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Cost-benefit analysis of urban subsidence mitigation strategies in Gouda, the Netherlands

Sien Kok and Saskia Hommes-Slag

Urban Soil and Groundwater Management, Deltares, 3508 AL Utrecht, the Netherlands

Correspondence: Sien Kok (sien.kok@deltares.nl)

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Abstract. This paper presents the approach and outcomes of an exploratory cost-benefit analysis of subsidence mitigation strategies in the inner city of Gouda, the Netherlands. Results indicate that especially the strategy focusing on reducing damage, rather than a strategy aiming to halt subsidence altogether, might have a positive economic rationale.

1 Introduction

In the Netherlands, subsidence of clay and peat soils is mainly caused by artificial lowering of phreatic groundwater levels, and soft-soil loading by buildings and infrastructure. Expected damages are significant: EUR $\sim$ 22 billion until 2050 (van den Born et al., 2016). As in the Netherlands land subsidence is mostly human-induced, much of this damage may be prevented: the rate of subsidence can be reduced, and/or structural or non-structural measures can be taken to minimize the negative consequences of land subsidence. As subsidence mechanisms and asset exposure characteristics differ across rural and urban areas, but also within urban areas (e.g. new urban developments versus historic city centers), the optimal approach needs to be locally customized.

1.1 Economic impact of subsidence

Economic impact assessments of (solutions for) subsidence can contribute to defining the optimal approach to dealing with subsidence, because (i) estimates of the magnitude of the socio-economic impact substantiate the need for action and help to identify and activate key stakeholders, and (ii) they provide the economic rationale of different strategies, e.g. in a cost-benefit analysis. However, despite these potentially useful applications of economic impact assessment in the context of subsidence, research on economic assessment in a subsidence context is still limited (Kok and Costa, 2020), as most subsidence-related research focuses on measuring, modelling and monitoring the subsidence process itself.

1.2 Subsidence in Gouda, the Netherlands

In this paper, we demonstrate how the economic rationale for interventions in a subsidence context was determined in the case of Gouda, the Netherlands. As part of the Living Lab project in which the subsidence problem and coping strategies are investigated by a consortium of the Municipality Gouda, Water Authority Rijnland and research partners, an exploratory cost-benefit analysis of the coping strategies was executed (Kok, 2018). Although economic estimates in the analysis are specific to the context of a subsiding historic urban zone with a mix of shallow and piled foundations, the methodological framework applied is applicable to other subsidence contexts as well.

2 Methods

2.1 The case study

The center of Gouda is subsiding with approximately 3–5 $\mathrm{mm\,yr^{-1}}$. Most likely, the subsidence is caused by a mix of compaction of shallow unconsolidated clay and peat layers as a result of urban loading and peat oxidation (van Laarhoven, 2017). Buildings in Gouda predating 1900 are mostly grounded on shallow (footing) foundations which settle along with the foundation depth (i.e. the upper soil). To prevent groundwater flooding subsequent to subsidence, the groundwater level has been artificially lowered a few times in the past by lowering the city canal water level. However, from 1900 onwards, building on timber pile foundations became common practice in the region – to be replaced around 1950 by concrete piles. Further lowering of the groundwater level, though desirable from the perspective of pluvial flood risk reduction, is expected to cause significant damage to timber pile constructions due to fungal degradation, which initiates after the normally inundated timber is exposed to oxygen.

2.2 Cost-benefit analysis

To define the economic rationale of alternative coping strategies for subsidence, we follow the general approach for cost-benefit analysis as prescribed by the Dutch government (Romijn and Renes, 2013), which includes 7 steps: (1) problem description, (2) describe the reference situation; (3) identify alternative strategies; (4) assess effects; (5) calculate (lifecycle) costs; (6) analyze uncertainties; and (7) provide an overview and conclusions. However, due to time constraints, this study does not yet include an uncertainty/ sensitivity analysis. Any costs and effects are calculated until 2100, with a discount rate of 4.5 % as prescribed in Dutch guidelines.

2.3 Reference situation

Assuming the historic trend of continuous lowering of the groundwater levels to continue, water levels will have to be lowered again in the near future, presumably leading to a continuation (or even acceleration) of the current subsidence rate of 3–5 $\mathrm{mm\,yr^{-1}}$. In time the lower ground water levels will lead to significant damage to approximately 400 timber pile foundations which will need to be restored. Furthermore, lifecycle costs of infrastructure (including e.g. roads, sewage, public space, utilities and embankments) will remain high as compared to their benchmark in non-subsiding areas, as subsidence accelerates their degradation.

2.4 Alternatives

In 2017, two policy pathways (hereafter: alternatives) were developed and analyzed: "Sustain Elevation" and "Managed Subsidence". The rationale of alternative "Keep height" is to prevent or reduce further subsidence of all buildings and infrastructure. This entails the replacement of all shallow building foundations in the inner city ($\sim$ 1500) with concrete pile foundations, as well as grounding road and sewage systems on piled foundations to stop then from subsiding. A positive effect is that the water level will not/to a lesser degree have to be lowered, resulting in an assumed slowing of the subsidence rate to an average 2–3 $\mathrm{mm\,yr^{-1}}$. The rationale of alternative "Managed Subsidence" lies in reducing negative consequences of subsidence, rather than preventing subsidence altogether. This entails the strengthening of structures to cope with potential damage, e.g. investing in measures to prevent damage to wooden pile foundations and waterproofing buildings to cope with high (ground)water levels.

2.5 Identifying and valuing subsidence effects

Similar to common practice in natural hazards, the socio-economic effects of subsidence can be divided in direct and indirect, market and non-market effects (Kok and Costa, 2020). A direct effect is an immediate consequence of subsidence– such as structural damage to infrastructure. An indirect effect is related to the consequences (Hallegatte and Przyluski, 2010) an event (e.g. subsidence) – such as the disturbance in traffic patterns due to structural damage of infrastructure. Whether an effect is market or non-market relates to whether the losses can be repaired or replaced by a purchase on the market. Non-market effects of subsidence include e.g. health impacts with increasing indoor humidity or damage to landscape quality and culture-historical values.

A range of economic valuation approaches can be applied to value these direct and indirect, market and non-market effects of subsidence. For market effects, market-price based methods such as damage (restoration) costs can be used. For non-market effects, stated or revealed preference methods, which observe willingness to pay by economic agents through their behaviour – like hedonic pricing analysing the impact of subsidence damage on housing prices (Pascual et al., 2010). In the case of limited data or time, cost or benefit transfer can be used: using results of economic valuation studies in a similar context.

To identify the most relevant effects of the project alternatives in the case of Gouda, a qualitative analysis based on expert judgement was executed. This analysis consisted of two steps: (1) identification of all possible direct and indirect effects of subsidence (ranging from e.g. operation and maintenance (O&M) costs to all types of infrastructure, to loss of cultural heritage, to health impacts due to increased indoor humidity) and (2) assignment of a score ranging from -2 to $+2$ to estimate the expected change under all alternatives in the future as compared to the present-day situation, with members from the project team. Based on this analysis, six key direct and indirect effects of the proposed interventions were selected to be quantified in the cost-benefit analysis: (1) damage of buildings due to differential settlement, (2) damage to timber pile foundations, (3) increased O&M of roads, (4) capital investments in the elevation of gardens and public space, (5) increased flood risk and (6) increased nuisance due to more frequent repair works on infrastructure and building foundations.

3 Results

3.1 Effects

Table 1 presents an overview of key assumptions for each alternative, and the valuation approach used to estimate this effect. No new valuation studies were executed for this study – instead, standard numbers from other sources were used where possible (benefit transfer).

3.1.1 Damage to buildings and foundations

Based on a study on the history of foundation practices near Gouda (Winsen et al., 2015), it can be derived that approximately 1500 out of 3000 buildings in the inner city have a shallow foundation; 450 a timber pile foundation and 1050 a concrete pile foundation. In the reference situation, it is assumed that over time with further lowering of the water table all timber pile foundations are subject to rot and will have to be replaced. Structural damage to buildings with shallow foundations occurs if the building does not settle in a uniform manner, but differentially. This may happen as a result of small variations in the subsurface: the building rotates along its axis and tears appear in walls – in the worst case leading to an unsafe situation over time (Peduto et al., 2019). Additionally, a problem may arise if neighbouring buildings have different foundation types but share a load-bearing wall: a building on shallow foundations will “drag” a house on timber piles along, resulting in structural damage to both buildings.

3.1.2 Water system

With continuous subsidence and climatic warming leading to a more intense hydrological cycle (Klein Tank et al., 2016), periods with a surplus (wet) and a deficit of water (drought) will occur more frequent. A wetter environment will lead to damage to green space in gardens and public parks; pluvial flooding will lead to damage to roads and buildings; and high groundwater levels will lead to increased humidity levels within buildings – causing damage to health, furnishing, walls and floors.

3.1.3 Other

Asset management of infrastructure is more expensive in a subsiding area. This goes for all types of infrastructure. In the case of Gouda, only additional LCC costs for road infrastructure are included as estimations for other types of infrastructure are not available (van den Born et al., 2016). Furthermore, we assume that private and public actors invest in elevating gardens and public space to keep level with infrastructure and the floor levels of buildings with a pile foundation. Finally, we addressed the expected increase/ decrease in nuisance from infrastructure and building restoration works: noise, vibration and reduced service levels.

3.2 Costs

Cost estimates presented in Table 2 are based on assumptions and standard prices from known similar cases of application (*cost transfer*). As the measures proposed under each reference alternative were not yet defined in detail, some assumptions were made to be able to arrive at an order of magnitude for investment costs of the proposed interventions.

3.3 Evaluation

Table 1 presents the outcome of the cost-benefit analysis. Benefits are expressed in reduced damages compared to the reference alternative. In the “Keep Height” alternative, the required investment costs of keeping buildings and infrastructure at their present level – mostly by installing concrete pile foundations – far outweigh the benefits. In “Managed Subsidence”, expected benefits do outweigh investment costs and there appears to be an economic rationale for this investment. However, as the scope of the study did not include elaborate sensitivity analysis, it is possible this outcome is not significant.

Investors and beneficiaries

There are three key stakeholders of the project in the inner city of Gouda: property owners, inhabitants and the Municipality itself. In the reference alternative, with further lowering of (ground)water levels, the highest expected damage lies with property owners as a result of the degrading timber pile foundations, damage due to differential settlement and the need to elevate gardens. In the “Sustain Elevation” alternative, the investment costs will lie mostly with the Municipality and property owners of buildings with a shallow foundation. Key beneficiaries of this alternative are property owners of piled foundations and the Municipality. In “Managed Subsidence”, property owners of shallow foundations invest in reducing structural damage and groundwater nuisance and are the key beneficiaries as well. A key “lesson learned” from the study is that the social and financial feasibility of “Sustain Elevation” is likely low as investment costs are very significant, and key beneficiaries (timber pile property owners) are not the same as the potential investors (shallow foundation property owners).

4 Discussion and conclusion

This study aims to support the Municipality of Gouda in the decision-making process on intervention strategies for the subsiding historic inner-city center of Gouda. Alternatives entail various solutions regarding the water system, investments in infrastructure, and investments in (foundations of) buildings. Results indicate that especially the strategy in which action is taken to mitigate the negative consequences of subsidence, rather than an alternative that tries to

Table 1. Overview of assumptions on key effect posts and applied valuation approach.

	Reference	Sustain elevation	Managed subsidence	Valuation approach	Unit price & Source
Differential settlement shallow foundations	10 %–20 % of buildings on shallow foundations will have damage from differential settlement. In 80 % of the cases, damage is limited. In 20 % of the cases, damage is severe due to shared load-bearing wall with neighbouring structure.	Replacement of shallow foundations with (concrete) pile foundations will take 20 years; this diminishes most expected damage due to differential settlement.	Buildings with shared load-bearing wall are disconnected to prevent future damage: this diminishes damage related to shared load-bearing walls.	Restoration costs	Assumed average EUR 4000 restoration costs/affected building (Shabha and Kuhwald, 1995; Bellaart, 2008).
Timber pile degradation	In the relatively short term, 75–150 foundations will need to be restored: in the longer term 300–375.	Due to reduced lowering of water tables, only 25–50 timber pile foundations need restoration.	Due to preventive measures, only 25–50 timber pile foundations need restoration.	Restoration costs	EUR 60 000 restoration costs/building (Veldkamp, 2012).
O&M roads	Higher LCC costs due to shorter lifetime of road infrastructure.	No increased O&M costs due to piled foundation under roads.	No increased O&M costs due to lightweight material under roads.	LCC costs	EUR 1.52 extra O&M costs $m^{-2}\,yr^{-1}$ (van den Born et al., 2016).
Elevation of gardens & Public space	Public and private actors elevate gardens and public space to prevent wetting and elevation differences.	Lower settlement rates lead to less need for elevation	Elevation limited only to extreme cases.	LCC costs	EUR 550 elevation of 20 m^2 garden (Offerteadviseur, 2017).
Water system	Additional damage due to flooding as retention capacity stays limited.	Slightly reduced damage due to improved sewage & road infrastructure.	Reduced flood damage due to investments in water proofing buildings.	Damage costs	Flood risk in inner city Gouda EUR ~ 6 million/year – incl damage to green infra, roads, buildings, furniture etc. Based on (Hoogvliet et al., 2012).
Nuisance due to increased works (foundations & infrastructure).	Piled foundation restoration and increased O&M of infrastructure lead to nuisance.	Increased nuisance due to fitting piled foundation under all (1500) shallow foundations.	Limited nuisance due to reduced damage to foundations and reduced works for infrastructure.	CVM	Value of nuisance: EUR 1.33 per hh* per day (Ruijgrok et al., 2006).

CVM: contingent valuation method. LCC: life cycle costs. * hh: household.

Table 2. Overview of investment costs and benefits (in EUR 10^6) of alternatives Sustain Elevation and Managed Subsidence – the latter expressed as reduced damage/lower costs in relation to the reference alternative (RA). Expected damage in RA is expressed in italic.

		Sustain Elevation	Managed subsidence	Stakeholder
Investment Costs (in million euros)				
New foundation under shallow		−46	0	Property owner
Inundate piled foundations		0	0	Property owner
Mitigate differential settlement		0	−3	Property owner
Waterproof buildings		0	−6	Property owner
Piled road foundation		−87	0	Municipality
Lightweight elevation roads		0	−2	Municipality
Total investments Costs		−133	−11	
Effects	Expected "damage" in RA	Keep Height	Managed subsidence	
Differential settlement shallow foundations	*−1.9*	1.6	1.7	Property owner
Timber pile degradation	*−8.7*	0.6	0.6	Property owner
O&M roads	*−3.4*	3.4	3.4	Municipality
Elevation of gardens & Public space	*−1.0*	0.5	0.5	Inhabitant, Municipality
Flooding	*−14.5*	1.1	9.8	All
Nuisance due to increased works (foundations & infrastructure)	*−1.5*	−1.5	0.0	Inhabitants
Total effects		6	16	
Cost-Benefit balance		−127	5	
Benefit-cost ratio		0.04	1.48	

halt subsidence altogether, might have an economic rationale for investment. Key benefits include reduced vulnerability to ground water and pluvial flooding and damage from differential settlement, and lower O&M costs of road infrastructure.

4.1 Reliability of results

The accuracy of this studies' results is probably low; the scope of the study did not allow for a sensitivity analysis nor for a solid (local) economic valuation approach – most prices are based on cost/ benefit transfer. Due to the relative novelty of the topic, there are no meta-studies available synthesizing information about costs, effectiveness of measures and damage related to subsidence, as commonly available in other policy contexts (e.g. flood risk). Furthermore, guidelines for economic valuation of subsidence effects are lacking and there are no established damage relations or standard numbers available for cost/benefit transfer. Necessary local information, e.g. on the expected impact of measures on subsidence rates, or character of the assets exposed was also limited. Future research efforts in establishing damage relations is required to increase the accuracy of economic impact assessment/cost-benefit analysis in a subsidence context.

4.2 Policy implications of CBA

The cost-benefit analysis brought valuable new insights to the decision making process, both on the side of the feasibility in terms of investment costs, as well as the economic rationale for investment (Bodemplus, 2018). Based on these insights, the Municipality of Gouda decided to focus future efforts in further developing the "Managed Subsidence" strategy. Despite the low accuracy of the results, the approach was "fit-for-purpose", i.e. it provided an idea of the order of magnitude of the costs and benefits of alternative strategies.

Data availability. The study (in Dutch) by Kok (2018) that provides the basis for this paper can be found on Deltares' repository page: http://publications.deltares.nl/1230530_002.pdf.

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