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Economic assessment of subsidence in Semarang and Demak, Indonesia

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Project statement

This report was written in the context of the **Building with Nature Indonesia Programme - *Securing Eroding Delta Coastlines*** by Ecoshape, Wetlands International, the Indonesian Ministry of Marine Affairs and Fisheries (MMAF), and the Indonesian Ministry of Public Works and Human Settlement (PU), in partnership with Witteveen+Bos, Deltares, Wageningen University & Research Centre, UNESCO-IHE, Blue Forests, and Von Lieberman, with support from the Diponegoro University, and local communities.

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Disclaimer

Project partners are committed to drive the current Building with Nature innovation trajectory, by demonstrating the approach in a case study site in Demak. Successful implementation requires in-depth system understanding, extensive stakeholder engagement, and adaptive management on the basis of monitoring and evaluation. We stimulate and support upscaling of the approach by disseminating knowledge, lessons learned and implementation guidance. Stakeholders interested to replicate our approach are strongly recommended to adhere to this guidance and bear full responsibility for the success and sustainability of the approach. The picture on the title page showcases one of the many rural areas in Demak that have been hit hard by floods due to the ongoing threat of subsidence.

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Summary

Context

In the past decades, economic growth has stimulated industrialization and urbanization in Indonesian coastal cities such as Semarang and Demak. Against this backdrop of economic growth, water demand in Semarang and Demak has increased over time. However, clean (piped) water supply has not kept pace with rising demand, and industrial activities largely rely on direct groundwater extraction.

Extraction of groundwater is expected to be the key driver of subsidence in the area, particularly in locations situated on unconsolidated sediments like the northern part of Semarang and Demak. In a natural state, subsidence due to consolidation of such sediments rarely exceeds 1 cm/year. However, over-extraction of groundwater can significantly exacerbate subsidence rates: in Semarang and Demak, subsidence exceeds 8 cm/year in the northern part of Semarang, and in Sayung District of Demak. In areas where the groundwater head drops most strongly, subsidence is more severe. This subsiding area hosts the majority of industries and is densely populated.

Subsidence can cause immense direct and indirect damage. Direct damage includes damage to infrastructures and buildings. Indirect damage includes increasing flood risk due to lower elevation, over time leading to permanent land loss. Attention for this issue is increasing in the area, and a subsidence roadmap is in the making to help adapt and mitigate the land subsidence.

Study aims

This study provides a basis for the development of this roadmap, by assessing the economic consequences under different subsidence scenarios. This provides a better understanding of the socio-economic impact of subsidence, and the economic rationale of (investment in) addressing this problem. An economic impact assessment can provide the economic rationale of implementing mitigative measures, and support decision making in this context. By comparing economic impacts of subsidence under business as usual (no additional measures taken) with economic impacts under alternative scenarios (additional measures taken), the benefits of taking action are identified and quantified. For example, the results can be used in Cost Benefit Analysis to weigh investment costs and benefits of different measures. Such results also can be used to determine the groundwater extraction taxes that would reduce incentives to over-extract groundwater, and as a result would mitigate regional welfare losses from land subsidence (Wade, Cobourn, Amacher, & Hester, 2018). Furthermore, an assessment of the economic impacts of subsidence can help increase the awareness and sense of urgency of addressing the subsidence problem.

Although the impacts are manifold, due to limitations in scope and data, this study quantifies only direct damage to roads and buildings, and indirect damage due to increased flood risk and land loss due to the lowering of the area that becomes below mean sea level. These impacts are likely the most significant, although damage to other types of infrastructure (e.g. drainage, sewage, railway) may also be significant. The damage due to increased flood risk, land loss, and road and building damage calculated in this study is estimated to be 60-80% of the total damage of subsidence (Lixin, et al., 2010). Indirect economic damage such as a traffic disruption, and production loss were not quantified in this study. Calculated damage is assessed using a risk-approach: overlying hazard and exposure maps, and using damage-effect relationships from global sources, or extrapolated from other areas.

Scenarios

We calculate damage between 2020-2040 with a Business as Usual (BAU) and two alternative scenarios: A) After 10 years, subsidence rate is half compared to the BAU and B) after 10 years, subsidence rate is a fourth compared to the BAU.

Results

By far the most significant economic impact of subsidence is land loss, followed by increased road maintenance costs and flood risk. There is a progressive scale between flood risk and land loss: land that is prevented from being fully lost is still subject to increased flood risk.

Summary of economic loss due to subsidence in Semarang and Demak in 2020-2040 (present value) in billion IDR. PM = Pro memorie: to be remembered when reviewing results from this study. All cells marked with PM were not included in the analysis. The results presented here are thus an underestimation of the total damages.

Effect	**Damage in Semarang (billion IDR)**			**Damage in Demak (billion IDR)**		
	A	**B**	**BAU**	**A**	**B**	**BAU**
Direct						
Increased road maintenance	**1,350**	**1,200**	**1,700**	**800**	**700**	**1,000**
Increased arterial road maintenance	**750**	**670**	**950**	**550**	**480**	**680**
Damage to buildings	**50**	**50**	**70**	**5**	**4**	**70**
Damage to other infrastructure	**PM**	**PM**	**PM**	**PM**	**PM**	**PM**
Indirect						
Land Loss	**56,000**	**14,000**	**76,000**	**27,000**	**23,000**	**37,000**
Increased Coastal Flood risk	**300**	**350**	**250**	**150**	**180**	**140**
Increased pluvial and fluvial flood risk	**PM**	**PM**	**PM**	**PM**	**PM**	**PM**
Reduced attractiveness of business climate; lower agricultural yields	**PM**	**PM**	**PM**	**PM**	**PM**	**PM**
Lower quality of life population	**PM**	**PM**	**PM**	**PM**	**PM**	**PM**
Total (present value in billion IDR)	**58,500**	**16,300**	**79,000**	**28,500**	**24,300**	**39,000**

The results of this study show that the damage over the course of 20 years under business as usual scenario (BAU) in Semarang amounts to 79 trillion IDR (present value; approx. 5.5 billion USD), while in Demak, the damage might amount to 39 trillion IDR. Per year, this translates into about 2% and 7% of GRDP for Semarang and Demak. If the subsidence rate is halved (scenario A), economic damage from subsidence is estimated at 58 trillion IDR and 29 trillion IDR respectively for Semarang and Demak. In other words, this means that by taking measures to reduce the subsidence rate by half, 21 trillion IDR in damage can be prevented in Semarang, and 10 trillion IDR in Demak (corresponding to approximately 1.48 and 0.74 billion $ respectively). Reducing subsidence rates to a fourth of compared the BAU (scenario B), economic damage of subsidence for Semarang and Demak are 16 trillion IDR and 25 trillion IDR respectively. Although a costly affair investing in measures that reduce subsidence rates by 75%, the reduction in the economic losses show that it is worth the investment: 63 trillion IDR and 14 trillion IDR economic damages avoided for Semarang and Demak respectively (corresponding to approximately 4,48 and 1,02 billion $ respectively).

These results only represent a part (estimated to be 60-80%) of the full extent of economic damage from subsidence in Demak-Semarang, as illustrated by the PM posts: the numbers above are an underestimation of the full range of economic costs of subsidence. In particular, the impact of subsidence on other infrastructures besides roads may be significant: water management infrastructure (drinking water and sewage pipes, drainage channels, pumping stations, dikes), transport infrastructure (railway, ports, airports) and telecommunication and energy infrastructure (e.g. oil and gas pipes, cables). Other potentially significant impacts include increased fluvial and pluvial flood risk, and reduced attractiveness of the business climate.

In conclusion

With subsidence rates reaching 8 cm/year in some areas, northern Semarang will have subsided by 1.5-2 in 20 years. If nothing is done to prevent this, the minimum expected damage is approximately 82.7 trillion IDR in Semarang and 30.9 trillion IDR in Demak. Furthermore, flood risks will continue increase, not just from the coast but also from alluvial and pluvial sources. Halving the land subsidence rate could reduce the minimum expected damage by approx. 21 trillion IDR in Semarang and 10 trillion IDR in Demak. Quartering the land subsidence rate could reduce the minimum expected damage by approx. 63 trillion IDR in Semarang and 14 trillion IDR in Demak. The result of this study shows that lowering subsidence by 50% can reduce the damage by 26% in Semarang and by 13% in Demak. By applying a combination of measures to lower the subsidence rate by 75%, the expected damage of subsidence in Semarang and Demak is estimated to be reduced by 80% and 37% respectively. This study shows that it is still possible to avoid damages, especially in Semarang, if a combination of measures is effectively taken to reduce subsidence rate. Potential measures to reduce the subsidence damage can be responsible use of water resources, piped drinking water supply, reduced water demand and recycling of available water.

Recommendations

Developing a method to prioritize adaptation and mitigation strategies for subsidence in Demak and Semarang is recommended. This should include a more elaborate assessment of impact that could not be quantified in this study, more cooperation and interviews with local stakeholders, quantification of effectiveness of suggested measures in reducing subsidence and the damage resulting from subsidence and finally, a more elaborate scenario assessment under BAU (high versus low economic development, climate change). We also recommend an exercise to attribute damage to specific stakeholder (groups), and to increase awareness on subsidence and the measures that can be taken.

Contents

1 Introduction

Over the course of the 20th century people and assets around the globe experience an increased exposure to natural hazards (Peduzzi, Chatenoux et al. 2012, Woodruff, Irish et al. 2013). The Intergovernmental Panel on Climate Change (IPCC) projects that this will only worsen as sea levels continue to rise with an estimated 3 mm/yr, and storms become more severe and frequent (Milly, Wetherald et al.2002, Donnelly, Cleary et al. 2004, Knutson, McBride et al. 2010, Lin, Emanuel et al. 2012). Coastal megacities are especially vulnerable, as they are often located in low-lying areas and/or river flood plains (McGranahan, Balk et al. 2007, Nicholls, Herwijer et al. 2007, Woodruff, Irish et al. 2013). In many coastal (mega) cities situated on soft soils, the effects of climate change are exacerbated due to land subsidence: many exhibit subsidence rates between 6–100mmyr (Erkens, 2015).

Subsidence in South East Asia

In South East Asia, land subsidence is a problem for many urbanized coastal cities like Jakarta (Letitre & Kooi, 2018), Bangkok (Phien-wej, Giao, & Nutalaya, 2006), Shanghai (Chai, Shen, Zhu, Zhang, & L., 2004), Hanoi (Phi & Strokova, 2015), and the Vietnamese Mekong delta (Erban, Gorelick, & Zebker, 2014). The main driver of subsidence in coastal regions is compaction of young alluvial deposits due to groundwater extraction (Krynine & Judd, 1957; Dudley, 1970; Bakr, 2015; Shen, Ma, Xu, & Ýin, 2013; Sun, Grandstaff, & Shagam, 1999; Mousavi, Shamsai, El Naggar, & Khamehchian, 2001). Driven by economic development,

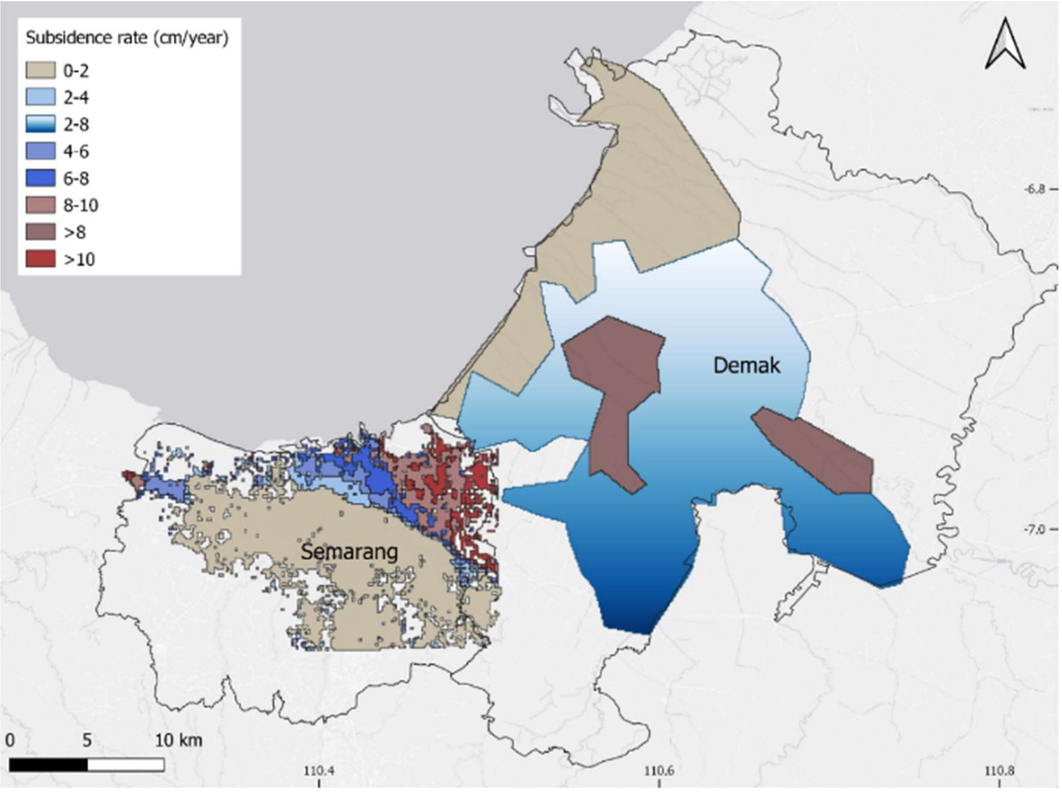


Figure 1.1 Subsidence rate in cm per year in Semarang (Ellipsis, 2020) and Demak (Yuwono, Subiyanto, Pratomo, & Najib, 2019)

ground water extraction rates continue to increase as populations grow in urban deltaic areas (Yeung 2001, Small and Nicholls 2003, Nicholls 2004, Hanson, Nicholls et al. 2011). Economic development is thus a double-edged sword, as it indirectly drives land subsidence and directly increases the total asset value at risk. Land subsidence causes significant structural damage and increases maintenance costs of roads, sewage, drainage, and flood protection infrastructure and buildings. Subsidence indirectly damages urban areas by increasing their exposure to floods (Hallegatte et al., 2013). Furthermore, subsidence in coastal wetlands such as mangroves can substantially increases chances of erosion and land loss. Deforestation of mangrove habitat can generate vast amounts of carbon to be released in the (Donato et al., 2011; Rovai et al., 2018). Overall, the total damages associated with subsidence worldwide is estimated in billions of dollars annually (Erkens, 2015).

Subsidence in Demak-Semarang

The deltaic area Semarang-Demak, located in the north of central Java, Indonesia has become an industrial epicentre in Indonesia, housing 783 large scale industries and more than 35000 small scale industries as of 2018 (Central Java Statistics Indonesia, 2020). In 2019, the industrial sector has contributed to 27.22% and 30.84% of the GDP of Semarang and Demak respectively. The population, fuelled by economic development, has grown from 1.3 million in 1995 to 1.8 million in 2018 in Semarang, and from 0.9 million to 1.2 million in Demak (Central Java Statistics Indonesia, 2020). As a result, water demand has risen from 48.5 million m^3 in 1999 and increased to 68.5 million m^3 in 2005. With the growing urbanization, the projected Semarang water demand is expected to be 336 million m^3 in 2030 (Central Java Government, 2020). However, the local drinking water company in Semarang and Demak, PDAM (Perusahaan Daerah Air Minum), only covers 61.2% and 23.68% of the administrative boundaries in Semarang and Demak respectively (Association of Indonesian Drinking Water Companies Central Java, 2020). Due to insufficient clean water provisioning, 24% of clean water demand in Semarang is fulfilled by means of groundwater extraction and industrial activities rely mainly on groundwater sources (Valentino, 2013). Based on data from 2011 and 2012, 53% of groundwater extraction permit was issued for industry and the rest was for domestic use. The deep groundwater extraction has led to significant subsidence in the area, with rates ranging from 0-2 cm to >10 cm per year. Most notable consequences in the area include damage to buildings and infrastructure and an increase coastal flood hazard.

Adaptation to land subsidence and flooding

To address the flood problem in the Semarang-Demak region, various adaptive measures have been taken over the past decades. Dikes have been constructed along the floodway canals and shorelines to prevent floods (van Beek, Letitre, Hadiyanto, & Sudarno, 2019), and a polder system including pumping stations have been installed to drain the protected but low-lying land. Roads and bridges are elevated yearly. To address fluvial flooding, floodways have been constructed. To address pluvial flooding, the drainage system in the city has been improved. To address coastal flooding, mangrove habitats have been restored (Andreas, Abidin, Gumilar, Sidiq, & Yuwono, 2017).

Mitigative Measures to slow down the subsidence in Semarang include coastal and integrated water resource planning and management (Marfai & King, 2008), public education (Marfai & King, 2008) and dam utilization to retain water for usage during the dry season (and prevent additional groundwater extraction) (van Beek, Letitre, Hadiyanto, & Sudarno, 2019). Since subsidence is intimately linked with the lack of water supply it can only be stopped if alternative water sources are available. It is difficult to quantify the impact of individual or combination of measures in slowing down subsidence rate as comprehensive monitoring of subsidence is absent.

In the long term, adaptation to flood risk such as building dikes provide only temporary solutions, as they fail to tackle the root cause of the problem. When planning for the medium and long-term effects of flood risk, relative sea level rise (rSLR) must be considered: the cumulative effect of sea level rise and land subsidence. Because of the slow onset and invisibility of subsidence as a hazard it is often not seen as an urgent problem (Lixin, et al., 2010).

Economic assessment of subsidence impact

An assessment of the economic impacts of subsidence can help increase the awareness and sense of urgency of addressing the subsidence problem. Furthermore, economic impact assessment can provide the economic rationale of implementing mitigative measures, and support decision making in this context. By comparing economic impacts of subsidence under a business as usual scenario (no additional measures taken) with economic impacts under alternative scenarios (additional measures taken), the benefits of taking action are identified and quantified.

In this report, the economic impact of subsidence in the Semarang-Demak region is assessed under three scenarios:

- Business as Usual (100% of current subsidence rate)
- Scenario A (50% of current subsidence rate)
- Scenario B (25% of current subsidence rate)

This will provide valuable insight in the economic damage that can be avoided by stopping or reducing groundwater extraction (the main driver of subsidence) in the area, and in providing economic justification of investment in mitigative measures. Policy alternatives and their investment costs are not included in this study: this topic is addressed in a parallel study by our partner *Witteveen + Bos*.

2 System Description

2.1 Geological characteristics of the study area

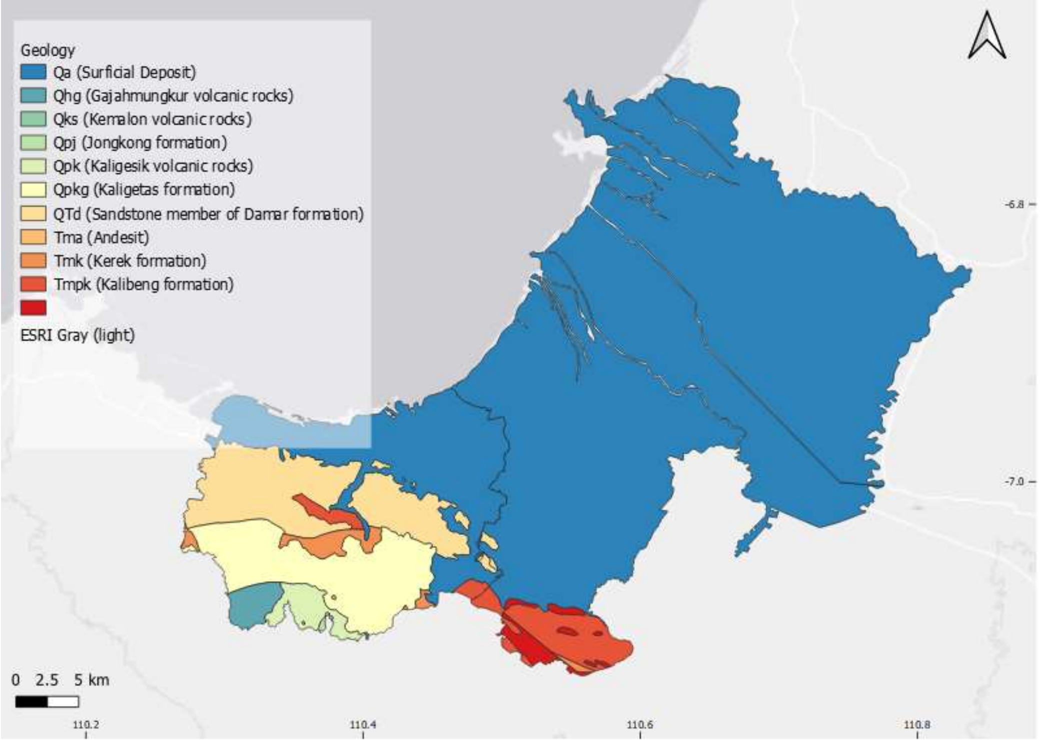


Figure 2.1: Geological map of Semarang modified from (Thanden, Sumadirdja, Richards, Sutisna, & Amin, 1996). Blue area indicates alluvial deposit / surficial deposit representing area that is most susceptible to natural compaction and subsidence.

Semarang Demak groundwater basin has surface area of 1.915 km^2 and extends far beyond the administrative boundaries of Semarang and Demak (Susanto, 2010). The north coastal plain of Semarang and the whole Demak area are characterized by alluvial deposit composed of very soft clay, soft clay, soft to medium sandy silt, and mixed of sand. The alluvial deltaic sediments that underline most of the coastal plain aquifer, are a thick sequence of clays. However, at shallow depth within the clays there are sandy layers forming a semi unconfined aquifer that is used for water supply by means of extraction wells (Suripin, 2012). As these areas have large amount of clays, these areas are most susceptible to natural compaction and subsidence.

2.2 Subsidence rates

Several investigations for the prediction and modelling of land subsidence in Semarang have been done by various researchers using various methods and approaches. Most of the researchers found that subsidence rates are highest in the northern part of Semarang especially in the north eastern region (Kuehn, et al., 2010; Putranto & Rude, Groundwater Problems in Semarang Demak Urban Area, 2011; Abidin, Andreas, Gumilar, Sidiq, & Fukuda, 2012; Islam, Yudo, & Sudarsono, 2017; Ismanto, Wirasatriya, Helmi, Hartoko, & Prayogi, 2009).

Table 2.1: Subsidence rate in Semarang from different authors and methods

Method	Year	Reference	Genuk [cm/year]	Harbour [cm/year]	Tawang [cm/year]	Marina [cm/year]	Airport [cm/year]
Levelling	2000-2001	(Murdohardono, Sudrajat, Wirakusumah, Kuhn, & Mulyasari, 2009)	4-8	8-20	6-8	4-8	2-4
Levelling	1999-2003	Centre of Environmental Geology	>6	>8	6-8	4-8	2-4
GPS	2009-2011 2008-2016	(Abidin, Andreas, Gumilar, Sidiq, & Fukuda, 2012; Andreas H. , et al., 2019)	9-15	6-9	3-7	6-9	3-6
Insar	Until 2019	(Ellipsis, 2020)	>10	6-10	6-8	3-6	0-4
SPN	2002-2006	(Kuehn, et al., 2010)	>7	>7	6-7	>7	5-6
DInSAR	2015-2016	(Islam, Yudo, & Sudarsono, 2017)	10	8-15	8	4-6	4-6
Modeling with Plaxis and Terzaghi	2002-2008	(Sarah, Syahbana, Lubis, & Mulyono, 2011)	-	-	3-7	-	-
Bench mark elevation and field measurement with DGPS	2009	(Ismanto, Wirasatriya, Helmi, Hartoko, & Prayogi, 2009)	>8.1	8.1-12	4.1-8	4.1-8	1.1-4
Microgravity	2002-2005	(Supriyadi, 2008)	<6.5	8-9.5	5-8	15	<6.5

Unlike Semarang, subsidence study in Demak is relatively scarce. Study from (Yuwono, Subiyanto, Pratomo, & Najib, 2019) using DSInSAR method indicates that subsidence in Demak is varied in time and space, with the highest rate in Sayung District. In Demak, Sayung district has subsidence rate up to 13 cm/year in 2017 (Yuwono, Subiyanto, Pratomo, & Najib, 2019).

2.3 Drivers of subsidence

Compaction is a natural process but can also be caused by uncontrolled usage and over-exploitation of ground water (Kuehn, et al., 2010). Natural subsidence rates rarely exceed 1 cm/year, whereas man-induced subsidence can reach 50 cm/year and even more (Dolan & Grant, 1986). Groundwater extraction induced subsidence occurs because water pressure in the aquifer drops causing consolidation and compression within the sand layers. A hydraulic gradient is developed between the aquifer and aquitard, starting a slow dewatering process of the clayey layers and aquitards (Kuehn, et al., 2010). Compaction of the soil increases its density and reduces its pore spaces. Soils are elastic material to only a limited extends. Soil compaction which beyond the elastic deformation becomes a plastic deformation and will not rebound even if the causes of that compaction is removed (Suripin, 2012).

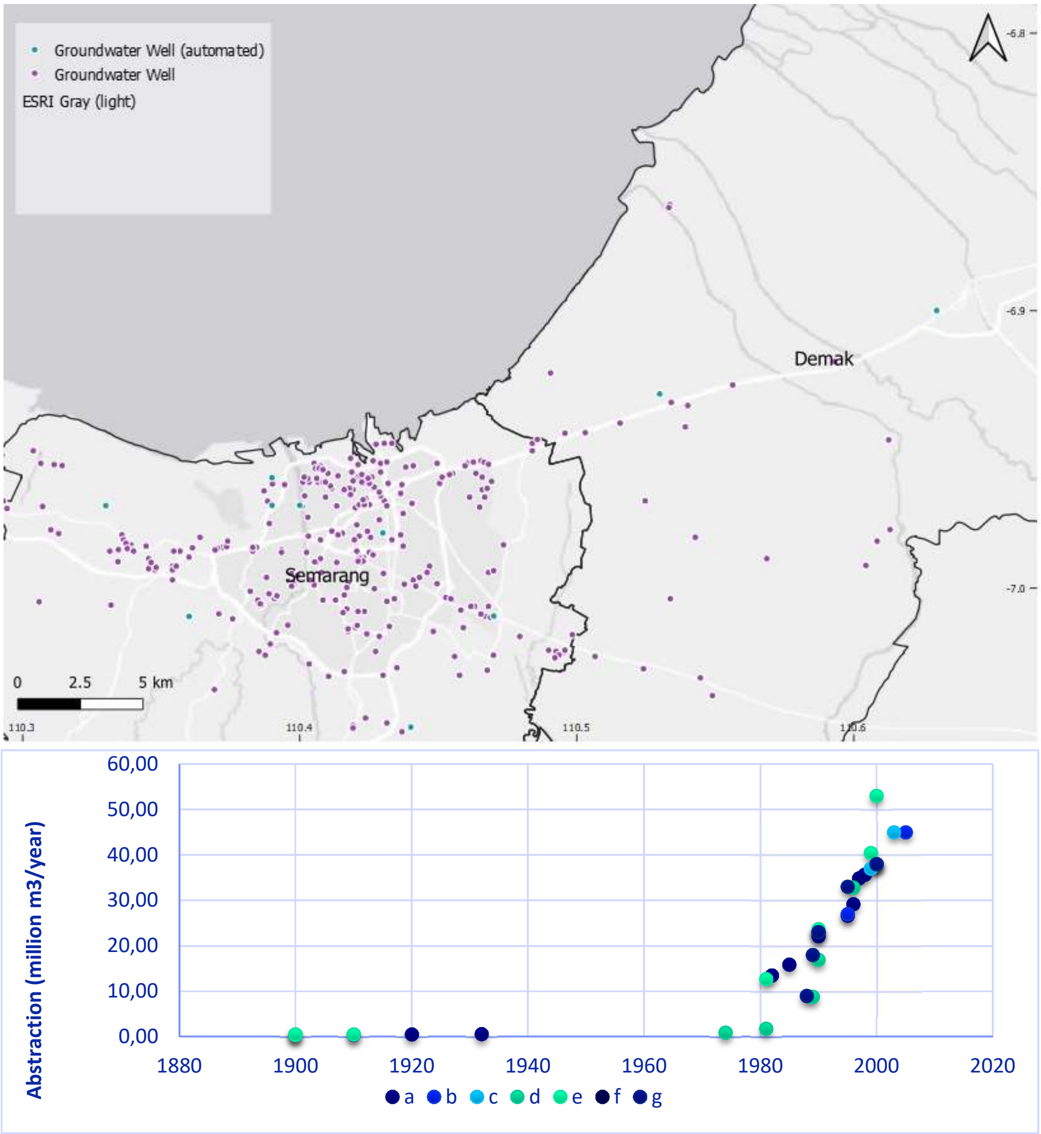


*Figure 2.2: **Top figure**: Groundwater well distribution in Semarang and Demak. **Bottom figure**: Semarang groundwater extraction from a) DGTL (Sihwanto & Iskandar, 2000), b) (Semarang City Governent, 2010) c) DGTL (Putranto & Rude, 2016), d) (Marsudi, 2000), e) (Schmidt, 2002), f) (GIM International, 2004), g) (Murdohardono, Sudrajat, Wirakusumah, Kuhn, & Mulyasari, 2009)*

In Semarang, groundwater has been exploited as a natural resource since 1841 (Putranto & Rude, 2016). Based on Semarang groundwater extraction data from different studies, groundwater extraction has increased substantially since 1980. Groundwater extraction rate in 1980 was less than 5 million m^3/year. While in 1990, the extraction rate was increased to approximately 20 million m^3/year. Only 10 years later in 2000, the extraction amount was drastically increased reaching almost 40 m^3/year. Even though the absolute values differ between different dataset (Figure 2.2), the overall patterns are similar, which shows the reliability of the data.

Despite of this substantial increase in groundwater extraction, groundwater monitoring is still considerably lacking with only ten automated groundwater monitoring wells in Semarang and

Demak. Figure 2.2 shows the distribution of monitoring groundwater wells in Semarang and Demak between 1980 to 2020 (Department of Energy and Mineral Resources Central Java, 2020).

The rapid subsidence area corresponds with where most groundwater head drop occurs. Spatial distribution of groundwater drop (Schmidt, 2002) from (Kuehn, et al., 2010) shows that the subsidence is only apparent within alluvium area. As the geological formation of Northern Semarang and Northern Demak is similar, Demak is also expected to experience subsidence in the area where over-extraction of groundwater occurs.

2.4 Current measures dealing with subsidence

Currently, there are several small-scale adaptation measures implemented by the local governments and individuals, aiming to reduce the damages of subsidence and risk of flooding, such as elevation of roads and buildings, construction of dikes and water management infrastructure (Andreas et al., 2017). Measures recently implemented in Semarang and Demak include:

- Projects addressing water resource and flood management;
    - Integrates water resource and flood management project in Semarang
    - Water resource planning (Pola Rencana Sumber Daya Air)
    - Construction of dikes and a polder system along floodway canal and shoreline (van Beek, Letitre, Hadiyanto, & Sudarno, 2019)
    - Construction of a pumping station (Andreas et al., 2017)
    - Construction of floodway to reduce fluvial flood hazard
    - Drainage masterplan in Semarang
    - Elevation of roads and bridges
    - Mangrove restoration
- Projects addressing sustainable land use
    - Land arrangement models Sukorejo
    - Coastal planning and management (Marfai & King, 2008)
- Projects addressing subsidence:
    - Drinking water master plan

At the national level, a working group aiming to create a national ‘roadmap for subsidence’ is in the process of being established, initiated by the Coordinating Ministry for Maritime and Investment (KEMENKO MARVES). At the local level, the public authorities in Semarang and Demak plan several measures that contribute to mitigation of subsidence risk and adapting to its consequences (mostly increasing flood risk):

- Projects addressing water resource and flood management:
    - Construction of retention ponds in North Semarang district
    - Construction of Coastal dikes in Tugu District, West Semarang District, North Semarang District and Genuk District
- Projects addressing subsidence cause (groundwater extraction)
    - Spatial plan of Semarang City 2011-2031: including improvement of water supply system, with development of four large and 19 smaller drinking water reservoirs.
    - Improvement and development of surface water infrastructure systems through a piping system in all district
    - Employment of rainwater in all districts
    - Restrictions on groundwater extraction in Tugu District, West Semarang District, North Semarang District, Central Semarang District, South Semarang

District, East Semarang District, Genuk District, Pedurungan District and Gayamsari District

The consequences of increased coastal flooding and land loss is evident in the housing market in the region. In some areas, people (with sufficient funds) elevate their house regularly – in some cases, up to 1 meter every 5 years. There are people that remain living in flooded areas, building a small bridge from their (elevated) house to the (elevated) road. In other permanently inundated areas, houses have been abandoned (Abidin et al. 2018). The study of (Ali, 2010) shows that the majority of inhabitants of communities impacted by coastal flooding have the aspiration to elevate their house (Table 2.2 and Table 2.3); however, this does not always happen due to the high costs.

To conclude, at present efforts focus mostly on adapting to the adverse consequences of subsidence, particularly increased flood risk. For the coming decade, there are several projects and regulations planned that do address the root cause of subsidence itself, i.e. groundwater extraction. Whether the scale of these plans and measures is sufficient to significantly reduce or stop the subsidence process is unknown. At the national level, the development of a Roadmap for Subsidence may offer strategic support in the medium to long term.

Table 2.2: Aspirations of the coastal flooding impacted community in Bandarharjo Village, Semarang modified from (Ali, 2010)

Aspiration	Frequency
Move to safer area	9
Elevate building	74
No aspiration	13
Others	4
Total	100

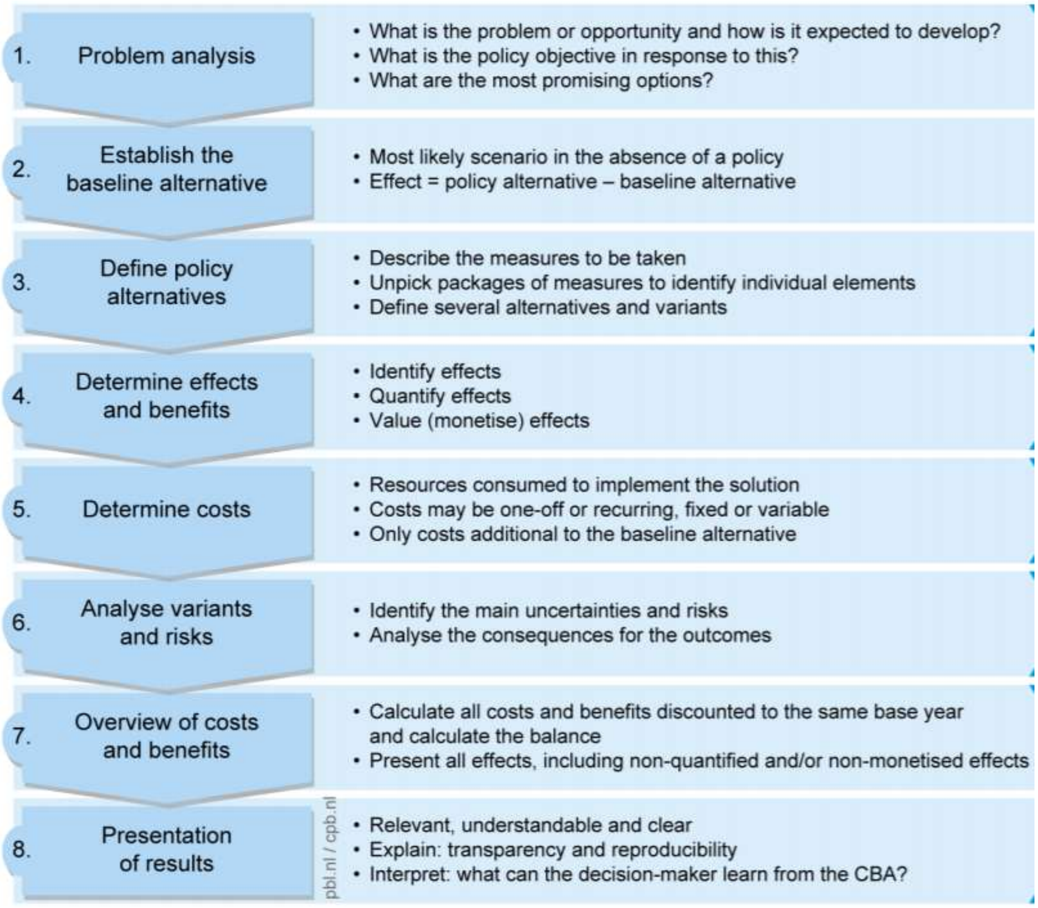
Table 2.3: Actual measures taken by coastal flooding impacted community in Bandarharjo Village, Semarang (Ali, 2010)

Measure	Frequency
Damming drainage channel	26
Make small embankments in the garden	35
No measure	30
Others	9
Total	100

3 Methods

To assess the economic rationale of investments or policy intervention regarding subsidence in Semarang and Demak, this study analyzes the economic damage of subsidence under three alternative scenarios. As such, this study provides a basis for a full cost-benefit analysis, in which investments costs of policy alternatives are compared against the expected effects (Romijn, 2013).

In this study we largely follow key steps from cost-benefit analysis (as presented in Figure 3.1; source Renes and Romijn (2013)): 1) problem analysis, 2) establishment of expected development of damage under a business-as-usual scenario 3) development of alternative scenarios, 4) an analysis of economic damage under these scenarios – where possible valued in monetary terms, 5) an overview of all damage effects is presented in which damage over a pre-determined period is discounted to the same base year.



1. Problem analysis
- What is the problem or opportunity and how is it expected to develop?
- What is the policy objective in response to this?
- What are the most promising options?

2. Establish the baseline alternative
- Most likely scenario in the absence of a policy
- Effect = policy alternative – baseline alternative

3. Define policy alternatives
- Describe the measures to be taken
- Unpick packages of measures to identify individual elements
- Define several alternatives and variants

4. Determine effects and benefits
- Identify effects
- Quantify effects
- Value (monetise) effects

5. Determine costs
- Resources consumed to implement the solution
- Costs may be one-off or recurring, fixed or variable
- Only costs additional to the baseline alternative

6. Analyse variants and risks
- Identify the main uncertainties and risks
- Analyse the consequences for the outcomes

7. Overview of costs and benefits
- Calculate all costs and benefits discounted to the same base year and calculate the balance
- Present all effects, including non-quantified and/or non-monetised effects

8. Presentation of results
- Relevant, understandable and clear
- Explain: transparency and reproducibility
- Interpret: what can the decision-maker learn from the CBA?

Figure 3.1 Generic approach for cost-benefit analysis. Source: Romijn & Renes (2013)

In this chapter, we identify key effects of subsidence and select effects which will be monetized (section 3.1), explain the overall approach of valuation (3.2) and elaborate how the effects will be quantified and monetized (section 3.3 and 3.4). Chapter 4 introduces the subsidence scenarios (policy alternatives).

3.1 Overview of subsidence damage

Hallegatte and Przyluski (2010) distinguish direct and indirect economic effects of natural hazards (e.g. subsidence). Direct effects of subsidence relate to loss of capital, increased life cycle costs or reduced performance as a result of direct damage to physical assets: including critical infrastructure, buildings and other physical elements in public or private space. Indirect economic effects of subsidence include 1) effects relating to direct, physical damage to infrastructure and buildings or 2) effects related to other natural hazards driven or aggravated by subsidence – such as flooding.

The potential types of subsidence damage in Semarang and Demak are listed in (Table 3.1). To assess the current situation in regard to these damage factors, a desk study and literature review has been applied: valuable sources describing damage in the area include Abidin et al. (2013); Andreas, Heri et al. (2019); Andreas et al. (2017) and Rahmawati and Marfai (2013). As can be seen in this Table, the economic implications of subsidence in the area are manifold, and already very visible on the ground today.

Based on this assessment, underlying literature, and subsidence damage in other countries (e.g. Lixin et al., 2010), we expect that the majority of economic damage includes damage to infrastructure and buildings (for illustrations, see Annex 8.2), increased risk of flooding and loss of land. The focus of this study will be on quantification of these aspects. Due to data and scope limitations, not all aspects can be monetized. Regarding flood risk, only coastal flood risk will be quantified as sufficient flood hazard models for pluvial and alluvial flooding are lacking[1]. Regarding damage to infrastructure, we will monetize only damage to roads due to limitations in data and damage relationships.

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[1] To calculate increased risk in fluvial and pluvial flooding, hydrological and hydrodynamic models are required, as well as a high(er) resolution DEM. As this data is not available and the development of such models is very time-intensive, we exclude fluvial and pluvial flooding risk assessment from this study.

Table 3.1. Overview of Direct and indirect damages related to subsidence.

Potential Damage	Description of damage	Current situation
Direct damage		
Damage to infrastructure (roads, railway, energy, telecommunication, drinking water, sewage, water management/ drainage)	Subsidence can cause damage to infrastructure if differential settlement exceeds design levels. This leads to increased maintenance costs (reconstruction or replacement cost, shorter functional lifetime), or conversely, decreasing performance levels of infrastructure. E.g. in drainage system, subsidence reduces the effectiveness of the system, which in turn increases risk of flooding.	Public authorities frequently raise public space/ roads to maintain elevation; Physical evidence throughout the area of structural damage to railway, roads, bridges and dykes. Adaptation measures such as new investment in dykes and pumping stations are occurring
Damage to structures like buildings including residential, industrial, public	(Differential) settlement of buildings leads to damage and possibly stability issues with the structure itself (walls, windows, doors), and to service pipes and cables. This leads to either prevention of replacement/ reconstruction cost, and/or a lower building quality affecting property values	Cracking and tilting of buildings are apparent in the north part of Semarang. To some extent, buildings subject to these issues have been abandoned (in areas with high subsidence rates and differential subsidence)
Damage to public/private green space	Subsidence leads to wetting of environment, with consequent damage to gardens and parks.	Public authorities are entitled to frequently raise public space to keep the environment dry
Indirect damage		
Increased flood risk (coastal, pluvial, fluvial)	The lower elevation of the land caused by subsidence increases the area susceptible to flooding (exposure). With a limited protection of the coastline from flooding, the area is particularly at risk from coastal flooding in the event of extreme tide. But with a lower elevation and damage/ lower functioning of the drainage system (canal elevation, water course, flood risk from pluvial and fluvial flooding increases as well (e.g. due to backwater effect). Flood risk has direct impact (damage to infrastructure, buildings, agriculture/aquaculture) as well as indirect impacts (business interruption, health risks).	The areas frequently subject to coastal flooding have expanded in the past decades. Important roads in Semarang and Demak are elevated after (coastal) flooding events. Evidence of adaptation measures, e.g. elevating roads and buildings, and abandonment of houses in flooded areas.
Business interruption	Damage to infrastructure and buildings, increased (restoration/ maintenance) works can cause business interruption (aside from business interruption due to increased flood events). As these often include planned events, impact is somewhat less than under a flooding event.	Traffic is frequently hampered by inundation of roads.
Reduced attractiveness of business climate	Over time, the high maintenance costs and or lower quality of infrastructure and buildings, increased risk of business interruption and increased flood risk reduce the attractiveness of the area for businesses in Semarang and Demak.	No data
Lower productivity agriculture (salinity, drainage problems)	Aside from damage due to flooding, the lower elevation of the land makes the area more susceptible to salt water intrusion. The salt water can infiltrate through the soil, increasing the salinity of the groundwater. Additionally, drainage problems may affect the agricultural yield.	Salt intrusion has significantly increased between 1995-2008: at present, most of the area has saline groundwater.
Loss of land near water bodies	Over time – in the absence of elaborate protection investments – the loss in elevation of the land will lead to permanent loss of the land, once the elevation is under mean sea level (further aggravated by sea level rise).	Since 1984, there have been significant loss of land to the sea that is estimated at around 2534 ha (see Figure 0.1 and Figure 8.2 in annex X)
Decreasing quality of living environment	Damage to infrastructure and buildings and increased flooding lead to a general decreasing quality of the living environment: this includes increased risk in health and sanitation.	Local population has taken some steps to improve situation, e.g. by elevating house

3.2 Economic valuation

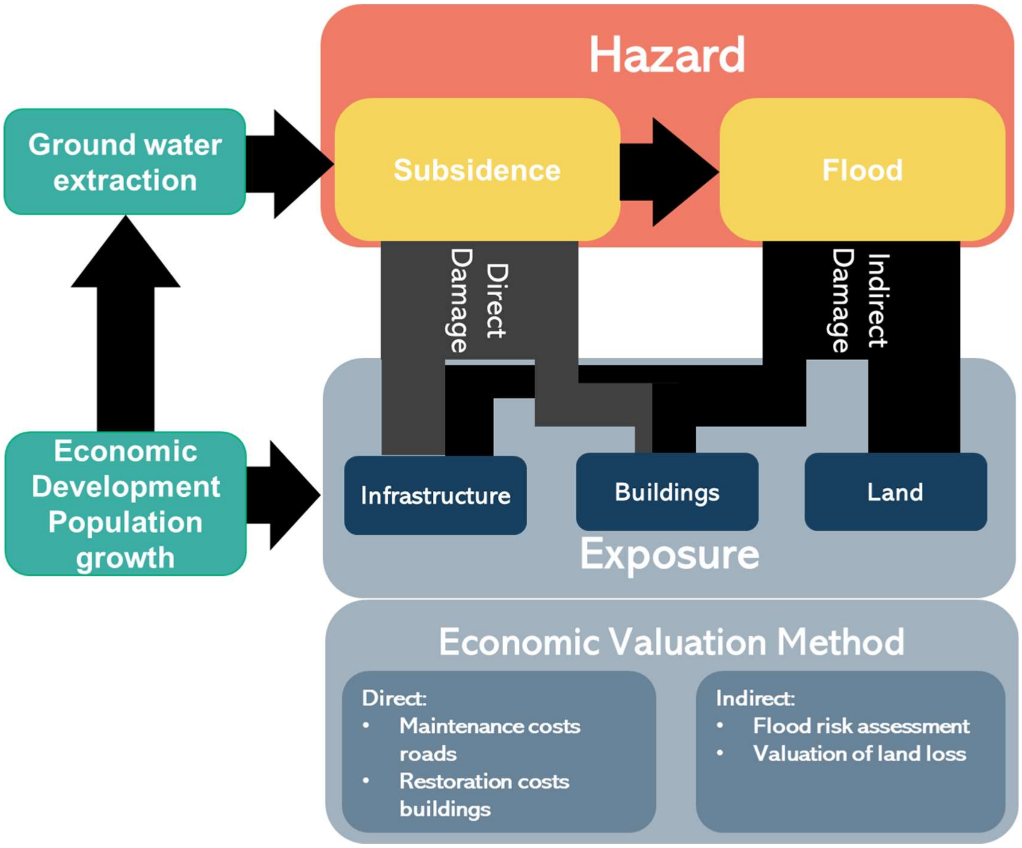

Figure 3.2. Schematic representation of the relationship between the drivers of subsidence (green), the hazards (red), exposure (grey blue) and the economic valuation methods used.

As discussed in section 3.1. we will assess economic damage of subsidence of two direct impacts (damage to infrastructure and to buildings), and two indirect impacts (land loss and increased flood risk). Other impacts that cannot be quantified due to data and time limitations, such as such as adverse health impacts, loss in landscape quality and social disruption, will be described qualitatively. Those impacts that do not have a direct reflection in a real market, are not addressed in this study as there is no good way to assess these impacts without elaborate local data collection.

Figure 3.2 shows a schematic overview of the methodology. To arrive at an economic value for subsidence effects, we use a risk approach to make the link between the hazard (subsidence or flood risk) and the exposed assets, such as roads and buildings and people.

This study examines the impact of subsidence directly, and the impact on flood risk. As the land sinks below the sea level (Clark, 2013) more areas will be susceptible to coastal flooding. Pluvial and fluvial flooding may also increase as inundation depths become larger, and the changing elevation complicates the discharge of water from the drainage system to rivers, and from the river to the sea, but these hazards are not quantified due to data limitations.

Exposure is the amount and type of assets exposed to the hazard. In this study, the assets under consideration include the land use type, infrastructure and buildings exposed to subsidence and coastal flooding.

Table 3.2 gives an overview of the approach used for each quantified effect, based on a combination of hazard and exposure information and the value or price of damage. The following sections (listed in the last column of the figure) will provide more background and underlying assumptions for estimating damage for each of these effects.

We calculate impacts of subsidence for 20 years in the future, for the period of 2020 to 2040. We assume damage will increase over time with average inflation over 2010-2020 4,65% (Central Bank of Indonesia, 2020). Building on recommendations from the ADB for Asia, we use a social discount rate of 10%. All values in this study are in price level of 2020. Results will be presented for Semarang and Demak separately, as well as together, as these have distinct jurisdictional mandates (local governments).

To some extent, there may be double counting between direct damage to roads and buildings and land loss, as there are no additional maintenance costs of assets located in lost land.

Table 3.2. Overview of the different evaluation approaches for each type of damage. The evaluation approach is explained in detail in the shown sections.

Potential Damage	Evaluation approach	Section
Direct damage		
Damage to infrastructure: roads	Additional costs in road maintenance = # m^2/road type/subsidence category * additional costs (IDR)/m2/road type/ subsidence category	3.3.2
Damage to buildings	Damage to buildings due to subsidence = # buildings/ subsidence category * estimate restoration costs (IDR)/building/subsidence category	3.3.3
Indirect damage		
Increased coastal flood risk	Increased coastal flood risk = ∫#ha per land use newly exposed to coastal flooding * damage-effect relationship (f(inundation depth, land use, return period)	3.4.2
Loss of land near water bodies	Economic value of land loss = #ha/land use type below MSL (Scenario A/B)*land price/ha/land use type (IDR)	3.4.3

Box 1: Background - economic valuation of subsidence impact
Estimation of direct market effects is relatively straightforward, particularly for structural damage (e.g. to roads and buildings): this can be estimated using cost-based approaches such as damage restoration costs and lifecycle cost. More time-intensive approaches such as revealed or stated preference can also be applied to estimate direct market effects (e.g. hedonic pricing): this includes for example the statistical analysis of a large dataset of house characteristics – and prices to derive the value of a single characteristic – e.g. the subsidence rate.

Indirect market effects can be estimated using production functions and revealed preference methods such as hedonic pricing, and by identifying the contribution of subsidence to risk to natural hazards or environmental impacts. In a data-scarce environment, the mitigation cost or engineering approach can also be applied: in this approach, the cost of preventing (negative consequences of) subsidence are used as a proxy for the economic value of the negative impacts. Although not technically correct, this approach does give valuable information: if the prevented negative consequences of subsidence are valued higher (e.g. by stakeholders/ expert assessment) than the mitigation costs, there is a rationale for prevention. Direct and indirect non-market effects can be estimated using revealed and stated preference methods which derive the willingness to pay or accept, such as contingent valuation (Damigos, Tentes, Balzarini, Furlanis, & Vianello, 2017), choice experiment and hedonic pricing (Willemsen, Kok, & Kuik, 2020; Wade, Cobourn, Amacher, & Hester, 2018).

3.3 Direct subsidence damage

Direct subsidence damage includes damage to infrastructure and buildings as a result of settlement. Expected economic damage is a function of hazard (subsidence rate), exposure (# exposed assets) and vulnerability (damage relationship per asset/subsidence rate).

For direct subsidence damage, damage-effect relationships – estimating e.g. amount of damage to buildings or roads under a specific subsidence rate – are largely missing. We therefore base the analysis on extrapolating numbers from locations where such damage relations have been established, complemented by assumptions described in the sections below. To calculate the direct damage to roads and buildings due to subsidence, we make use of damage restoration costs.

3.3.1 Subsidence hazard

Subsidence data is derived from Ellipsis data (Ellipsis, 2020) for the Semarang area and from available DSInSAR data (Yuwono, Subiyanto, Pratomo, & Najib, 2019) for the Demak area[2]. The subsidence rate is generally higher in the Northeastern part of Semarang, and in the Sayung and Karangtengah district in Demak. In the Genuk district in north-eastern Semarang, where the Genuk Industrial area is located, subsidence is particularly severe with > 10 cm / year (Figure 1.1).

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[2] Ellipsis subsidence rate was derived from Sentinel-1A bi-monthly observation data that was taken since April 2016 to October 2019 and processed with inSAR (Interferometric synthetic aperture radar) technique (Ellipsis Earth, 2020). Demak subsidence data was derived using DinSAR (Interferometric synthetic aperture radar) techniques and GNSS (Global Navigation Satellite System) technology to predict the rate of land subsidence coastal of Demak.

3.3.2 Damage to roads

Additional lifecycle costs of roads = # m^2/road type/subsidence category * additional costs (IDR)/m^2/ year/ subsidence category

Subsidence leads to differential settlement, tilting and cracks/ potholes in roads, reducing their quality. To maintain a stable performance level (quality), more maintenance is needed[3].

Data on location and type of roads in the area is derived from the critical infrastructure dataset (Central Java Government, 2020): Figure 3.3. Two types of roads can be distinguished: large, arterial roads (highways) and regular roads.

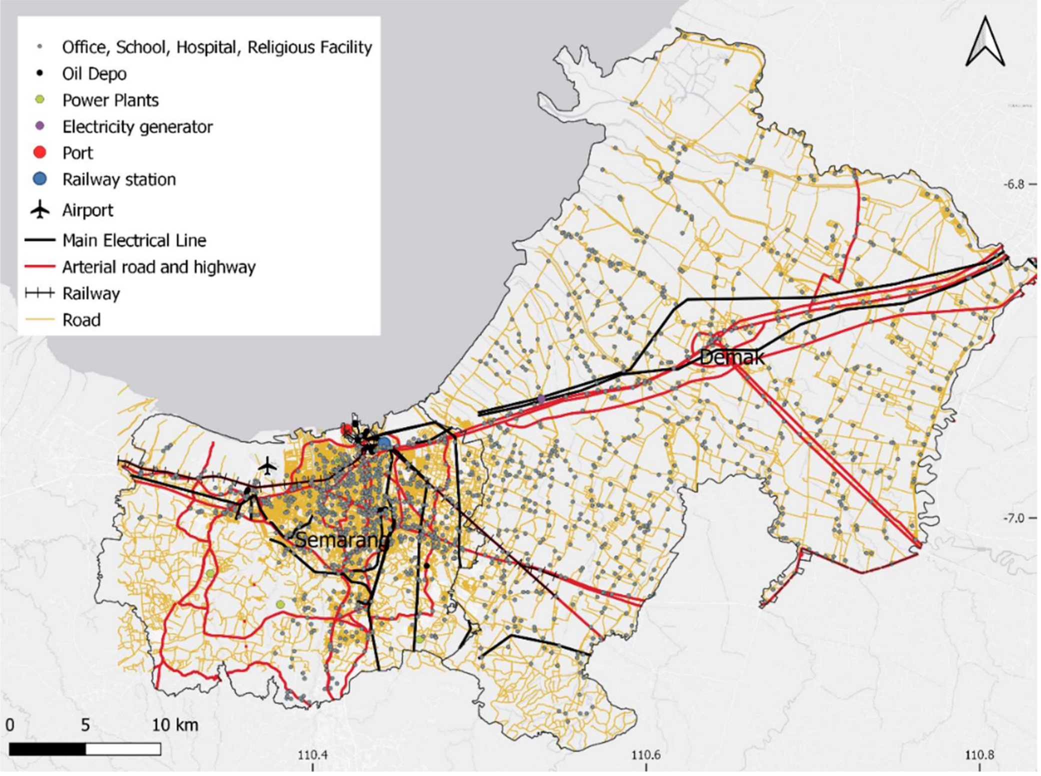

Figure 3.3 Critical infrastructure in Semarang and Demak (Central Java Government, 2020)

Roads that are subject to subsidence have a shorter lifetime and they have to be periodically elevated and require more frequent maintenance. This results in higher lifecycle costs. To estimate the additional life-cycle costs of roads as a result of subsidence, we take the following assumptions:

- The service level of a regular road is lower than an arterial road: we assume that this translates in a factor 1,5 higher maintenance costs per m^2 for arterial roads compared to regular roads.
- Damage-effect relationships on subsidence and life cycle costs for roads are largely missing. A recent study on additional maintenance costs for regular roads under subsidence from the Netherlands (van de Ridder et al., 2020) does give an average additional costs of €2,1/m^2 per year. Most locations in the studied area subside on average 0,5-1 cm. In absence of better, local estimates, we extrapolate this result to

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[3] If this increased maintenance is not done, the service level of the road reduces: this also has economic consequences, like increased travel time, damage to vehicles and lower safety (more incidents).

this study. As the Netherlands have one of this highest performance levels for roads in the world, we assume that this estimate (€2,1/year for a rate between 0,5-1 cm) translates to the Indonesian context for higher subsidence rates: 2-4 cm/year. Adjusted for price level 2020 based on OECD price indices[4] this is 13.409 IDR/m^2/year[5] .

- We assume areas with lower subsidence rate have lower costs (-20%) and areas with higher rates (>4 m) have higher costs (+20%)
- Based on the above, we assume the following additional maintenance costs due to subsidence (Table 3.3).

Table 3.3 Assumed additional maintenance costs due to subsidence in IDR/year/m^2 road

Subsidence rate	**Assumed additional maintenance costs in IDR/year**	
	Arterial road	Regular road
0-2 cm/year	16.080	10.720
2-4 cm/year	20.100	13.400
>4 cm/year	24.120	16.080

3.3.3 Damage to buildings

Damage to buildings due to subsidence = # buildings/ subsidence category * restoration costs (IDR)/building/subsidence category

Economic damage to buildings resulting directly from subsidence includes (restoration/ and or loss of building value due to) tilting of the house, cracks, damage to windows and doors. In extreme form, this may lead to integral instability and danger of collapse. There is no detailed study of the extent and underlying causes[6] of damage to buildings in the area but is clear that these issues occur (see 8.2).

Building data was generated from Open Street Map database (Openstreetmap, 2020). In Semarang, this covers all buildings in the area affected by subsidence. In Demak however, building information in the database is incomplete and does not cover the entire study area: this may lead to underestimation of building affected by subsidence.

To estimate the direct damage to buildings due to subsidence, we take the restoration costs approach[7]. As damage-effect relationships are largely lacking (i.e. how high are restoration costs for buildings under certain subsidence rate), we extrapolate results from the Netherlands

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[4] Comparative price level provides a measure of the differences in the general price level between countries. Indices are derived from https://data.oecd.org/price/price-level-indices.htm

[5] The order of magnitude of our assumptions seems realistic, based on reported costs for elevating roads in the project area. Reported costs for elevating an arterial road with 40 cm are 5000 million IDR / km (Pramesti, 2020). Elevating costs for smaller roads are 551 million IDR / km (Electronic Procurement Services Demak Government, 2020). Assuming an arterial road is 20 m broad, annual additional costs/km amount to IDR 420 million based on our assumptions. This corresponds to the costs for elevating it once every 12 years, which seems a reasonable interval.

[6] There might e.g. be different impacts based on building age, type and quality of the foundation/ overall construction.

to the study area. As type of buildings, subsidence and damage mechanisms are not similar between the two countries, we conservatively take the following assumptions;

- Restoration costs for buildings in Indonesia are 50%[8] of those in the Netherlands (Costa et al., 2020; see also Table 24 in Annex), after adjusting the price level based on OECD price indices
- We assume that damage from buildings in low-medium and medium damage categories (i.e. filling up cracks up to 15 mm, repainting in and/ or outdoors) is restored once every 10 years: as superficial damage is restored but underlying building foundations are not strengthened, the effect will be short-lived.
- Damage from buildings in a severe damage class will be restored once between 2020-2040 (i.e. repainting, filling cracks >20 mm width, restoring tilted floors, stuck windows and door frames, stabilization of building foundation) – assuming that during maintenance preventive measures are taken to avoid further damage.

Table 3.4 Assumed damage restoration costs for buildings affected by subsidence

Subsidence rate	Assumed damage level	Restoration costs/building in IDR
0-2 cm/year	Low-medium	29.000
2-4 cm/year	Medium	170.000
>4 cm/year	Severe	587.000

3.4 Indirect subsidence damage

Indirect subsidence damage includes damage related to direct, physical damage to infrastructure and buildings (e.g. business interruption or health risks) or 2) direct effects related to other natural hazards driven or aggravated by subsidence – such as flooding. In this study, we focus on the latter, and monetise impacts of subsidence in relation to increasing flood risk, and land loss to the sea (permanently inundated).

3.4.1 Flood hazard

A flood hazard is defined as the probability (e.g. 1:10 years) and intensity (inundation depth, extent) of coastal flooding.

Table 3.5 gives information about the extreme storm surge in the area, based on global data. As the variance of the storm surge for different return periods is very small (less than 0.01), we use the extreme storm surge value of 2 m for all flood return periods, instead of assigning the different inundation depths for each different return period. To single out the effect of subsidence on the flood hazard, we consider the potential flood extent as key hazard parameter for both increased flood risk and land loss. Other factors related to flood risk such as daily and monthly tidal oscillations, sea level rise, changing extreme storm surge, tsunami's and hurricane conditions and land use change (which do affect the coastal hazard in the area are assumed to remain constant for the purpose of this analysis (Muis, et al., 2020) .

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[8] Costa et al show restoration costs in €/m^3. In the Netherlands, buildings are on average 200 m^3 in size. For Indonesia, we assume buildings are 50% of this: 100 m^2.

Table 3.5: Extreme storm surge for different return period in Semarang - Demak area (Muis, et al., 2020)

Station Location	**Return Period / Storm surge (m)**									**Average (m)**	**Variance (m)**
	2	**5**	**10**	**25**	**50**	**100**	**250**	**500**	**1000**		
Demak	1.92	1.94	1.96	1.98	2.00	2.01	2.04	2.05	2.07	2.00	0.00

To calculate the development of potential flood extent (inundated areas) over time, we calculate elevation in 2040 by subtracting the total subsidence between 2020-2040[9] from the current (2020) Digital Elevation Model (DEM).

The area below storm surge height but above mean sea level and connected to the sea in the projected 2040 DEM, is considered as the increased flood extent due to subsidence. Projected areas that are below mean sea level in 2040 and connected to the sea are considered as permanently inundated and therefore considered lost (land loss). These areas are excluded from the flood risk assessment (section 3.4.2); economic costs of land loss is valued in a different manner, as described in section 3.4.3.

To isolate the impact of additional subsidence over the period of 2020-2040 on land loss and increased flood risk, we only consider *additional flood risk extent* between 2020-2040 compared to the current flood extent.

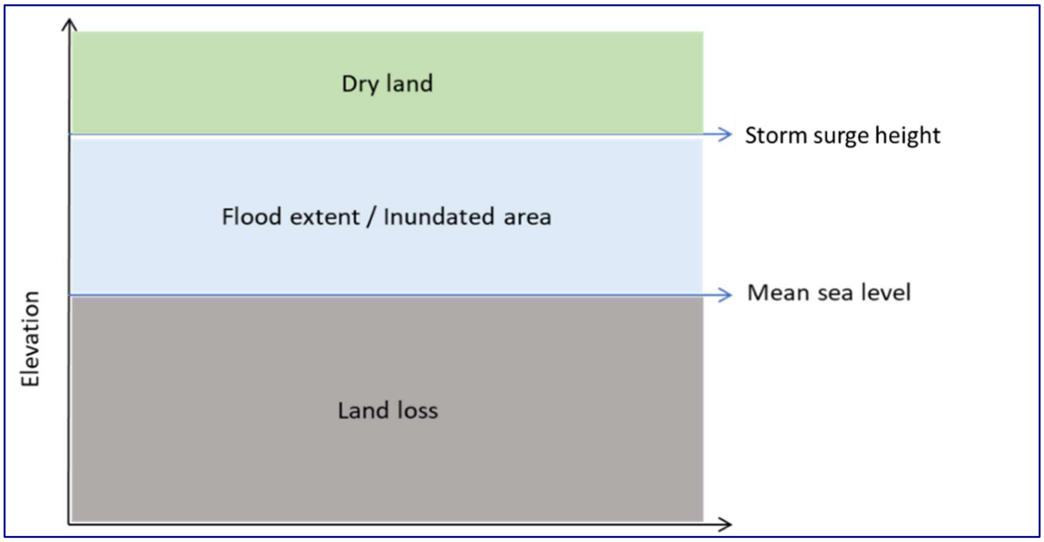

Figure 3.4 Overview of assumptions regarding flood hazard and land loss in relation to elevation in 2040

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[9] Based on the assumption the current subsidence rates remain constant over time.

3.4.2 Increased coastal flood risk

Increased coastal flood risk =

$$\int (\text{\# ha per land use newly exposed to coastal flooding (DEM2040) x damage} - \text{effect relationship } \left(\text{f(inundation depth, land use, return period)}\right))$$

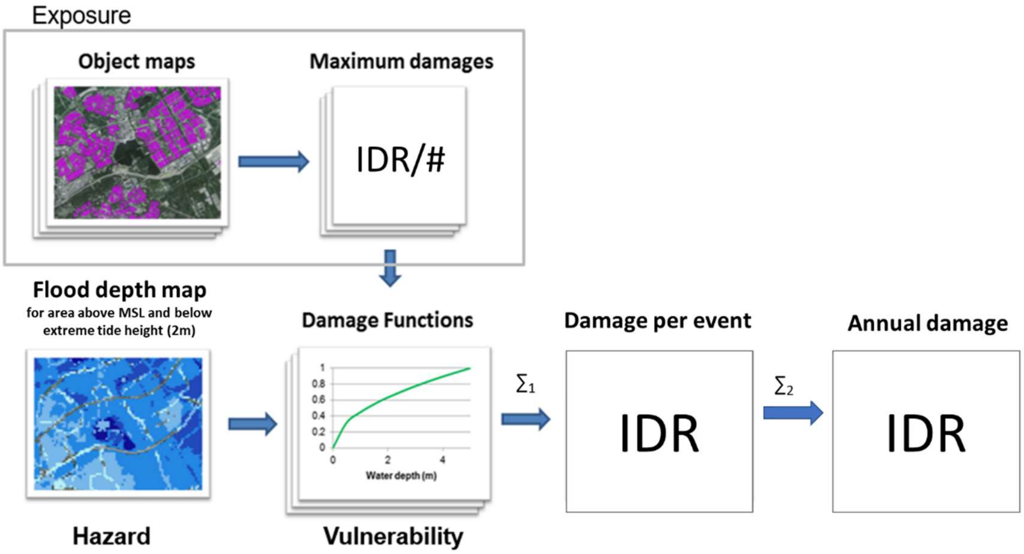

Figure 3.5. Overview of the damage calculation procedure in this study. ∑1 is a calculation in which the discount rate is applied, and ∑2 is a calculation in which the Expected annual damage (EAD) from coastal flooding is calculated

Figure 3.5 gives an overview of the flood risk damage calculation procedure in this study. The steps and data are further explained in this section.

Potential flood extent maps (3.4.1) are overlaid with the land use map to calculate the number of hectares of exposed residential, industry, agriculture, and aquaculture area. The land use map used for this assessment is the Central Java Government spatial planning map for 2030 (Figure 3.6), since there are no maps for 2020 and 2040. As the planned development in the area (e.g. urbanisation, expansion of industrial areas) is likely to continue after 2030, this may lead to an underestimation of damage for the period 2030-2040, and an overestimation for 2020-2030.

Damage resulting from a flood event is dependent on the inundation depth and land use type. To derive damage for each inundation depth in each different land use type we use the database with Indonesia-specific depth-damage functions (Huizinga, de Moel, & Szewczyk, 2017). This dataset contains damage curves depicting fractional damage as a function of water depth as well as the relevant maximum damage values for a variety of assets and land use classes derived from extensive literature survey. The estimated damage for each inundated depth taken is presented in Table *3.6*. Aquaculture damage is not available in hence we assume that aquaculture damage is equal to agriculture damage.

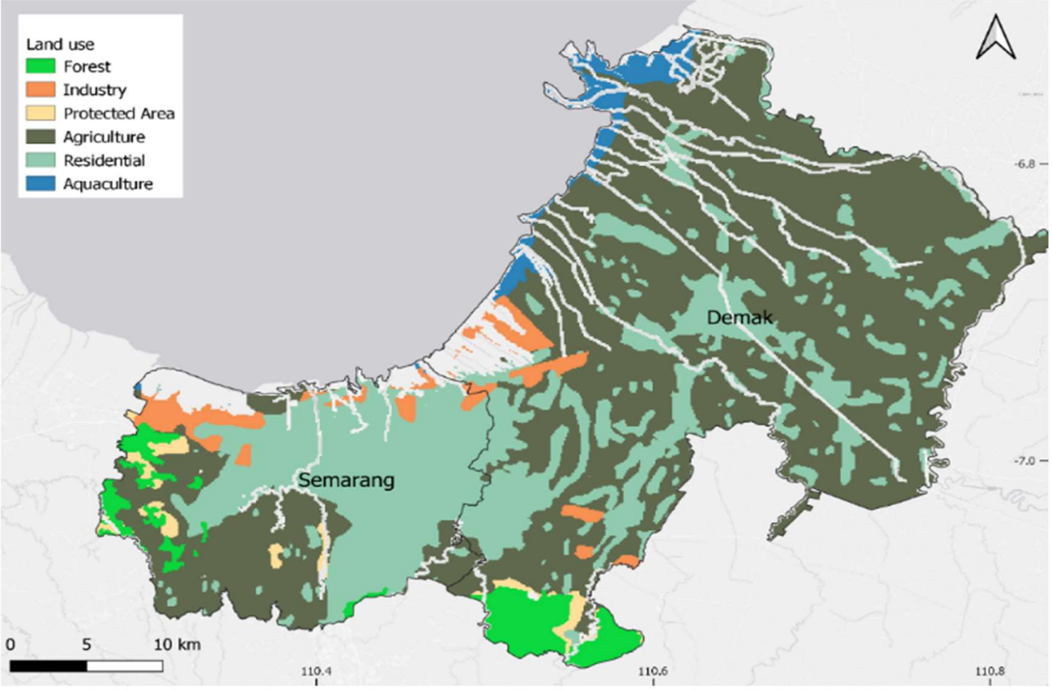

Figure 3.6 Planned land use in Semarang and Demak (Semarang Municipality Government, 2011; Central Java Government, 2020)

Table 3.6: Maximum damage of flooding for each land use type (Huizinga, de Moel, & Szewczyk, 2017) *between 2020-2030.*

Inundation Depth (m)	Maximum damage (2010 value)
Residential	105600 IDR / m^2
Industry	475200 IDR / m^2
Agriculture	140800 IDR / hectare
Aquaculture	140800 IDR / hectare

For each land use type, damage is calculated as a function of inundation depth and the maximum damage, following the function presented in Figure 3.7. We combine above factors to calculate expected annual damage (EAD) from coastal flooding by taking the integral of the damage as function of the return periods, as illustrated in Figure 3.8.The dots are the calculated damages at different return periods; the blue line is the linear interpolation between each flood return period damage calculations. As the storm surge height does not significantly vary for different return periods (Table 3.5 and Figure 3.4), we use the average storm surge height for all flood return period, therefore, damage for different flood return periods in this study are equal. The blue surface under this dotted line is the EAD in million IDR/year. To calculate the present value of this flood risk over 20 years, this EAD is discounted.

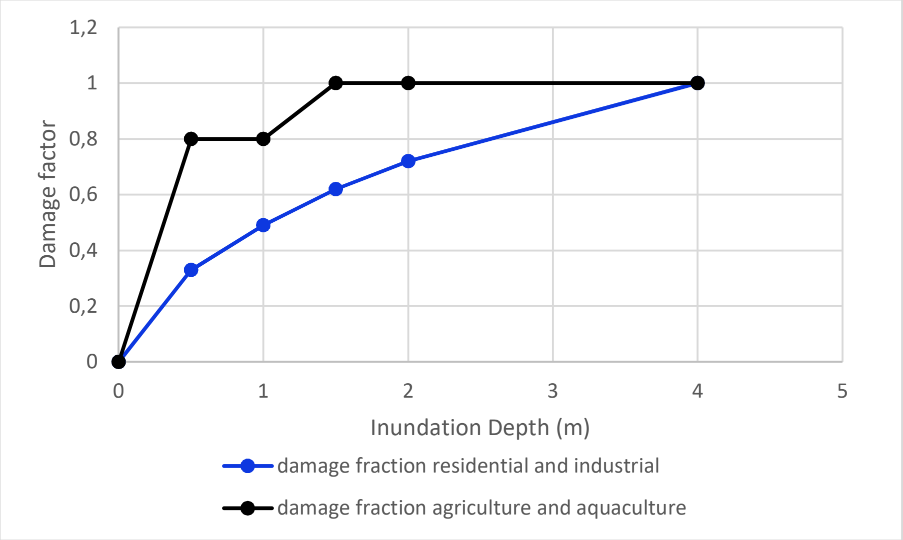

Figure 3.7. Depth damage function used in this study to calculate the damage of residential, industrial, agriculture, and aquaculture to different inundation depth. The calculated damage is the product of damage factor times maximum damage (see also Table 3.6*)*

3.4.3 Loss of land

Economic value of land loss = #ha/land use type below MSL (Scenario A/B) * land price/ha/land use type (IDR)

Over time – in the absence of extensive investments in coastal protection – the coastline will move inwards, and land is permanently lost. Section 3.4.1 explains how we calculate the extent of land lost to the sea by 2040. The economic value of land loss is based on the average land price per land use type.

The land use map used for this assessment is the Central Java Government spatial planning map for 2030 (Figure 3.6). For the year 2040 we assume land use is the same as in 2030.

Land prices give a reasonable proxy for the economic value of land. To calculate the damage from land loss, we therefore use land prices. As comprehensive regional data is lacking, we assume land prices based online advertisements covering residential, industrial, and agricultural areas (rumah123.com, 2020; olx.com, 2020). We assume the value of aquaculture land is similar to agricultural land. We further assume land prices will increase over time with average inflation over 2010-2020 4,65% (Central Bank of Indonesia, 2020)(Table 3.7).

To calculate the economic damage from land loss between 2020 and 2040, we further assume that the rate of land loss between 2020 and 2040 is linear.

Table 3.7 Overview of land prices (price level 2020) per land use type

Land use type	**Land price (million IDR/m2, 2020)**	
	Semarang	Demak
Residential	8.90	3.54
Industry	6.47	2.32
Agriculture	0.11	0.30
Aquaculture	0.11	0.30

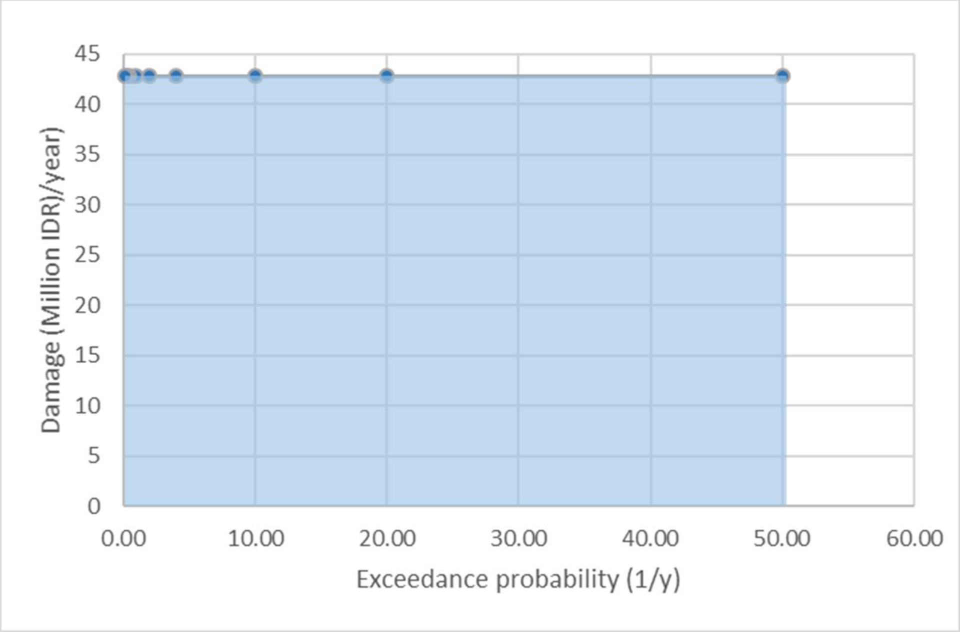

Figure 3.8. Illustration of calculation of the Expected Annual Damage (EAD). The dots are the results from the damage calculation at different return periods and the blue area represents the EAD

3.5 Overview of data sources

In Table 3.8 an overview is presented of the datasets used to calculate subsidence impacts in this study.

Table 3.8: List of datasets used for the calculation in this study

Type	Data	Source
Hazard	Subsidence rate Semarang	(Ellipsis, 2020)
	Subsidence rate Demak	(Yuwono, Subiyanto, Pratomo, & Najib, 2019)
	Extreme storm surge	(Muis, et al., 2020)
	Digital Elevation Model	DEMNAS
Exposure	Land use	(Semarang Municipality Government, 2011; Central Java Government, 2020)
	Vital infrastructure of Semarang and Demak	(Central Java Government, 2020)
	Building	(Openstreetmap, 2020)

4 Subsidence scenarios

In this study, we assess the economic impact of subsidence in Semarang and Demak in two subsidence scenarios:

1. Scenario A, where the subsidence rate is reduced to half its current rate after 10 years.
2. Scenario B, where the subsidence rate is reduced to a quarter of its current after 10 years.

Economic impact is assessed over a time span of 20 years: from 2020 to 2040 and compared against a business as usual scenario.

4.1 BAU (Business as usual)

In BAU, the subsidence rate will remain constant over time. Currently planned measures that address groundwater extraction are assumed to either be ineffective in significantly reducing the subsidence rate or will not take effect until after 2040. With ongoing economic growth, the number of assets exposed to subsidence and aggravated coastal flooding will be higher: to address this, we use land use map of 2030. Although economic growth will likely also increase groundwater demand and consequent subsidence, this relationship a knowledge gap and cannot be quantified: we therefore assume the current subsidence rate will continue but not increase in the future.

4.2 Scenario A: subsidence rate reduced by 50%

Experiences from other countries indicate that with full effort in minimizing subsidence, the process can be significantly reduced over the span of 10 years after measures have been taken (Sato, Haga, & Nishino, 2006). Building on this, we assume that in this the subsidence rate will remain constant in the first 10 years (2020-2030), and then be reduce by 50% as a result of efforts to mitigate subsidence.

4.3 Scenario B: subsidence rate reduced by 75%

We assume that in scenario B the subsidence rate will remain constant in the first 10 years 2020-2030), and then reduce by 75% as a result of efforts to mitigate subsidence.

5 Results

5.1 Direct subsidence damage

5.1.1 Road infrastructure

Based on overlaying the subsidence map and road map in GIS, the amount of km road impacted per subsidence class was calculated, presented in Table 5.1.

Table 5.1. Overview of # road (in km) impacted per subsidence rate.

subsidence (cm/year)	# Road impacted (km)			
	Road		Arterial Road	
	Semarang	Demak	Semarang	Demak
0-2	1202	160	125	0
2 to 4	127	744	5	91
4 to 6	149		12	
6 to 8	153		15	
8 to 10	229	138	26	23
> 10	125		8	

Based on these quantities and the prices (for additional maintenance) presented in Table 3.3[10], the annual costs of additional road maintenance due to subsidence amount to 128 billion IDR/year in Semarang and 80 million IDR/year in Demak for regular roads, and 72 billion IDR/year and 55 billion IDR/year respectively for arterial roads.

Under BAU, in which subsidence is expected to continue in the same rate, this amounts to 4307 billion IDR in present value. For scenario A, in which subsidence rate is halved after 10 years when measures come into effect, this amounts to 3456 billion IDR. For Scenario B this amounts to 3030 billion IDR.

5.1.2 Damage to buildings

Based on overlaying the subsidence map and building data from Openstreetmap (see 3.3.3), the amount of buildings impacted per subsidence class was calculated (Table 5.2).

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[10] To arrive from IDR/m2 road to IDR/ km, we assume average width of arterial road 20m, and for regular road 5 m

Table 5.2 Number of buildings affected by subsidence

subsidence (cm/year)	**Affected Buildings (unit)**	
	Semarang	Demak
0-2	220148	2447
2 to 4	25201	25135
4 to 6	29833	
6 to 8	32124	
8 to 10	43036	1110
> 10	28165	

Based on these quantities and the prices for restoration of damage presented in Table 3.4, we calculate the damage to buildings due to subsidence (cracks, damage to windows etc).

In scenario BAU in Semarang, the present value of damage to buildings amounts to IDR 66 billion, and in Demak IDR 6 billion. In Scenario A, damage is respectively IDR 53 billion and IDR 8 billion. In Scenario B, damage is respectively IDR 47 and 4 billion.

5.1.3 Other

Aside from damage to roads and buildings, there are many other physical assets that may be damaged by subsidence and thus lead to restoration costs/ higher maintenance, or lower service levels. These include damage to drinking water and water management infrastructure (sewage pipes, drainage channels, pumping stations, dikes), transport infrastructure (railway, ports, airports) and telecommunication and energy infrastructure (e.g. oil and gas pipes, cables). It was not possible to monetize these impacts, but there is already evidence these assets are subject to damage from subsidence in the area (illustrations in 8.2): it can be expected this will continue in the future.

5.2 Indirect subsidence damage

5.2.1 Increased coastal flood risk

To calculate the increase in coastal flooding relative to the current condition due to subsidence, the increase in areas exposed to inundation are calculated for Semarang and Demak under subsidence scenario A and B (see 3.4.2). Land that becomes permanently inundated is deemed lost (see following section 5.2.2). Both for Semarang and Demak, inundation depths are exceeding 1,5 m. In Semarang, mostly residential and industrial areas become subject to inundation, in Demak mostly agricultural areas.

In Semarang, 249 hectares will become subject to inundation under BAU (additional to current flood extent in 2020); 456 hectares under scenario A, and 327 hectares under scenario B. The difference between scenario A and B and BAU is explained as under BAU more land will be permanently lost instead of just subject to additional flooding.

In Demak, 765 hectares will become subject to inundation under scenario BAU (and also a significant amount of land will be permanently lost, see next section 5.2.2). Under scenario A, less land will become subject to flooding than in BAU. Scenario B has the highest increase in total hectares flooded. These results might seem counterinitiative as Scenario B presumes lowest subsidence rate. However, scenario B has the highest flood extent because scenarios

A and BAU have high loss of land. Thus, more area under scenario B becomes subject to flooding instead of being completely lost (Table 5.3 and Table 5.5; see also in Annex).

Table 5.3 Additional inundated area under BAU, scenario A and B in 2040, as compared to the current situation (2020) in Semarang and Demak

Area	Additional flood risk area addition under scenario A (hectares)	Additional flood risk area addition under scenario B (hectares)	Additional flood risk area under BAU (hectares)
Semarang	456	327	249
Demak	597	886	765

In present value, the overall increased flood risk due to subsidence over 2020-2040 amounts to 390 billion IDR in BAU, 392 billion IDR in scenario A, and 158 billion IDR in scenario B.

Table 5.4:Damage from coastal flooding in Semarang and Demak relative to current condition for different land use types (present value, in IDR x billion)

	Land Use	A	B	BAU
Semarang	Residential	164	132	140
	Industrial	136	216	108
	Agriculture	0	0	0
	Aquaculture	0	0	0
	Total	**300**	**348**	**248**
Demak	Residential	25	46	54
	Industrial	121	135	88
	Agriculture	0	0	0
	Aquaculture	0	0	0
	Total	**146**	**181**	**142**

5.2.2 Loss of land

As can be seen in Figure 5.1, already in the current situation quite some land has been lost to the sea in the past decades (in grey). If land subsidence continues unabated (BAU) further loss of land will be significant (in green); if subsidence can be halved (scenario A) much land loss will be prevented (in blue), and almost all can be prevented in scenario B with quartered subsidence rate (in black).

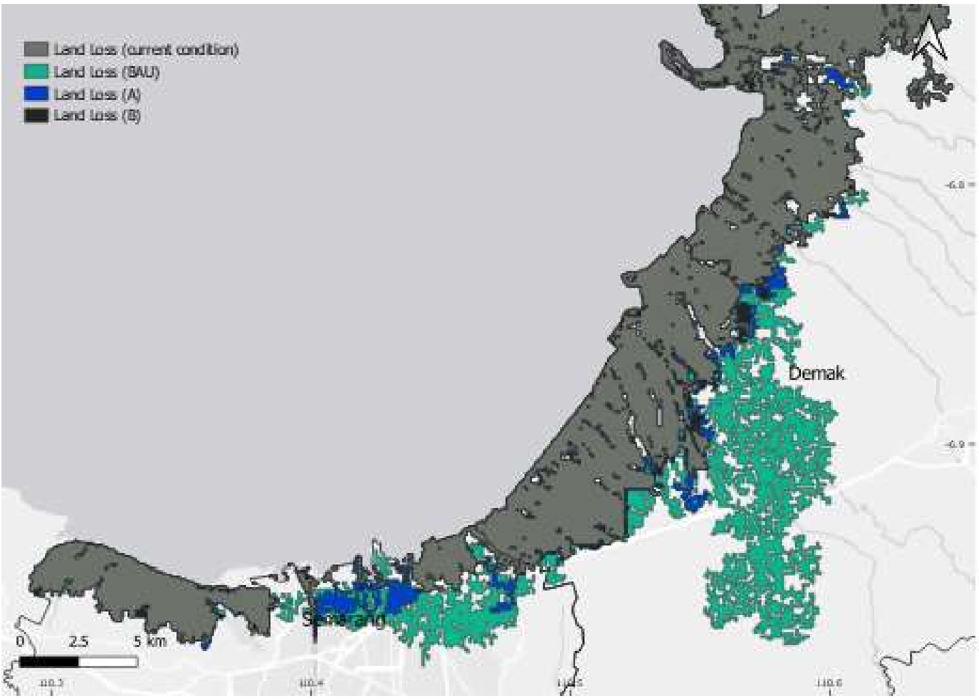

Figure 5.1: Loss of land under the different scenarios and current condition.

Table 5.5: Land Loss under BAU, scenario A, and scenario B in Semarang and Demak as compared to 2020

Area	**Land Loss addition under scenario A (hectares)**	**Land Loss addition under scenario B (hectares)**	**Land Loss addition under BAU (hectares)**
Semarang	**1216**	**671**	**1738**
Residential	893	513	1313
Industrial	289	125	388
Agriculture + aquaculture	34	33	37
Demak	**4989**	**4046**	**6463**
Residential	736	601	1160
Industrial	275	218	436
Agriculture + Aquaculture	3978	3227	4867

Table 3.7 in section 3.4.3 gives an overview of the land value (price level 2020) for different land use types in Semarang and Demak.

Economic damage due to loss of land is calculated as the product of lost area (Table 5.5) and its land value (Table 3.7). Although overall less land is lost in Semarang, the damage is relatively high as compared to Demak due the higher land value, as mostly industrial and residential land is lost (Table 5.5). Total economic damage under BAU is IDR 113 trillion, IDR 83 trillion in scenario A, and IDR 37 trillion in scenario B.

Table 5.6: Damage from land loss in Semarang and Demak relative to current condition for different land use types (present value, in IDR x billion)

	Land Use	A	B	BAU
Semarang	Residential	45002	11628	62428
	Industrial	10727	2074	13714
	Agriculture	23	60	25
	Aquaculture	1	1	1
	Total	**55753**	**13764**	**76168**
Demak	Residential	16328	14100	23325
	Industrial	3509	2892	5252
	Agriculture	7254	6204	8481
	Aquaculture	66	68	108
	Total	**27157**	**23263**	**37166**

5.2.3 Other

Aside from increased coastal flood risk and land lost permanently to the sea, subsidence also increases pluvial and fluvial flood risk. As the hydrodynamic structure of the land changes, it will become increasingly difficult for rivers to discharge to the sea, leading to high water levels at the river mouth and farther inland. Furthermore, it will become increasingly difficult to drain (rain)water from quickly subsiding areas, leading to inundation during rain event.

The high (shallow) groundwater tables and increasing salinization of groundwater in the area will also negatively affect agricultural yields (aside from flooding).

Overall, the increasing flood risk and land loss, lower yields of agriculture, and lower quality and/ or higher costs for upkeep of buildings and infrastructures will reduce the attractiveness of the entire area for businesses: as illustrated by the recent decision in Jakarta to relocate administrative functions elsewhere.

For the population, all these impacts – increasing flood risk, damage to infrastructure, lower agricultural yields and negative implications for the business climate, reduce the quality of life in general.

5.3 Overview of economic impact of subsidence

Table 5.7 shows the overview of economic impacts of subsidence under BAU, scenario A and B over 2020-2040, in billion IDR. The most significant impact of subsidence by far is land loss, followed by increased costs for maintenance of roads and arterial roads, and increased coastal flood risk.

Table 5.7: Summary of economic loss due to subsidence in Semarang and Demak in 2020-2040 (present value) in billion IDR. PM = Pro memorie

Effect	**Damage in Semarang (billion IDR)**			**Damage in Demak (billion IDR)**		
	A	**B**	**BAU**	**A**	**B**	**BAU**
Direct						
Increased road maintenance	1346	1180	1677	798	700	994
Increased arterial road maintenance	764	670	951	549	481	684
Damage to buildings	53	47	66	5	4	66
Damage to other infrastructure	PM	PM	PM	PM	PM	PM
Indirect						
Land Loss	55753	13764	76168	27157	23263	37166
Increased Coastal Flood risk	300	348	248	146	181	142
Increased pluvial and fluvial flood risk	PM	PM	PM	PM	PM	PM
Reduced attractiveness of business climate; lower agricultural yields	PM	PM	PM	PM	PM	PM
Lower quality of life population	PM	PM	PM	PM	PM	PM
Total (present value in billion IDR)	**58216**	**16009**	**79110**	**28655**	**24629**	**39052**

If no new policy adopted (BAU), the total order of magnitude of impacts monetized in this study is around IDR 76 trillion for Semarang, and IDR 37 trillion for Demak, corresponding to approximately $5,4 billion and $2,6 billion. By reducing subsidence with 50 % (Scenario A) or 75 % (Scenario B) after 10 years, respectively 30% and 66s% of this damage can be prevented (Table 5.8).

These results do not give a full picture of the extent of damage (prevented) under different subsidence scenarios, as not all effects could be quantified. In terms of economic impact, particular increased pluvial and fluvial flood risk may be expected to significantly increase with land subsidence. Other infrastructures beside roads will likely also have significantly higher life cycle costs due to subsidence. Furthermore, consequences of subsidence may lead to a reduced attractiveness of the business climate, possibly lower agricultural yields and an overall lower quality of the life for the population. These effects are mentioned in overview Table 5.7 as Pro Memorie (PM): to be remembered when reviewing results from this study.

Table 5.8 shows the benefits of Scenario A and B as compared to the damage incurred by land subsidence under BAU. In Semarang, reducing subsidence has benefits of respectively IDR 21 trillion and IDR 63 trillion under Scenarios A and B. In Demak, reducing subsidence has benefits of respectively IDR 10 and 14 trillion for scenario A and B.

Table 5.8 Benefits of Scenario A and B as compared to damage under BAU (in billion IDR, present value)

	Semarang		**Demak**		**Total**	
Effect	A	B	A	B	**A**	**B**
Reduction LCC regular roads	331	497	196	295	**528**	**792**
Reduction LCC arterial roads	188	282	135	203	**323**	**484**
Prevented damage to buildings	13	20	61	62	**75**	**82**
Land Loss Prevented	20415	62404	10009	13903	**82819**	**23912**
Coastal Flood risk reduction	-52	-100	-4	-39	**-152**	**-143**
Total benefits	**20895**	**63103**	**10397**	**14424**	**83593**	**25127**

Sensitivity analysis

In annex C the sensitivity of some key elements from the analysis is tested: the accuracy of the DEM, and the (not yet solidified) plans for a sea wall.

Accuracy of the Digital elevation model

The DEM is the basis for the calculation of the amount of land that will be lost and/ or subject to flooding, in relation to the current situation (by subtracting expected subsidence in 2040 from the 2020 DEM). In relation to land loss, results indicate that the outcome highly depends on the quality of the DEM. If the DEM overestimates actual elevation (i.e. actual elevation is lower), the results remain relatively similar. However, if the DEM underestimates actual elevation (i.e. actual elevation is higher), this results in significantly lower land loss.

Flood risk adaptation plans: sea wall

There is currently a plan to establish a 27 km long sea wall along Semarang-Sayung coastline section. If this sea wall is successfully installed, the low-lying area in northern Semarang will still be connected to the sea and therefore still be subject to land loss and increased flood hazard. In the Sayung district in Demak however, the sea wall will significantly prevent further land loss and increased flood coastal risk.

Other key assumptions

Besides the impacts above which have been studied in more detail, the following factors/ assumptions may be expected to have a high impact on the results in this study:

- *Cost transfer from the Netherlands for buildings and infrastructure:*
  Despite conservative extrapolation, transferring costs from the Netherlands – with very different type of buildings and performance levels – may lead to an overestimation of damage.

- *Discount rate and time horizon*;
  In absence of a specific recommendation from the Indonesian public authorities on which discount rate to use in economic appraisal studies, we used a social discount rate of 10% as recommended by the ADB. This is quite high: a lower (or no) discount rate would give very different estimates. The selected time horizon is also important: 20 years is relatively short. The impact of (reducing) subsidence will last beyond 2040.

- *Set-up of scenario A and B.*
  For both scenarios we assume that measures to reduce subsidence will not be effective in the first 10 years: damage is the same as BAU. Although it may be technically correct, this means that in practice we only review (reduced) damage in the period between 2030-2040. This may lead to an underestimation of the benefits of reducing subsidence.

6 Discussion, conclusions and recommendations

6.1.1 Discussion/ study limitations

In this study we did a quick scan of potential economic impact of subsidence in Semarang and Demak. As there was limited data available – particularly regarding damage-effect relationships of direct infrastructure (how much damage is caused by a certain amount of subsidence), many assumptions were taken to enable this – necessarily coarse – assessment of potential damage, and not all identified impacts have been quantified. These assumptions may lead to an over – or underestimation of the actual damage due to subsidence. We shortly discuss the most prominent limitations of this study.

Development of damage under BAU

Economic development in the area will lead to 1) increased exposure to damage and 2) possibly speeding up of subsidence rate with drinking water demand (and groundwater extraction). In the analysis we only address the former, by using prognosis land use maps for 2030 (no maps available for 2040). As little is known about the relation between groundwater extraction, we assume the subsidence rate to be constant. If in reality increased groundwater extraction leads to more subsidence, this means our results could be an underestimation. If on the other hand the negative impacts of subsidence lead to a reduced attractiveness of the business climate and moving away of water-intensive industries towards 2030/2040, the corresponding reduced groundwater extraction and subsidence rate could lead to an overestimation of our results. Beyond the economic development over time, we have assumed in this study that implementation of flood risk adaptation (e.g. 27 km long sea wall) and subsidence mitigation plans (piped water supply) will either come into effect after 2040 or not be effective before that time; if these measures are implemented successfully in the short term, this means we overestimate development of damage under BAU (particularly in relation to flood risk and land loss).

Flood risk and land loss

The model used to assess additional coastal flood extent and land loss in this model is very simplistic: a comparison between areas on DEM (2020 and 2040) with the mean sea level and average storm surge height under extreme events. This disregard any flood risk protection measures currently in place, or small-scale adaptation measures (e.g. dikes, mangroves, elevated roads) that may to some degree alleviate coastal flood risk. Regardless, overall, we have reasonable confidence in this assessment as satellite images show that this analysis works well for the current situation (2020) – in the past decades, already a significant amount of land has been lost. A large gap in this study is the lack of flood risk assessment of fluvial and pluvial flooding due to time and data limitations (such studies require complex flood modelling). As subsidence will likely lead to hydrodynamic changes in the landscape and increasing difficulty to discharge rainwater to the rivers, and river water to the sea, it is expected both types of flood risk will increase significantly due to subsidence.

Cost transfer

As there are no damage-effect relationships established for the local context regarding the impact of subsidence on roads and buildings, cost transfer from the Netherlands has been used to estimate these impacts. The Netherlands have very high standards for performance of roads; one of the highest in the world. Transferring cost estimates for management to Indonesia (despite adjusting for the price level) inadvertently assumes the same performance level for Indonesian roads. This has been addressed by adjusting the extrapolation to some extent (cost estimate for 0-2 cm subsidence in NL correspond to 2-4 cm in Indonesia), but this is quite arbitrary. The same goes for damage to buildings: damage restoration costs and damage-effect relationships (i.e. X cm of subsidence leads to Y level of damage) are likely very different in Indonesia. This has been addressed to some extent (assuming damage in Indonesia is 50% of that in Dutch context), but these assumptions may lead to over- or underestimation.

6.1.2 Conclusions

Against a backdrop of economic growth, water demand in Semarang and Demak have increased over time, leading to significant groundwater extraction which in turn has spurred subsidence in the area: in some locations over 8 cm/year. To address this issue, a roadmap for mitigating and adapting to subsidence will be developed in coming years. In support of this roadmap, this study addresses the following questions: '*how much economic damage will caused by subsidence if no new policy is adopted (business as usual; BAU), and how much of this damage can be prevented under two alternative scenarios (A and B) in which subsidence is reduced by respectively 50 and 75% after 10 year?* This will provide valuable insight the economic rationale of taking mitigative (or adaptive) measures.

We identified the following key economic impacts of subsidence: damage to infrastructure (e.g. roads, railway, drinking water, water management), damage to buildings, increased flood risk and eventual land loss, reduced attractiveness of the business climate, lower agricultural production and decreased quality of life for the population. Of these measures, damage to roads and buildings, coastal flood risk and land loss have been monetized. Other impacts, in particular damage to other types of infrastructure (e.g. water management, sewage), fluvial and pluvial flood risk and reduced attraction of the business climate are likely also significant in terms of economic impact but could not be quantified due to time and data limitations.

If no new policy is adopted (BAU), the total order of magnitude of impacts monetized in this study is around IDR 76 trillion for Semarang, and IDR 37 billion for Demak, corresponding to approximately $5,4 billion and $2,6 billion. These findings are in line with the two studies that we could find in Asia that conducted a similar economic cost assessment (Lixin et al., 2010b & Hu et al., 2013). Lixin et al (2011) found that in the Chinese metropolis of Tianjin, the total damages of subsidence are approximately $18 billion and that these damages could be reduced up to 74% if appropriate measures are taken. A study on one of the sub-districts in Tianjin by Hu et al (2013) estimated damages at $ 5.3 billion. Our findings for Semarang and Demak show that damages can be reduced up to 66% when reducing land subsidence by 50%, which is similar to the range found in the study of Lixen. The most significant impact of subsidence by far is land loss, followed by increased costs for maintenance of roads and increased coastal flood risk.

These results indicate that damage from subsidence in Semarang and Demak is very significant, particularly in relation to land loss. Direct damage to buildings and infrastructure is significant as well for individual home owners and infrastructure owners. The extent of flood risk and land loss, and the long duration before measures could take effect (10 years), demonstrate a high urgency to act in the short term.

6.1.3 Recommendations

Preventing the damages of subsidence can be done in a myriad of ways. Conducting an economic cost assessment as done in this report, provides a basis for substantiating and comparing the economic rationale of interventions for example in a cost-benefit analysis. To support development and prioritization of adaptation and mitigation strategies for subsidence in Demak and Semarang, development of a full cost-benefit analysis is recommended. In such an analysis investment costs are compared against the broad spectrum of benefits of investment including avoided damages from subsidence. For example, the benefits of investing in water supply and sanitation do not only contribute to reducing subsidence but are also known to improve local economic and health conditions (Mock et al., 2017). A cost-benefit analysis should encompass the following elements. First, a more elaborate study including assessment of impact that could not be quantified in this study, such as fluvial and coastal flood risk and damage to other types of infrastructure. Second, cooperation and/ or interviews with local stakeholders such as infrastructure owners would be very valuable in gathering relevant data such as dose-effect relationships and cost estimates. Third, a CBA should include a more elaborate assessment of the effectiveness of suggested measures in reducing subsidence and/ or the damage resulting from subsidence. Fourth, a more elaborate scenario assessment under BAU (high versus low economic development, climate change) would be valuable.

We also recommend an exercise to attribute damage to specific stakeholder (groups), as this will be valuable in local dialogue on subsidence, measures and awareness raising.

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8 Annex

8.1 Additional hazard and exposure information

8.1.1 Land loss

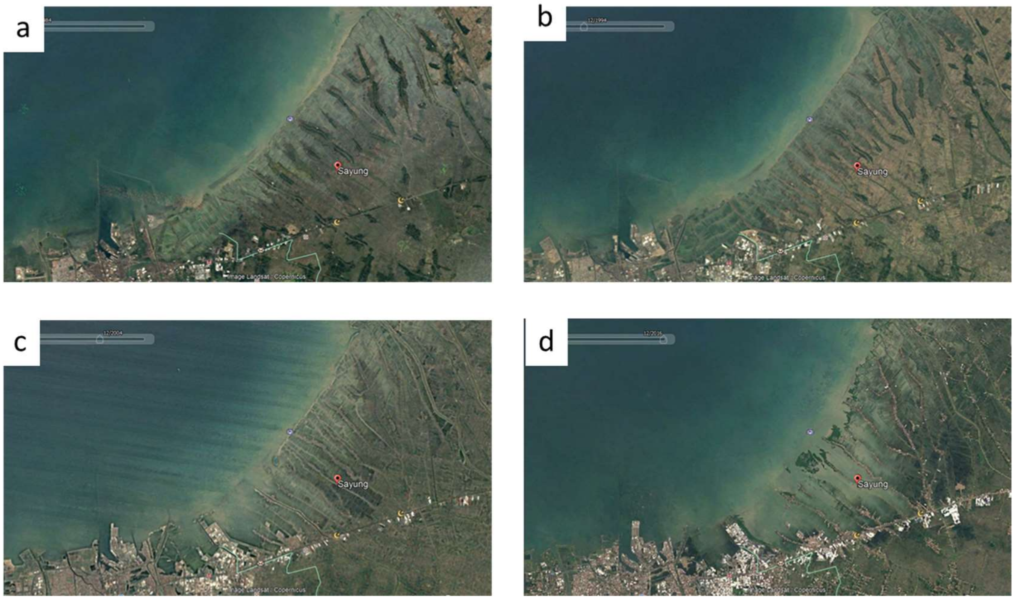


Figure 8.1 Loss of land between 1984-2020. The image was taken at year a) 1984, b)1994, c)2004, and d) 2016. Source: google maps

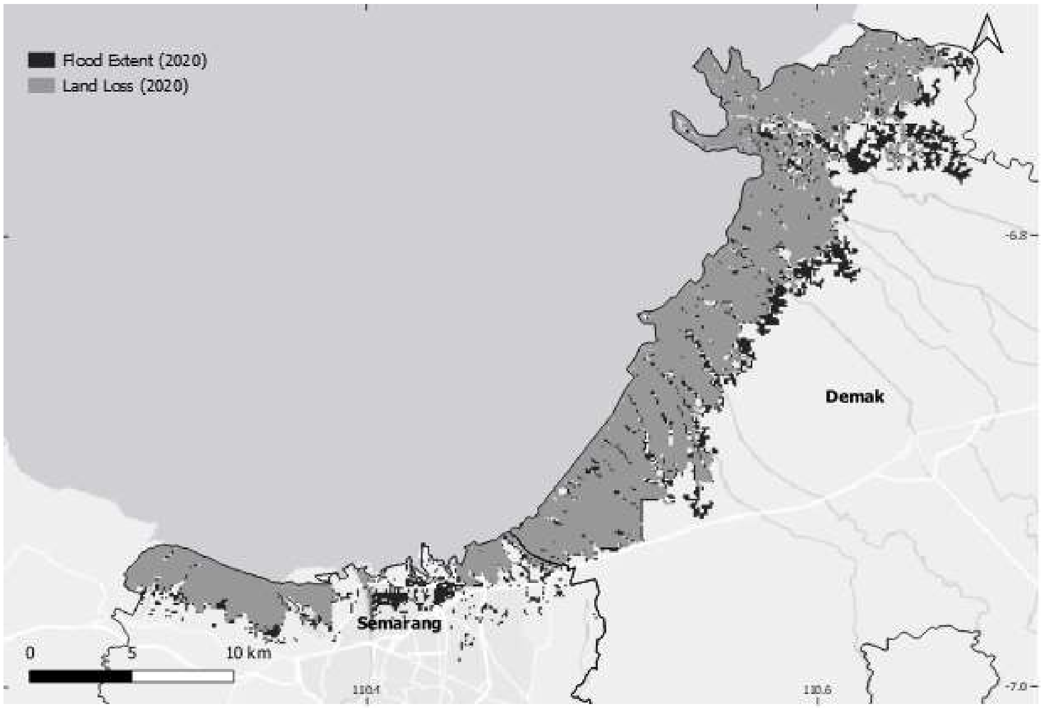


Figure 8.2: Land loss and inundated area in current condition

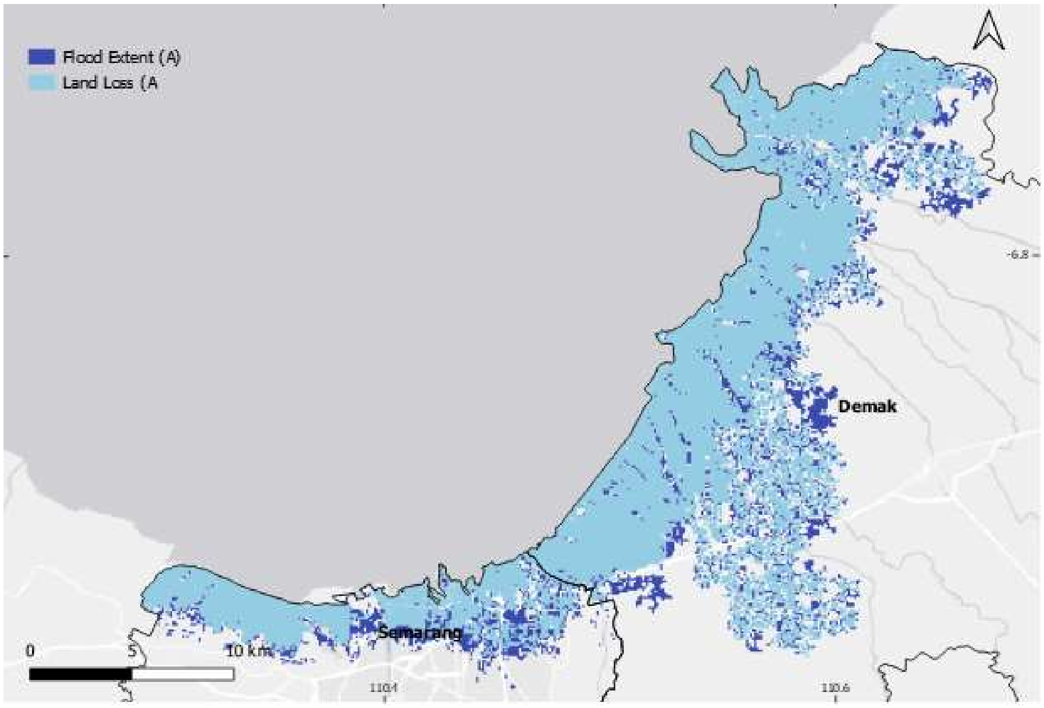
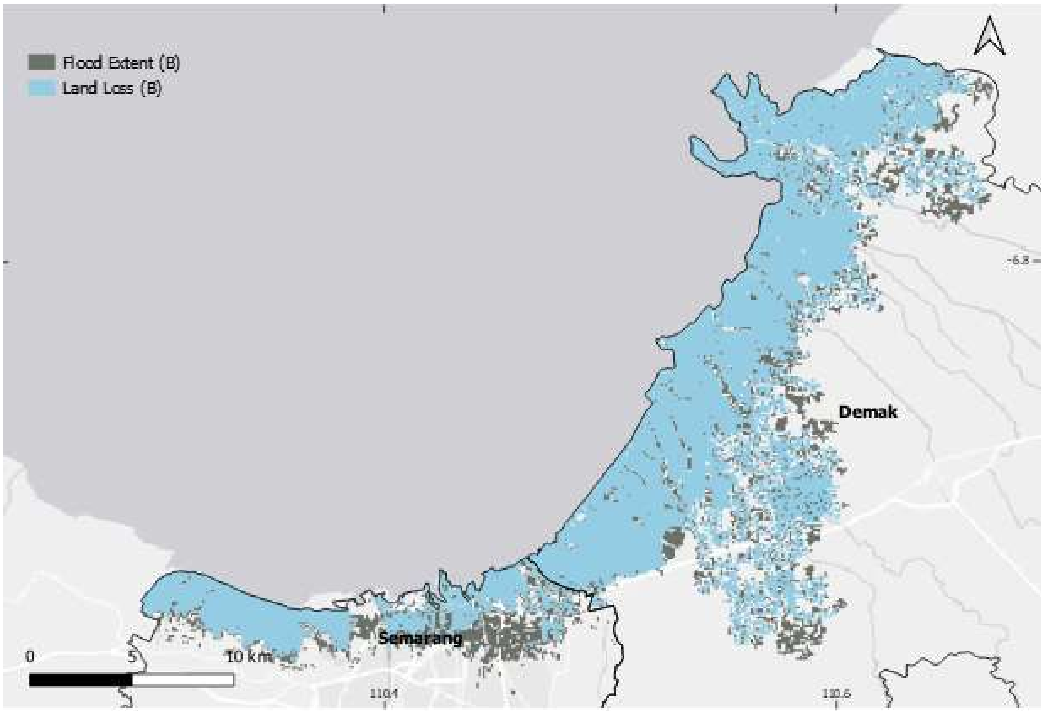


Figure 8.3: Land loss and inundated area in halved subsidence rate condition (scenario A)



8.4: Land loss and inundated area in quartered subsidence rate condition (scenario B)

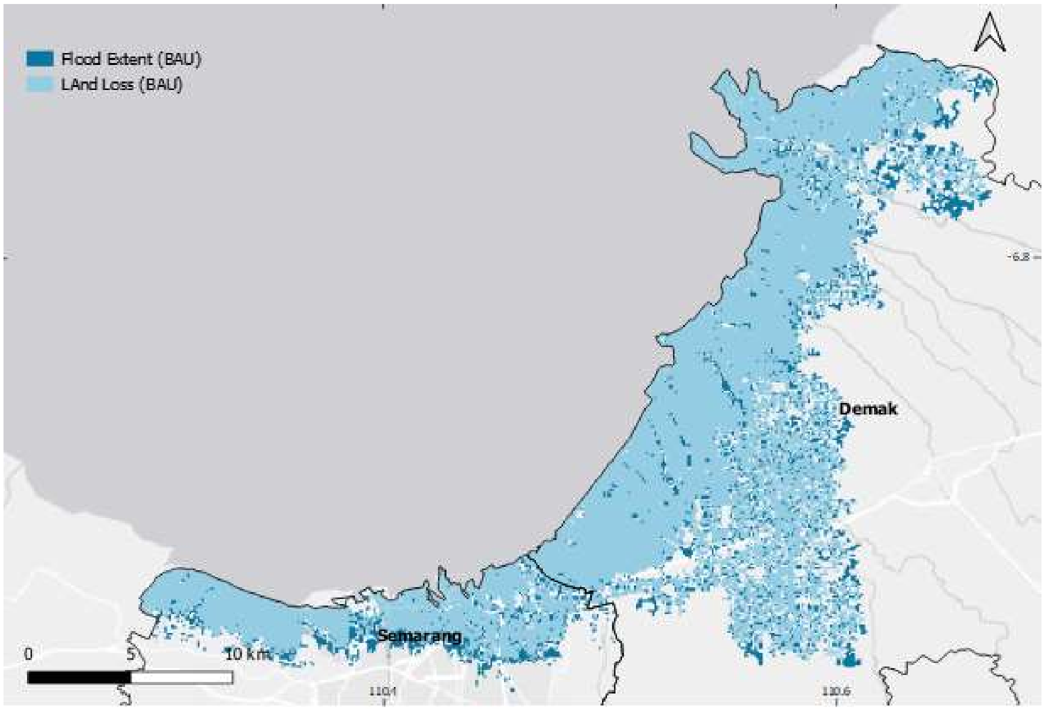


Figure 8.5: Land loss and inundated area in business as usual condition

Figure 8.6: Area close to Semarang airport that is permanently inundated, hence considered as land loss in this study.

Figure 8.7: Street view of the area in Figure 8.6 (Google Earth, 2020)

8.2 Subsidence impacts

Figure 8.8 Illustration of subsidence impacts in Semarang. From Abidin et al (2012).

8.9: Evidence of land loss (Hutton, 2020)

8.10: Evidence of elevated road in subsiding area (Hutton, 2020)

8.3 Economic valuation

In Table 8.1 the method to monetize the market subsidence effect in this study is presented.

Table 8.1: Economic costs of subsidence

	Market
Direct	• Loss in critical infrastructure like drinking water infrastructure, waste water treatment, surface water management/ drainage, railway, energy and telecommunication facilities, are difficult to be monetized as there is no available replacement cost or increase maintenance cost dataset of those type infrastructures. Therefore, in this study, we only qualitatively assess the potential damage attributed to these critical infrastructures by calculating the number of critical infrastructures impacted by subsidence without quantify the economic value of the exposed asset. • Loss in structures like buildings including houses, factories, public/private space, gardens, and parks are also difficult to be monetized as there is no comprehensive study on subsidence-damage relation on these kinds of structures. Therefore, in this study, we only qualitatively assess the potential damage attributed to these critical infrastructures by calculating the number (or length) of the structures impacted by subsidence without quantifying the economic value of the exposed asset. • Increased life cycle costs or reduced performance are calculated by calculating the increased maintenance cost and will be further explained in section 3.3
Indirect	• Business interruption can be monetized using production function approach (Kreibich & Bubeck, 2015). This can be done by estimating the lost value of the production due to the impact of subsidence, i.e. the decreased in productivity during the coastal flooding event related to subsidence. To do this analysis, the production lost must be specifically attributed to the increased risk of coastal flooding related to subsidence. As there is no available dataset of loss of productivity in Semarang and Demak area related to coastal flooding and subsidence, therefore, this approach is not conducted in this study. • Reduced attractiveness of business climate is also difficult to be monetized. This might be monetized by applying stated preference method with extensive questionnaire and interview. Due to the limitation of this study and the COVID-19 restriction, this approach is also not conducted in this study. • Changes in elevation and slope of streams, canals, drainage, and reduced drainage capacity causing fluvial flood damage can be monetized by calculating the increase in fluvial risk damage. However, this calculation involves the hydrodynamic model of fluvial flooding and is outside the scope of this study. • Aggravated coastal flood damage is calculated and further explained in section 3.4 • Increased salinization can further lower agricultural production. However, attribution of salinization to subsidence is not a straightforward approach as this approach requires groundwater and transport modeling and outside the scope of this study. • Loss of land near water bodies is calculated and further explained in section 3.5 • Loss of property value can be analyzed by applying the hedonic pricing method (Willemsen, Kok, & Kuik, 2020). However, this approach requires an extensive dataset on sales and characteristics of property and this dataset is currently not available. Therefore, this approach is also not included in this study.

Table 8.2 Assumptions for restoration costs subsidence damage, extrapolating restoration costs for the Netherlands based on (Costa et al., 2020) *to Indonesian price level in 2019 (based on https://data.oecd.org/price/price-level-indices.htm)* .

Damage level	Damage	Reparation works	*Average restoration costs per €/ m3 of building*	in € / M3 on price level Indonesia**	Average restoration costs per IDR/ building (100 M^3)
D0	No damage				
D1	Very small cracks in inner wall (up to 1 mm width)	Repainting indoors	*€3,25*	0,621	10376
D2	Cracks up to 5 mm width in inner and outer walls, slightly sticking doors and windows.	Repainting indoors, filling in cracks, equipment rental (e.g. scaffolding)	*€ 15*	2,868	47890
D3	Cracks with a width of 5-15 mm, sticking doors and windows, possible damage to utility infrastructure (sewage, drinking water)	Repainting indoors, filling in cracks, restoration plaster/ stucco , equipment rental (e.g. scaffolding)	*€ 53*	10,13	2E+05
D4	Cracks of 15-25 width, walls bulging or sagging: loss of carying capacity. Damage to pipes. Strongly sticking doors and windows.	Repainting indoors, filling in cracks, restoration plaster/ stucco , equipment rental (e.g. scaffolding), restoration of floors and window frames	*€ 184*	35,18	6E+05
D5	Cracks of over 25 mm width. Walls lose carying capacity; windows break; risk of instability/ collapse of building	Repainting indoors, filling in cracks, restoration plaster/ stucco , equipment rental (e.g. scaffolding), restoration of floors and window frames, restoration and/ or stabilization of foundation	*€ 670*	128,1	2E+06

8.4 Sensitivity analysis

8.4.1 Sensitivity to discount rate

Nominal values (no discount rate)

Component	Damage in Semarang (billion IDR, nominal value)			Damage in Demak (billion IDR, nominal value)		
	B	**A**	**BAU**	**B**	**A**	**BAU**
Land Loss	175618	33509	264905	74381	57351	117999
Coastal Flooding	-63	202	-316	129	302	107
Increase Road Maintenance	1984	2688		1239	1679	
Increase Arterial Road Maintenance	1118	1515		868	1176	
Damage to buildings	154	208		14	20	
Total						

8.4.2 Flood risk and land loss - sensitivity to DEM

A sensitivity analysis is also conducted by introducing the vertical uncertainty of one meter. One meter is selected to represent the DEMNAS vertical inaccuracy (Nurtyawan & Fiscarina, 2020). The difference between estimated land loss under current condition with three different DEM are shown in Figure 8.11. It shows that the estimated area loss is dependent on the DEM used. The results of estimated additional land loss using the DEMNAS and DEMNAS-1m are relatively comparable under BAU (Table 8.3). However, DEMNAS+1m input yields to significantly lower land loss addition under BAU. It infers that if the DEMNAS used for the calculation of the study underestimates the current elevation in the northern part of Semarang, the damage calculated might be overestimated.

Table 8.3: Addition of land loss under BAU in Semarang sensitivity analysis

Scenario	Addition of land loss (hectares) using DEMNAS + 1 meter	Addition of land loss (hectares) using DEMNAS	Addition of land loss (hectares) using DEMNAS – 1 meter
BAU	351	1738	2345

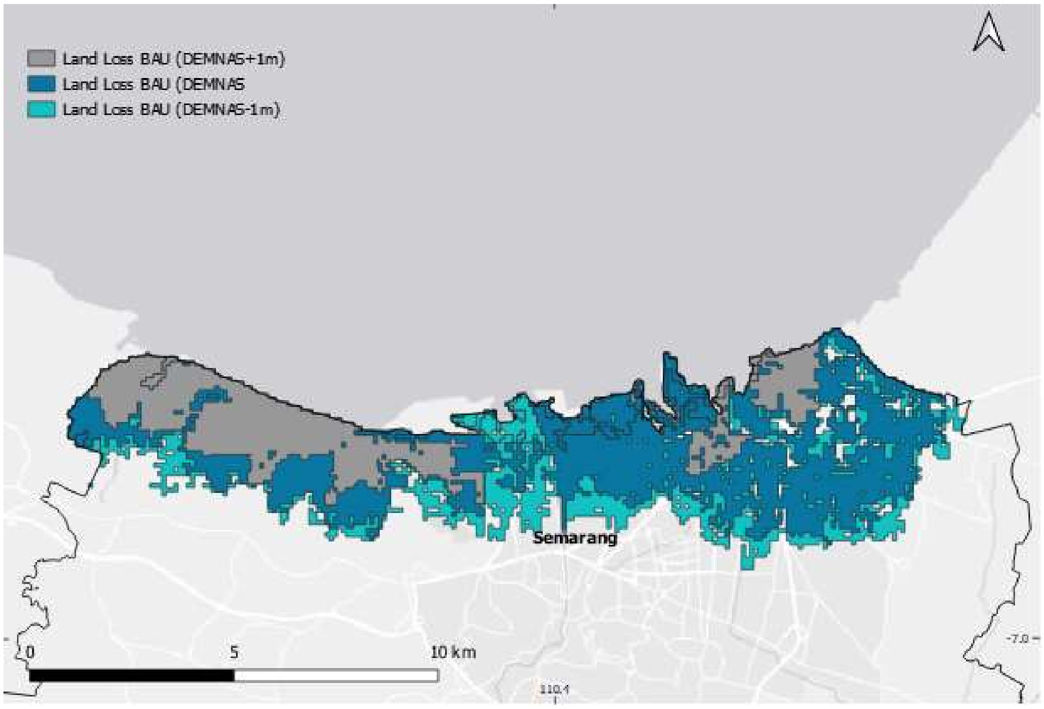


Figure 8.11: Sensitivity of land loss calculation to DEMNAS. Dark grey area indicates the estimated current land loss with the current DEMNAS+1m, the dark blue area indicates the estimated land loss with the current DEMNAS, and the turquoise area indicates the estimated land loss with the current DEMNAS+1m

To check the sufficiency of DEMNAS as the main input in the calculation of the land loss area, the current land loss is examined by visualizing the area below mean sea level under current condition. Figure 8.12 shows a good agreement between calculated area below mean sea level and area covered with water in Google Satellites image. The current inundated area is estimated by visual delineation of the area covered with water and connected to the sea in google satellites image. The result shows that the estimated current land loss with visual delineation is 2387 hectares, while the calculated current land loss with DEMNAS input is 2554. The calculated land loss differs with the calculated land loss in section 5.2.2 (Table 5.5) as in this section, the calculated land loss covers forest, river flood plain, and protected area that were not included in land loss damage estimation. The estimated land loss with DEMNAS shows the good agreement with the area that is currently already permanently inundated. Therefore, DEMNAS is considered sufficient in this preliminary economic damage valuation study.

Table 8.4: Comparison between current land loss with DEMNAS input and visual delineation using satellites image

Scenario	Current land loss (hectares) using DEMNAS	Current land loss (hectares) with visual delineation
2020	2554	2387

Figure 8.12: Calculated current area under mean sea level (land loss) in North Eastern Semarang and North Western Demak overlaid with google satellites image (Google Satellites, 2020)

8.5 Flood risk and land loss - impact of planned toll road

There is currently a plan to establish Semarang-Sayung sea wall that is also served as a toll road with length of 27 Km. The seawall is designed to prevent coastal erosion and damage from wave action and storm surges, such as flooding. This project has investment value of IDR 15 trillion (Ministry of Publuc Work, 2020) while the operational and maintenance costs reach 100 billion rupiah per year (Juyantono, Alvianto, Dipl, & Sentani, 2019). For the implementation plan in Semarang, the sea wall is planned as a protection from sea water, as well as a vehicle access road. In addition, this embankment will also directly function as a polder embankment for the East Semarang water system. This designed sea wall is already incorporated the subsidence effect; hence the sea water would not overtop the dike at least within 20 years period.

Figure 8.13 shows the planned sea wall, the estimated land loss, and inundated area under current condition. It shows that for Semarang area, inundated area behind the sea wall will still be connected to the sea, hence the sea wall will not reduce the impact of subsidence in Semarang. This also applies to scenario A, B, and BAU, where the projected inundated area in Semarang will still be connected to the sea.

Unlike in Semarang, this sea wall might reduce the land loss and inundated area in Sayung district, Demak, under scenario A, scenario B, and BAU scenario as this projected land loss and inundated area are not connected to the sea anymore with the establishment of the sea wall. Under BAU, this sea wall might protect 189 hectares of residential land, 110 hectares of industrial land, and 73 hectares of agriculture land from land loss. Under scenario A, this sea wall might protect 87 hectares of residential area and 53 hectares of industrial area from land loss. Under scenario B, the sea wall might protect 76 hectares of residential area and 53 hectares of industrial area from land loss.

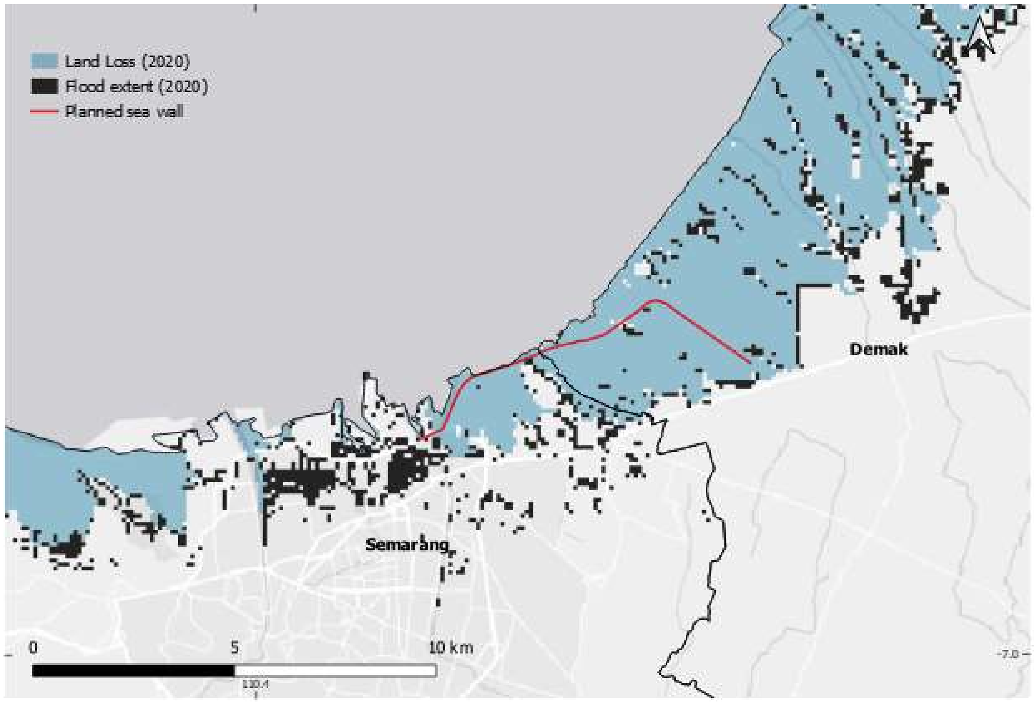


Figure 8.13: The estimated land loss and inundated area under current condition and the planned sea wall

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