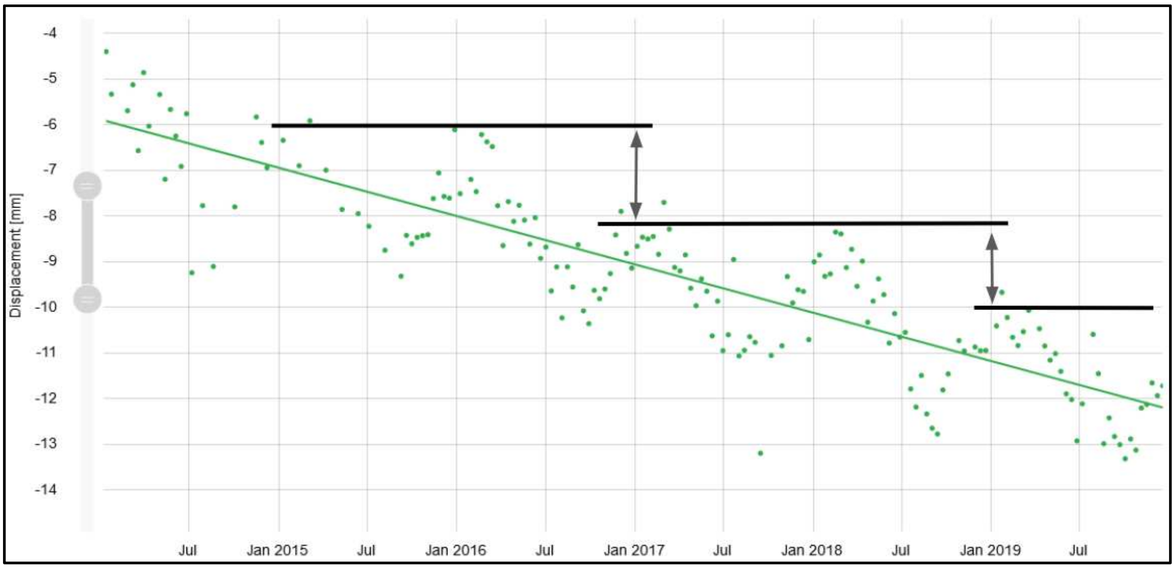

Figure 8: A subsection of Figure 7, from January 2016 to January 2020 with the black lines the displacement at the beginning and end of the year is marked, with the black arrows the permanent displacement is marked. For the year 2016 also the total movement is marked with the blue line and arrows.

4. Conclusions

The effects of climate change in Europe are already being felt. Municipalities, housing corporations and homeowners are all seeking to quantify the effects of climate change on their houses. Knowledge on the state of house foundations is difficult to obtain without intrusive investigations, furthermore it is near-impossible to have measurements of subsidence on all houses in a municipality/owned by housing corporation by traditional in-situ measurements such as levelling. By using InSAR, quantitative assessments of subsidence can be obtained for all houses as well as other potential indicators of poor foundation such as building tilt. This enables wide area assessments of areas of highest risk and supports budgeting and maintenance planning.

References

European Environment Agency. (2019). *Heavy Precipitation in Europe.* Retrieved January 25th, 2023 from https://www.eea.europa.eu/data-and-maps/indicators/precipitation-extremes-in-europe-3/assessment-1

Klimaatadaptie Nederland. (n.d.). *Climate change.* Retrieved November 18th, 2022 from https://klimaatadaptatienederland.nl/en/themes-sectors/themes/climate-change/

KNMI. (n.d.). *Archief maand/seizoen/jaaroverzichten.* Retrieved November 20th, 2022 from https://www.knmi.nl/nederland-nu/klimatologie/maand-en-seizoensoverzichten/

Kok, S., van der Putten, S., Kraus, J., (2021). Naar een kennisagenda funderingsproblematiek. Duiding van de omvang en aard van de problematiek en kennisvragen daarbij. https://www.deltares.nl/app/uploads/2021/07/11206466-BGS-Kennisagenda-funderingsproblematiek_def.pdf

NLOG. (n.d.). *Boreholes.* Retrieved November 15th, 2022 from https://www.nlog.nl/en/boreholes

TNO. (n.d.). Foundation problems throughout the Netherlands. Retrieved November 15th, 2022 from https://www.tno.nl/en/sustainable/safe-sustainable-living-environment/building-innovation/foundation-problems/

van Asselen, S., Erkens, G., Stouthamer, E., Woolderink, H. A., Geeraert, R. E., & Hefting, M. M. (2018). The relative contribution of peat compaction and oxidation to subsidence in built-up areas in the Rhine-Meuse delta, The Netherlands. *Science of the Total Environment*, *636*, 177-191.