Assessing the Mainstreaming of Land Subsidence Risk in Spatial and Development Planning: Evidence from Coastal Semarang, Indonesia

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Abstract

Spatial planning in coastal areas involves balancing economic development with the management of long-term environmental risks. Semarang City's coastal zone faces severe land subsidence, with rate reaching approximately 10–13 cm per year, exacerbating the impacts of sea-level rise and climate change. This study examines the extent to which land subsidence issue has been incorporated into spatial and development planning policies in Semarang City. Using a qualitative approach based on content analysis of spatial and development planning documents across multiple governance levels, the findings reveal that despite long-standing scientific evidence, land subsidence is not formally designated as a disaster-prone area within spatial planning documents. Effective spatial planning is expected to respond to the disaster risks through adaptive and mitigative policies and programs that reflect environmental carrying capacity and regional support capacity. However, the limited mainstreaming of land subsidence risk has resulted in spatial planning and development practices that insufficiently integrate these environmental considerations. The study highlights a critical gap between scientific knowledge and planning implementation and underscores the need for stronger institutional integration of land subsidence risk to support sustainable coastal urban development.

Keywords: *Coastal Area, Land Subsidence, Mainstreaming, Policy Evaluation, Spatial Planning.*

1. Introduction

The coastal area of Semarang City is currently facing a serious threat from land subsidence, a geophysical phenomenon characterized by the gradual or sudden sinking of the Earth's surface due to the movement of subsurface materials, driven by both natural processes and anthropogenic activities (Fulton, 2006; Solihuddin et al., 2021; Bonì et al., 2023; Perkins, 2021). One of the most significant anthropogenic contributors to this phenomenon is the excessive extraction of groundwater, which leads to the compaction and settling of clay layers within aquifers, thereby causing the ground surface to sink where groundwater is extracted (Belland et al., 2024; Setyawan et al., 2015; Perkins, 2021). The rate of land subsidence varies across different areas and is strongly influenced by geological conditions along Semarang's coastal zone (Marfai & King, 2007; Abidin et al., 2013; Saputra et al., 2017). Furthermore, the rapid industrial development in the northern coastal region of Semarang has increased the area's vulnerability to the impacts of land subsidence (Husnayaen et al., 2018; Hadi et al., 2020).

Climate change-induced sea level rise further exacerbates the region's vulnerability, compounding the impacts of land subsidence (Avornyo et al., 2024; Abidin et al., 2015; Saputra et al., 2017; Triana & Wahyudi, 2020).The resulting effects include tidal flooding (locally known as rob), seawater intrusion at depths of 0-6 meters to 6-15 meters (Supriyadi et al., 2013; Supriyadi et al., 2021), shoreline changes, and spatial planning challenges, all of which pose significant threats to the resilience of Semarang's coastal

zones (Husnayaen et al., 2018). The accelerating pace of urban development, economic activities, and population growth has made the threat of land subsidence increasingly alarming (Saputra et al., 2017), these conditions heighten the vulnerability and disaster risks faced by local communities, including increased intensity and spread of flood-affected areas, tidal inundation, coastal erosion, extreme weather events, and the loss of livelihoods (Wetlands International Indonesia, 2021; Abidin et al., 2015; Avornyo et al., 2024).

Numerous studies indicate that land subsidence in Semarang is not a recent phenomenon; rather, it has occurred over an extended period (Aditiya & Ito, 2023). Land subsidence represents a complex environmental issue that affects not only environmental quality but also the trajectory of urban development, economic growth, provision of essential public services, and the broader dynamics of future urban governance (Hamdani et al., 2021; Bagheri-Gavkosh et al., 2021; Hasibuan et al., 2023). In response, the central government has planned the construction of the Semarang-Demak Toll Road, integrated with a coastal sea wall designed to mitigate tidal flooding and land subsidence impacts in Semarang, as outlined in Presidential Regulation No. 109 of 2020 on the Third Amendment to Presidential Regulation No. 3 of 2016 concerning the Acceleration of National Strategic Projects (Ministry of Finance of Indonesia, 2024). A comprehensive planning approach to land subsidence disaster management is urgently needed to prevent greater future losses (Erkens & Stouthamer, 2020). Innovations in adaptation and mitigation strategies must involve multiple stakeholders to support the effective implementation of future response measures (Saputra et al., 2017). By evaluating the incorporation of land subsidence risk within spatial and development planning instruments, this study aims to identify existing gaps and policy consistencies, how far this land subsidence issue risk has been mainstreamed into spatial and development planning instrument. The results are intended to inform more effective planning interventions and support evidence-based decision-making for sustainable coastal urban development.

2. Methodology

This paper examines land subsidence governance in Semarang through a descriptive qualitative design, employing content analysis of planning documents. The study area encompasses the northern coastal zone of Semarang City, where land subsidence remains pronounced particularly along the eastern coastal corridor adjacent to Demak Regency. Data were derived primarily from an extensive document-based literature review, a well-established qualitative technique for generating empirical insights from written materials and strengthening analytical credibility (Bowen, 2009). In line with the holistic orientation of qualitative inquiry, the study draws on multiple sources to build a comprehensive understanding of the problem context and institutional responses (Nassaji, 2015). The analysis covered a wide range of spatial planning and development planning instruments across governance levels, including national-level policies and plans and local government (Semarang City) planning documents. The research proceeded in two stages. First, it synthesized scientific and policy literature to map the trajectory and spatial distribution of land subsidence in Semarang over time. Second, it systematically analyzed planning documents to assess the extent to which land subsidence risk has been mainstreamed, how the issue is framed, recognized, and translated into planning directions, programs, and implementation commitments within spatial and development planning products from the national to the municipal level.

3. Result and Discussion

3.1 Result

This section presents the results of the study, which are organized into two main components. First, it provides an overview of land subsidence occurring in the study area, including its spatial distribution and temporal characteristics as documented in the literature and policy sources. Second, it examines the extent to which land subsidence risk has been mainstreamed into spatial and development planning instruments across different levels of government.

3.1.1 Overview of Land Subsidence in Semarang City

Land subsidence in Semarang City has been recorded for at least the past few decades, with observations dating back to 1991. During this early period, the rate of subsidence was recorded at a minimum of 0.7 cm per year, which increased significantly by the end of the observation period in 1997, reaching up to 16.5 cm per year (Marfai & King, 2007). Various studies have been conducted using different approaches and methodologies to examine the spatial distribution and subsidence rates across Semarang's northern coastal area (see Table 1). Several observations indicate that the North Semarang and Genuk subdistricts are among the most severely affected, with annual subsidence rates exceeding 8 cm, and in some cases, reaching more than 1 meter per year at certain measurement stations.

Spatial data from the Semarang City Planning Agency reveal that land subsidence is concentrated in the northern coastal zone, which, according to the spatial planning framework, is designated as an industrial area. Land subsidence represents a complex environmental issue and is closely linked to the region's environmental carrying capacity (Hasibuan et al., 2023). Economic activity in North Semarang, primarily driven by the industrial sector, contributes significantly to groundwater extraction, thereby exacerbating the severity of land subsidence in the area (Hamdani, 2021;Marfai & King, 2007; Gaffara et al., 2017). Excessive groundwater consumption by industries in Semarang generally occurs at depths of 60–180 meters. This aggravates land subsidence, particularly since the affected areas lie within a zone of

recent sedimentation that is still undergoing natural compaction processes (Hadi et al., 2020; Lo et al., 2022; Belland et al., 2024). Temporal measurements of land subsidence rates are summarized in Table 1.

Table 1: Historical Land Subsidence Data in Semarang City Over the Past 30 Years

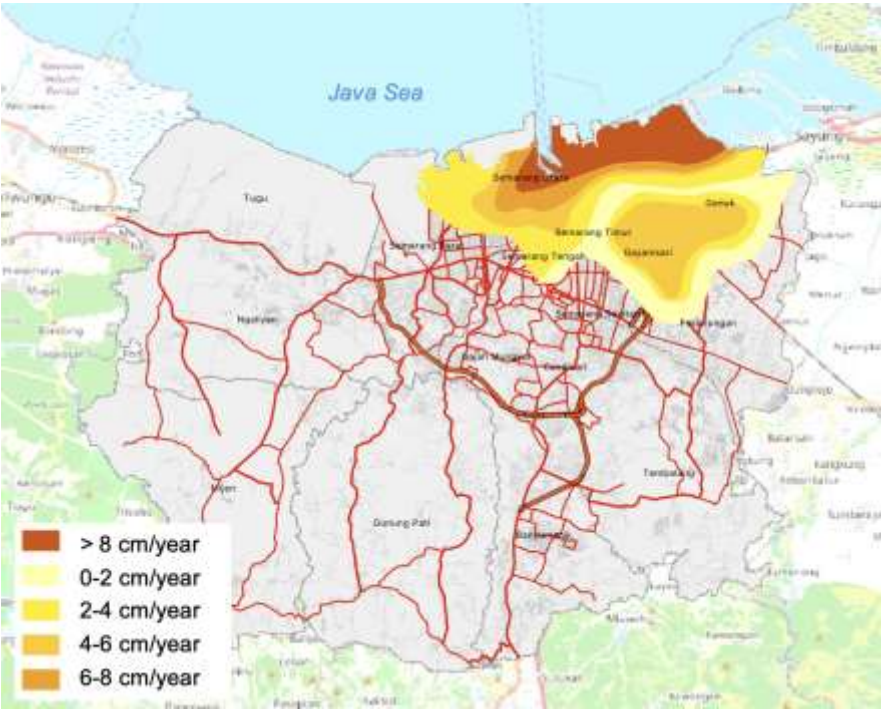| Observation Period		Result of Observation (cm/year)		Method Used	Reference
Start	End	Minimum	Maksimum		
1991	1997	0,7	16,5	GPS	(Marfai & King, 2007)
2002	2006	n/a	10	SAR interferometry (InSAR)	(Kuehn et al., 2010)
2003	2007	4	36	SBAS Envisat-ASAR dataset	(Yastika et al., 2019)
2007	2011	4	36	SBAS ALOS-PALSAR dataset	(Yastika et al., 2019)
2007	2008	n/a	15	InSAR	(Abidin et al., 2013)
2008	2009	0,8	13,5	GPS	(Abidin et al., 2010)
2008	2011	0,44	13,5	GPS	(Abidin et al., 2013)
2008	2011	0	19,7	GPS	(Gumilar et al., 2013)
2008	2016	8,6	150	GPS	(Andreas et al., 2019)
2009	2010	0	9,9	DInSAR	(Husnayaen et al., 2018)
2011	2018	n/a	13,95	GPS Geodetik	(Pramudyo et al., 2022)
2011	2018	n/a	62,1	Numerik Elemen Hingga	(Pramudyo et al., 2022)
2012	2012	0	140	Geospasial Analisis	(Yuwono et al., 2013)
2012	2012	n/a	140	Pengamatan Langsung	(Yuwono, 2013)
2013	2015	2,03	15,49	DInSAR	(Islam et al., 2017)
2015	2017	12	22	DInSAR	(Rimba & Yastika, 2020)
2015	2021	1,8	6	DInSAR	(Ardha et al., 2022)
2015	2017	4	36	Sentinel-1A dataset	(Yastika et al., 2019)
2016	2019	n/a	13	InSAR	(Tirta et al., 2023)
2017	2020	n/a	24	GMTSAR	(Sidiq et al., 2021)

Source: Analysis, 2026

Figure 1. Land Subsidence Elevation Map
(Semarang City Spatial Plan (RTRW) 2011–2031)

3.1.2 Identification of Land Subsidence Mainstreaming Efforts

Land subsidence in Semarang City has been documented since 1991 (Marfai & King, 2007) necessitating prompt government responses. However, a review of spatial and development planning documents reveals that efforts to reduce the associated risks remain minimal. In various spatial and development planning documents of Semarang City, the terminology used to refer to land subsidence varies, including terms such as *land subsidence*, *tanah ambles*, *amblesan tanah*, *amblesan*, *penurunan muka tanah*, and *penurunan tanah*. In the regional regulation of Semarang City, Number 5/2021 concerning the revision of the Spatial Plan (RTRW) 2011-2031, the term land subsidence appears only once in the main body of the text, specifically in Article 36, paragraph (2), item (b): "development in reclamation areas

must consider disaster mitigation and adaptation related to land subsidence." In comparison, the previous spatial plan (Regional Regulation No. 14/2011) did not include land subsidence as part of the designated disaster-prone areas. Despite the revision, the new RTRW still does not classify land subsidence areas as formal disaster-prone zones, although the appendix includes a map indicating elevation changes due to subsidence (see Figure 1). The omission of land subsidence from the disaster-prone zoning framework results in a lack of regulatory mechanisms to control spatial utilization in affected areas. Other relevant documents include the Regional Medium-Term Development Plan (RPJMD) as outlined in Regional Regulation No. 6/2021 and the Regional Long-Term Development Plan (RPJPD) under Regional Regulation No. 6/2010. In both, land subsidence-related terms appear only three times.

A stark contrast is observed in the Strategic Environmental Assessment (KLHS) for the revised RTRW of Semarang City, which contains 91 references to land subsidence. In the chapter on the Influence of Planning Policy Programs (KRP) on Environmental Conditions and the chapter on the Formulation of Alternative Improvements to KRP, many spatial structure and land-use pattern plans are located in areas that are highly vulnerable to land subsidence and pose significant risks to environmental sustainability. The findings of this KLHS should therefore serve as a key reference in the preparation of the revised RTRW, ensuring that urban development is aligned with and responsive to existing environmental conditions. From a regional perspective, neither the revised RTRW of Central Java Province nor the Central Java Provincial Coastal and Small Islands Zoning Plan (RZWP3K) for 2018–2038 contains any substantive discussion of land subsidence as a disaster, nor do they designate land subsidence–prone areas. References to this hazard are extremely limited and appear only once, in passing, within the Central Java Provincial Medium-Term Development Plan (RPJMD).

At the national scale, the central government appears to demonstrate greater awareness of land subsidence as a disaster affecting several Indonesian cities, including Semarang. References to land subsidence are found in the spatial planning document for the National Strategic Area Spatial Plan of the Kendal–Demak–Ungaran–Salatiga–Semarang–Purwodadi Urban Area (RTR KSN Kedungsepur) as well as in the National Medium-Term Development Plan (RPJMN) 2020–2024, with a total of 42 occurrences of the term related to land subsidence disasters. However, in the National Spatial Plan (RTRWN) stipulated under Government Regulation No. 17 of 2017, provisions addressing land subsidence disasters are not included in the main body of the document.

An examination of how spatial planning and development planning documents reflect the urgency of addressing land subsidence disasters indicates that this issue has received very limited attention from the government, particularly at the local government level, despite land subsidence falling within the authority and responsibility of local administrations. The inclusion of land subsidence issues in KLHS documents remains largely ineffective if the findings are not translated into spatial planning instruments—specifically within the indicative program matrices—and, more importantly, into development planning documents that are directly linked to budgeting and work plan systems of local government agencies. This situation aptly illustrates the characterization of land subsidence as a "sleeping hazard," whereby the disaster does not constitute a primary focus or priority in disaster management efforts (Marfai & King, 2007; Saputra et al., 2017; (Batubara et al., 2023).

Figure 2. Planned Alignment of the Sea Dike and Semarang-Demak Toll Road
(SIMPULKPBU, 2023)

Table 2: Review of Planning Documents Related to Land Subsidence

No	Document	In the article/ section	Words count	Terminology Used
		Local level		
1.	Semarang City Regional Regulation No. 5 of 2021 concerning the Amendment to Semarang City Regional Regulation No. 14 of 2011 on the Semarang City Spatial Plan (RTRW) for 2011–2031	Article 36 paragraph (2) point (b)	1	Land subsidence*
2.	Semarang City Regional Regulation No. 6 of 2021 concerning the Medium-Term Regional Development Plan (RPJMD) for 2021–2026	Subsection 2.1.3.1 Subsection 4.3.5 Table 4.6	3	- *Tanah ambles* - *Amblesan tanah* - *Amblesan*
3.	Semarang City Regional Regulation No. 8 of 2025 concerning the Medium-Term Regional Development Plan (RPJMD) for 2025–2029	Subsection 2.1.3.9 Subsection 2.3.2.6 Subsection 2.1.1.6 Subsection 2.1.1.7 Subsection 2.1.7	10	- *Penurunan muka tanah* - *Penurunan tanah* - Land subsidence*
4.	Semarang City Regional Regulation No. 6 of 2010 concerning the Long-Term Regional Development Plan (RPJPD) for 2005–2025	Subsection 2.1.9 Subsection 2.2.9	3	- Land subsidence* - *Penurunan muka tanah*
5.	Semarang City Regional Regulation No. 6 of 2010 concerning the Long-Term Regional Development Plan (RPJPD) for 2025–2045	Subsection 2.1.6 Subsection 3.1.12	25	- Land subsidence* - *Penurunan muka tanah* - *Penurunan tanah* - *amblesan*
6.	Strategic Environmental Assessment (SEA) of the Revised Semarang City Spatial Plan	Subsection 2.2.1 Subsection 2.2 Table 2.2 Subsection 5.1 Table 6.1 Table 6.5 Table 6.8 Table 6.9 Table 6.10 Table 6.11 Table 7.1 Indicative Program Table	91	- *Penurunan muka tanah* - *Penurunan tanah* - *Ambles*
Total			**108**	
		Province Level		
1.	Central Java Provincial Regulation (Peraturan Daerah) No. 16 of 2019 concerning the Amendment to Central Java Provincial Regulation No. 6 of 2010 on the Central Java Provincial Spatial Plan (RTRW) for 2009–2029	0	0	Land subsidence prone areas are not included in natural disaster–prone zones
2.	Strategic Environmental Assessment (SEA) of the Revised Central Java Provincial Spatial Plan	Table 28.	1	*Penurunan Tanah*
3.	Central Java Provincial Regulation (Peraturan Daerah) No. 5 of 2019 concerning the Central Java Provincial Medium-Term Development Plan (RPJMD) for 2018–2023	0	0	Land subsidence prone areas are not included in natural disaster–prone zones
4.	Central Java Provincial Regulation No. 12 of 2023 concerning the Central Java Provincial Development Plan (RPD) for 2024–2026	Subsection 4.1 Subsection 7.3.7	4	Land subsidence Penurunan muka tanah
5.	Central Java Provincial Regulation (Peraturan Daerah) No. 8 of 2025 concerning the Central Java Provincial Medium-Term Development Plan (RPJMD) for 2025–2029	Subsection 2.1.1.6 Subsection 2.1.3.9 Subsection 2.1.7 Subsection 2.3.2.6	8	Land subsidence Penurunan muka tanah, penurunan tanah

No	Document	In the article/ section	Words count	Terminology Used
6.	Central Java Provincial Regulation (Peraturan Daerah) No. 13 of 2018 concerning the Coastal and Small Islands Zoning Plan (RZWP3K) of Central Java Province for 2018–2038.	0	0	There is no discussion of disasters occurring in the coastal and small island areas of Central Java
Total			**13**	
		National Level		
1.	Government Regulation (Peraturan Pemerintah) No. 17 of 2017 concerning the Amendment to Government Regulation No. 26 of 2008 on the National Spatial Plan (RTRWN)	0	0	Land subsidence prone areas are not included in natural disaster–prone zones
2.	Presidential Regulation (Peraturan Presiden) No. 60 of 2022 concerning the National Strategic Area Spatial Plan for the Kendal–Demak–Ungaran–Salatiga–Semarang–Purwodadi Urban Area.	Article 105 Article 114 Article 117	13	- *Amblesan tanah* - Land subsidence - *Penurunan tanah*
3.	Presidential Regulation of the Republic of Indonesia No. 18 of 2020 concerning the National Medium-Term Development Plan (RPJMN) for 2020–2024	Chapter VI Table of Strategic Project Plans Table of the RPJMN 2020–2024 Development Matrix	29	- *Penurunan tanah* - *Land subsiden*
Total			**42**	

Source: Compilation of Semarang City Government Documents, 2026

One proposed governmental intervention is the construction of the Semarang-Demak toll road integrated with a giant coastal seawall. This infrastructure spans a planned alignment of 26.7 kilometers and is intended to address both tidal flooding and land subsidence affecting Semarang City and Demak Regency (Figure 2) (SIMPULKPBU, 2023; KPIP, 2023; Nuswantoro, 2023). The project requires land acquisition totaling 539.7 hectares (Nuswantoro, 2023). Based on information from The Ministry of Public Works and Housing, to mitigate land subsidence and its associated secondary disasters, the Kaligawe-Sayung section of the Semarang-Demak toll road will function as a polder system to hold back seawater. The integrated seawall and toll road will include retention ponds, pumps, sluice gates, and a regional drainage system under the management of the Pemali-Juana River Basin Authority.

3.1.3 Land Use Allocation Within Land Subsidence Prones Area

An overlay analysis between planned land-use allocation and land subsidence hazard zones reveals that a substantial proportion of designated urban functions in Semarang City are located within areas experiencing varying degrees of land subsidence. The analysis categorizes subsidence rates into five classes, ranging from 0–2 cm/year to greater than 8 cm/year, and quantifies the corresponding land-use allocations within each class. The results indicate that residential areas (*kawasan perumahan*) represent the largest share of planned land use located in subsidence-prone zones, with a total area of approximately 1,814 ha. These residential allocations are predominantly situated within zones experiencing moderate subsidence rates (2–6 cm/year), although portions are also located in areas with higher subsidence rates exceeding 6 cm/year.

Significant exposure is also observed in trade and urban service areas, accounting for approximately 1,363 ha, followed by industrial areas (*kawasan industri*) covering around 577 ha. These land-use categories are distributed across multiple subsidence classes, indicating that key economic and infrastructure functions are planned within zones subject to ongoing ground deformation. Overall, the findings demonstrate that planned land-use allocation in Semarang City is spatially intertwined with zones of land subsidence, encompassing residential, economic, infrastructural, and environmental functions. A detailed breakdown of built-up land-use categories and their corresponding exposure to land subsidence rates is presented in Figure 3.
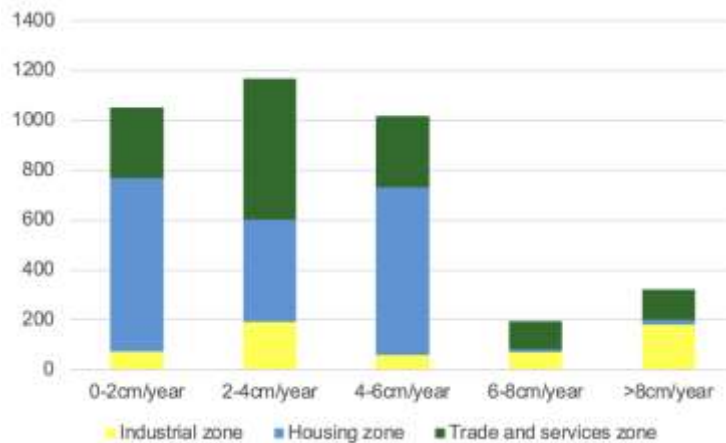
*Figure 3. Distribution of Built-up Areas Across Land Subsidence Rates in Semarang City
(Semarang City Spatial Plan (RTRW) 2011–2031)*

The review further shows that the main body of the RTRW of Semarang City does not contain specific provisions governing spatial utilization in areas vulnerable to land subsidence. In addition, an internal inconsistency is identified: while the regulation introduces restrictions on groundwater extraction (article number 34 paragraph (3) point a), the indicative program matrix simultaneously includes groundwater use as one of the city's clean water supply sources in all sub-regencies.

3.2 Discussion
3.2.1 Land Subsidence as a Marginalized Slow-Onset Disaster
The findings reveal a clear mismatch between the severity of land subsidence impacts in Semarang City and the degree to which this hazard is formally recognized within spatial and development planning instruments. Despite being empirically documented for more than three decades and reaching extreme rates in the northern coastal zone, land subsidence remains weakly institutionalized within statutory planning frameworks, both at the municipal and provincial levels. It is essential to consider who holds the authority over the issue. In Indonesia, According to Regulation of the Minister of Agrarian Affairs and Spatial Planning Number 11 of 2021, The provincial government holds authority over coastal areas, where the most significant land subsidence is occurring, particularly in the northern part of the city. However, the Semarang City Government is responsible for managing the inland areas that are directly affected by the consequences of subsidence, such as infrastructure damage and land instability. However, various planning documents in provincial level nor municipal level fail to indicate strong efforts or awareness regarding the regulation and control of land use and development in the northern coastal areas of Semarang, which are at risk of sinking every year. The absence of land subsidence from the disaster-prone zoning framework of the RTRW of Semarang City further illustrates this governance gap. Although elevation change maps are included in the plan's appendices, land subsidence is not formally designated as a disaster-prone area, thereby limiting the regulatory capacity of spatial planning instruments. Without explicit hazard classification, spatial plans lack a clear legal basis to restrict land use, regulate development intensity, or enforce preventive environmental safeguards in affected areas. This finding aligns with broader disaster risk governance literature, which highlights how slow-onset hazards tend to be marginalized within policy and planning frameworks that are designed primarily around event-based risks (Kelman, 2015). Unlike rapid-onset hazards such as floods or earthquakes, land subsidence does not immediately disrupt urban systems or generate sudden crisis events (Batubara et al., 2023). As a result, development activities; particularly industrial expansion and residential growth, continue in subsidence-prone areas, even as long-term risks intensify. This dynamic has been widely observed in subsiding coastal cities, where incremental ground deformation is normalized within everyday urban functioning until critical thresholds are exceeded (Boni et al., 2023; Erkens & Stouthamer, 2020).

In Semarang, this normalization is evident in the ongoing allocation of residential, industrial, and service land uses in zones that experience moderate to high rates of land subsidence, as demonstrated by the overlay analysis. Similarly, other regions such as Jakarta and Shanghai, which also face land subsidence, have been significantly impacted by the uncontrolled extraction of groundwater through well drilling. According to Batubara et al. (2023) and Yan et al. (2022), this uncontrolled groundwater extraction is believed to be one of the major contributors to the exacerbation of land subsidence. Batubara et al. (2023) specifically note that in Jakarta, the management of groundwater use and regulation remains inadequate. Residents do not report their well drilling activities, and the government has not conducted proper data collection on groundwater usage. As a result, the government cannot track how much water is extracted annually for domestic use, which further complicates the development of effective management strategies.

3.2.2 Connecting Scientific Knowledge and Planning Instruments

Various studies have been conducted on land subsidence; however, most of these studies, as summarized in Table 1, focus primarily on the historical occurrences of land subsidence or the rates of subsidence. This study attempts to bridge the gap between the findings of geographical and engineering researchers and the approach of sustainable and resilient urban development management. A key insight from this study is the persistent disconnect between the scientific knowledge on land subsidence and its integration into statutory planning and development instruments. Scientific studies in Semarang have consistently documented the spatial extent, causes, and rates of land subsidence, identifying groundwater over-extraction, geological conditions, and industrial activity as the primary contributing factors (Hadi et al., 2020; Marfai & King, 2007; Yuwono et al., 2013). Despite this comprehensive scientific understanding, the integration of this knowledge into formal urban planning processes remains limited, resulting in insufficient policy measures to address land subsidence effectively.

However, this robust evidence base is only weakly reflected in binding spatial regulations and development priorities (Batubara et al., 2023). A study by (Belland et al., 2024) further reveals that authorities have failed to translate the data generated by researchers into effective political and development policies. The contrast between the KLHS and RTRW of Semarang City is particularly striking. While the KLHS extensively acknowledges the risks of land subsidence and identifies spatial plans that are misaligned with the environmental carrying capacity, these findings are not effectively integrated into the core of the spatial planning documents, especially in zoning regulations and indicative program matrices. This gap between environmental assessments and statutory planning outcomes is not unique to Semarang; similar implementation gaps have been observed in other contexts, where sustainability instruments often function more as advisory documents than as enforceable decision-making tools (Noble, 2021; Therivel, 2010).

This disconnect undermines the role of spatial planning as a preventive and adaptive instrument for disaster risk reduction. According to mainstreaming frameworks, effective disaster risk integration requires that hazard knowledge be embedded not only in diagnostic documents but also in zoning provisions, development controls, program prioritization, and budgeting mechanisms (Birkmann et al., 2013; UNDRR, 2019). In Semarang, the limited incorporation of land subsidence into development planning documents such as the RPJMD further constrains the ability of local governments to allocate resources, design sectoral programs, and coordinate institutional responses to this long-term hazard. The persistent and continuous problem of land subsidence in Semarang City requires comprehensive planning. Data on subsidence trends should be utilized as a key input to support effective adaptation and mitigation strategies for this hazard (Andreas et al., 2018; Aditiya & Ito, 2023).

The continued exclusion of land subsidence from disaster-prone area classification has broader implications for coastal urban resilience in Semarang. Spatial planning decisions that permit intensive land use in subsiding areas increase exposure not only to land subsidence itself but also to compound hazards, including tidal flooding, sea-level rise, and infrastructure failure. Recent studies emphasize that the interaction between land subsidence and coastal flooding significantly amplifies disaster risk in deltaic and low-lying cities, particularly under climate change conditions (Abidin et al., 2015; Nicholls et al., 2021; Avornyo et al., 2024). From a governance perspective, reliance on large-scale structural interventions, such as the Semarang–Demak toll road and integrated sea wall, without parallel regulatory and planning reforms risks reinforcing a reactive and infrastructure-centric approach to disaster management. While such projects may reduce short-term exposure to tidal flooding, they do not address the underlying drivers of land subsidence, particularly unsustainable groundwater extraction and land-use pressures. Similar critiques have been raised in studies of coastal megacities, where engineering solutions are implemented in the absence of comprehensive land-use control and demand-side water management, ultimately limiting long-term effectiveness (Baldassarre et al., 2019; Herrera-garcía et al., 2021). Strengthening the integration of land subsidence risk into statutory spatial and development planning is therefore essential to support sustainable coastal urban development in Semarang. This includes formal recognition of land subsidence as a disaster risk, alignment between KLHS findings and zoning regulations, and the incorporation of subsidence mitigation measures into development programs and budgetary frameworks. Without such integration, planning instruments risk perpetuating spatial patterns that exacerbate environmental degradation and socio-economic vulnerability in the city's coastal areas.

It is important to note that this assessment represents an early-stage evaluation of land subsidence issues within the context of Semarang's urban and spatial planning. The focus was primarily on identifying the extent of recognition and integration of LS concerns into planning documents rather than offering a comprehensive evaluation of their full implementation. Future research is needed to explore in greater depth how these findings can inform effective governance frameworks and practical mitigation strategies.

4. Conclusion

This study highlights a critical gap in Semarang's urban planning regarding land subsidence, a phenomenon that continues to significantly affect the city's infrastructure and development. Despite extensive documentation of land subsidence over the past decades, particularly in the northern coastal areas, the issue remains weakly institutionalized in both municipal and provincial planning frameworks. The findings show that while land subsidence is recognized in certain planning documents, it is not sufficiently addressed through concrete policies or integrated into long-term development strategies. The disconnect between scientific knowledge and planning pr actives is evident, as planning documents fail to translate

detailed subsidence data into actionable, enforceable regulations. The absence of strong zoning regulations or land-use controls in areas heavily impacted by subsidence exacerbates the risks of infrastructure damage and land instability, particularly in rapidly developing coastal zones. To mitigate these risks, there is an urgent need for stronger integration of land subsidence considerations into both spatial and development planning. This includes clearer guidelines for land use in subsidence-prone areas, stronger enforcement mechanisms, and more coordinated efforts between provincial and municipal authorities. Without these changes, Semarang's vulnerability to subsidence will continue to increase, compromising the city's long-term sustainability and resilience. Future research could explore how other cities facing similar subsidence challenges have successfully integrated these issues into their planning processes, providing a model for improving governance and risk mitigation strategies in Semarang.

References

Abidin, H. Z., Asndreas, H., Gumilar, I., & Sidiq, T. P. (2010). Studying Land Subsidence in Semarang (Indonesia) Using Geodetic Methods. *FIG Congress 2010 Facing the Challenges – Building the Capacity*, 1–15. https://www.researchgate.net/publication/242692619

Abidin, H. Z., Andreas, H., Gumilar, I., Sidiq, T. P., & Fukuda, Y. (2013). Land subsidence in coastal city of Semarang (Indonesia): Characteristics, impacts and causes. *Geomatics, Natural Hazards and Risk*, *4*(3), 226–240. https://doi.org/10.1080/19475705.2012.692336

Abidin, H. Z., Andreas, H., Gumilar, I., & Wibowo, I. R. R. (2015). On correlation between urban development, land subsidence and flooding phenomena in Jakarta. *IAHS-AISH Proceedings and Reports*, *370*, 15–20. https://doi.org/10.5194/PIAHS-370-15-2015

Aditiya, A., & Ito, T. (2023). Present-day land subsidence over Semarang revealed by time series InSAR new small baseline subset technique. *International Journal of Applied Earth Observation and Geoinformation*, *125*, 103579. https://doi.org/10.1016/J.JAG.2023.103579

Andreas, H., Abidin, H. Z., Sarsito, D. A., & Pradipta, D. (2018). INSIGHT ANALYSIS ON DYKE PROTECTION AGAINST LAND SUBSIDENCE AND THE SEA LEVEL RISE AROUND NORTHERN COAST OF JAVA (PANTURA) INDONESIA. *Geoplanning: Journal of Geomatics and Planning*, *5*(1), 101. https://doi.org/10.14710/geoplanning.5.1.101-114

Andreas, H., Zainal Abidin, H., Gumilar, I., Purnama Sidiq, T., Anggreni Sarsito, D., & Pradipta, D. (2019). On the acceleration of land subsidence rate in Semarang City as detected from GPS surveys. *E3S Web of Conferences*, *94*. https://doi.org/10.1051/e3sconf/20199404002

Ardha, M., Khomarudin, M. R., Pranowo, W. S., Chulafak, G. A., Yudhatama, D., Mujio, & Pravitasari, S. (2022). Spatial information on the rate of subsidence in North Coastal Area of Java and the estimation of inundation in 2031. *IOP Conference Series: Earth and Environmental Science*, *1109*(1). https://doi.org/10.1088/1755-1315/1109/1/012022

Avornyo, S. Y., Minderhoud, P. S. J., Teatini, P., Seeger, K., Hauser, L. T., Woillez, M. N., Jayson-Quashigah, P. N., Mahu, E., Kwame-Biney, M., & Appeaning Addo, K. (2024). The contribution of coastal land subsidence to potential sea-level rise impact in data-sparse settings: The case of Ghana's Volta delta. *Quaternary Science Advances*, *14*, 100175. https://doi.org/10.1016/J.QSA.2024.100175

Bagheri-Gavkosh, M., Hosseini, S. M., Ataie-Ashtiani, B., Sohani, Y., Ebrahimian, H., Morovat, F., & Ashrafi, S. (2021). Land subsidence: A global challenge. *Science of The Total Environment*, *778*, 146193. https://doi.org/10.1016/J.SCITOTENV.2021.146193

Baldassarre, G. Di, Sivapalan, M., Rusca, M., Cudennec, C., Garcia, M., Kreibich, H., Konar, M., Mondino, E., Mård, J., Pande, S., & Sanderson, M. R. (2019). *Sociohydrology : Scienti fi c Challenges in Addressing the Sustainable Development Goals Water Resources Research*. 6327–6355. https://doi.org/10.1029/2018WR023901

Batubara, B., Kooy, M., & Zwarteveen, M. (2023). Politicising land subsidence in Jakarta: How land subsidence is the outcome of uneven sociospatial and socionatural processes of capitalist urbanization. *Geoforum*, *139*, 103689. https://doi.org/10.1016/J.GEOFORUM.2023.103689

Belland, M., Kooy, M., & Zwarteveen, M. (2024). Destabilizing the science of soils: Geoscientists as spokespersons for land subsidence in Semarang, Indonesia. *Environment and Planning E: Nature and Space*, *7*(2), 882–903. https://doi.org/10.1177/25148486231184064

Birkmann, J., Cardona, O. D., Carreno, M. L., Barbat, A. H., Pelling, M., Schneiderbauer, S., Kienberger, S., Keiler, M., Alexander, D., Zeil, P., & Welle, T. (2013). Framing vulnerability, risk and societal responses: the MOVE framework. *Nat Hazards*, *67*, 193–211. https://doi.org/10.1007/s11069-013-0558-5

Bonì, R. P., Teanti, P., Minderhoud, C., Zoccarato, L., Tosi, C., Guardiola-Albert, M., Béjar-Pizarro5, G., Bru, P., Ezquerro, G., & Herrera, R. (2023). Investigating land subsidence trend in the major coastal cities of Europe. *UNESCO Land Subsidence International Initiative, 10th Int. Symposium on Land Subsidence*, 43–48.

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, *9*(2), 27–40. https://doi.org/10.3316/QRJ0902027

Erkens, G., & Stouthamer, E. (2020). The 6M approach to land subsidence. *Proceedings of the International Association of Hydrological Sciences*, *382*, 733–740. https://doi.org/10.5194/piahs-382-733-2020

Fulton, A. (2006). *LAND SUBSIDENCE: WHAT IS IT AND WHY IS IT AN IMPORTANT ASPECT OF GROUNDWATER MANAGEMENT?*

Gaffara, G., Rahmawati Hisbaron, D., & Marfai, M. A. (2017). Land Use Changes Analysis For Land Subsidence In Coastal Areas (Case Study: North Semarang District). *Indonesian Journal of Geography*, *44*(1), 121–134. www.semarangsubsidence.net

Gumilar, I., Abidin, H. Z., Sidiq, T. P., Andreas, H., Maiyudi, R., Gamal, M., & Fukuda, Y. (2013). Mapping And Evaluating The Impact Of Land Subsidence In Semarang (Indonesia). In *Indonesian Journal of Geospatial* (Vol. 2, Number 2).

Hadi, Sudharto P, Anggoro, S., Purnaweni, H., Yuliastuti, N., Ekopriyono, A., Hamdani, R. S., & Hadi, S P. (2020). *Assessing the giant sea wall for sustainable coastal development: case study of Semarang City, Indonesia* (Vol. 13, Number 6). http://www.bioflux.com.ro/aacl

Hamdani, R. (2021). Monitoring and Addressing Land Subsidence Hazards in Semarang. *Encyclopedia.Pub*, 1–21. https://encyclopedia.pub/entry/18055

Hamdani, R. S., Hadi, S. P., & Rudiarto, I. (2021). Progress or regress? A systematic review on two decades of monitoring and addressing land subsidence hazards in Semarang city. In *Sustainability (Switzerland)* (Vol. 13, Number 24). MDPI. https://doi.org/10.3390/su132413755

Hasibuan, H. S., Tambunan, R. P., Rukmana, D., Permana, C. T., Elizandri, B. N., Putra, G. A. Y., Wahidah, A. N., & Ristya, Y. (2023). Policymaking and the spatial characteristics of land subsidence in North Jakarta. *City and Environment Interactions*, *18*, 100103. https://doi.org/10.1016/J.CACINT.2023.100103

Herrera-garcía, B. G., Ezquerro, P., Tomás, R., Béjar-pizarro, M., López-vinielles, J., Rossi, M., Mateos, R. M., Carreón-freyre, D., Lambert, J., Teatini, P., Cabral-cano, E., Erkens, G., Galloway, D., Hung, W., Sneed, M., Tosi, L., Wang, H., Ye, S., & Asia, E. (2021). Mapping the global threat of land subsidence. *Science*, *371*(6524), 34–26. https://doi.org/10.1126/science.abb8549

Husnayaen, Rimba, A. B., Osawa, T., Parwata, I. N. S., As-syakur, A. R., Kasim, F., & Astarini, I. A. (2018). Physical assessment of coastal vulnerability under enhanced land subsidence in Semarang, Indonesia, using multi-sensor satellite data. *Advances in Space Research*, *61*(8), 2159–2179. https://doi.org/10.1016/j.asr.2018.01.026

Islam, L. J. F., Prasetyo, Y., & Sudarsono, B. (2017). ANALISIS PENURUNAN MUKA TANAH (LAND SUBSIDENCE) KOTA SEMARANG MENGGUNAKAN CITRA SENTINEL-1 BERDASARKAN METODE DINSAR PADA PERANGKAT LUNAK SNAP. *Jurnal Geodesi Undip*, *6*(2).

Kelman, I. (2015). Climate Change and the Sendai Framework for Disaster Risk Reduction. *International Journal of Disaster Risk Science*, *6*(2), 117–127. https://doi.org/10.1007/s13753-015-0046-5

KPIP. (2023, December 28). *Percepatan Penyelesaian Proyek Strategis Nasional Jalan Tol Semarang-Demak untuk Meningkatkan Konektivitas dan Pengendalian Banjir Rob di Jawa Tengah Bagian Utara*. Https://Kppip.Go.Id/Berita/Percepatan-Penyelesaian-Proyek-Strategis-Nasional-Jalan-Tol-Semarang-Demak-Untuk-Meningkatkan-Konektivitas-Dan-Pengendalian-Banjir-Rob-Di-Jawa-Tengah-Bagian-Utara/Nggallery/Thumbnails.

Kuehn, F., Albiol, D., Cooksley, G., Duro, J., Granda, J., Haas, S., Hoffmann-Rothe, A., & Murdohardono, D. (2010). Detection of land subsidence in Semarang, Indonesia, using stable points network (SPN) technique. *Environmental Earth Sciences*, *60*(5), 909–921. https://doi.org/10.1007/s12665-009-0227-x

Lo, W., Purnomo, S. N., Dewanto, B. G., Sarah, D., & Sumiyanto. (2022). Integration of Numerical Models and InSAR Techniques to Assess Land Subsidence Due to Excessive Groundwater Abstraction in the Coastal and Lowland Regions of Semarang City. *Water (Switzerland)*, *14*(2). https://doi.org/10.3390/w14020201

Marfai, M. A., & King, L. (2007). Monitoring land subsidence in Semarang, Indonesia. *Environmental Geology*, *53*(3), 651–659. https://doi.org/10.1007/s00254-007-0680-3

Ministry of Finance of Indonesia. (2024, April 12). *Development of the Semarang–Demak Toll Road Project*. Https://Kpbu.Kemenkeu.Go.Id/Berita/Read/1427/Perkembangan-Proyek-Jalan-Tol-Semarang-Demak.

Nassaji, H. (2015). Qualitative and descriptive research: Data type versus data analysis. In *Language Teaching Research* (Vol. 19, Number 2, pp. 129–132). SAGE Publications Ltd. https://doi.org/10.1177/1362168815572747

Nicholls, R. J., Lincke, D., Hinkel, J., Brown, S., Vafeidis, A. T., Meyssignac, B., Hanson, S. E., Merkens, J., & Fang, J. (2021). *A global analysis of subsidence, relative sea-level change and coastal flood exposure*. *11*(April).

Noble, B. F. (2021). Strategic environmental assessment in Canada. In *Handbook on strategic environmental assessment constitute* (pp. 305–318).

Nuswantoro. (2023, December 15). *Menyoal Proyek Tol dan Tanggul Laut Semarang Demak*. Https://Www.Mongabay.Co.Id/2020/07/03/Menyoal-Proyek-Tol-Dan-Tanggul-Laut-Semarang-Demak/.

Perkins, S. (2021). Often driven by human activity, subsidence is a problem worldwide. *Proceedings of the National Academy of Sciences of the United States of America*, *118*(20). https://doi.org/10.1073/pnas.2107251118

Pramudyo, T., Muslim, D., & Nur, A. A. (2022). Characterization of Land subsidence Based on Analysis of Geotechnical Data and Groundwater Level of North Semarang Area, Central Java Province. *JURNAL LINGKUNGAN DAN BENCANA GEOLOGI*, *13*(3), 156–171. http://jlbg.geologi.esdm.go.id/index.php/jlbg

Rimba, A. B., & Yastika, P. E. (2020). Indonesia: Threats to physical urban water problems; Indonesia: Threats to physical urban water problems. *E3S Web of Conferences 148, 06001*, 1–6. https://doi.org/10.1051/e3sconf/20

Saputra, E., Hartmann, T., Zoomers, A., & Spit, T. (2017). Fighting the Ignorance: Public Authorities' and Land Users' Responses to Land Subsidence in Indonesia. *American Journal of Climate Change*, *06*(01), 1–21. https://doi.org/10.4236/ajcc.2017.61001

Setyawan, A., Fukuda, Y., Nishijima, J., & Kazama, T. (2015). Detecting Land Subsidence Using Gravity Method in Jakarta and Bandung Area, Indonesia. *Procedia Environmental Sciences*, *23*, 17–26. https://doi.org/10.1016/j.proenv.2015.01.004

Sidiq, T. P., Gumilar, I., Meilano, I., Abidin, H. Z., Andreas, H., & Permana, A. (2021). Land Subsidence of Java North Coast Observed by SAR Interferometry. *IOP Conference Series: Earth and Environmental Science*, *873*(1). https://doi.org/10.1088/1755-1315/873/1/012078

SIMPULKPBU. (2023, November 15). *Simpul KPBU, Jalan Tol Semarang-Demak yang Terintegrasi Tanggul Laut Kota Semarang*. Http://Simpulkpbu.Pu.Go.Id/Project/Read/121/Jalan-Tol-Semarang-Demak-Yang-Terintegrasi-Tanggul-Laut-Kota-Semarang.

Solihuddin, T., Husrin, S., Mustikasari, E., Heriati, A., Kepel, T. L., Salim, H. L., Risandi, J., & Dwiyanti, D. (2021). Coastal Inundation and Land Subsidence in North Coast of West Java: A New Hazard? *IOP Conference Series: Earth and Environmental Science*, *925*(1). https://doi.org/10.1088/1755-1315/925/1/012015

Supriyadi, Fitrianto, T. N., Khumaedi, & dan Sugiyanto. (2021). Identification of seawater intrusion in Kota Lama Semarang and surrounding based on geoelectrical resistivity survey. *Journal of Physics: Conference Series*, *2019*(1). https://doi.org/10.1088/1742-6596/2019/1/012087

Supriyadi, Khumaedi, & Yusuf, M. (2013). PENELITIAN INTRUSI AIR LAUT DI KAWASAN SEMARANG UTARA DENGAN METODE GAYA BERAT MIKRO ANTAR WAKTU. *Jurnal Fisika*, (1).

Therivel, R. (2010). *Strategic Environmental Assessment in Action* (Second Edi). Routledge.

Tirta, B., Waryono, D., Sawarendro, & Popang, M. (2023). PENURUNAN MUKA TANAH (LAND SUBSIDENCE) DAN DAMPAKNYA TERHADAP STRATEGI PENGELOLAAN AIR DI KOTA SEMARANG, PROVINSI JAWA TENGAH. *Pertemuan Ilmiah Tahunan Ke-40 HATHI*, 1–4. https://www.researchgate.net/publication/373487334

Triana, K., & Wahyudi, A. J. (2020). Sea level rise in Indonesia: The drivers and the combined impacts from land subsidence. *ASEAN Journal on Science and Technology for Development*, *37*(3), 115–121. https://doi.org/10.29037/AJSTD.627

UNDRR. (2019). *Global Assessment Report on Disaster Risk Reduction*.

Wetlands International Indonesia. (2021). *Assessment and Roadmap: Towards Adapting and Mitigating Land Subsidence in Central Java Province*.

Yan, X., Xu, Y., Yang, T., Tosi, L., Stouthamer, E., Minderhoud, P., Teatini, P., Kooi, H., Andreas, H., Pradipta, D., Donnici, S., & Bonì, R. (2022). Sustainable development of coastal cities through control of land subsidence: Activities of IGCP Project 663 in Jakarta. *Episodes*, *45*(1), 101–108. https://doi.org/10.18814/epiiugs/2021/021014

Yastika, P. E., Shimizu, N., & Abidin, H. Z. (2019). Monitoring of long-term land subsidence from 2003 to 2017 in coastal area of Semarang, Indonesia by SBAS DInSAR analyses using Envisat-ASAR, ALOS-PALSAR, and Sentinel-1A SAR data. *Advances in Space Research*, *63*(5), 1719–1736. https://doi.org/10.1016/j.asr.2018.11.008

Yuwono, B. D. (2013). KORELASI PENURUNAN MUKA TANAH DENGAN PENURUNAN MUKA AIR TANAH DI KOTA SEMARANG. *TEKNIK*, *34*, 188–195. https://doi.org/10.14710/teknik.v34i3.6725

Yuwono, B. D., Abidin, H., & Hilmi, M. (2013). Analisis geospasial penyebab penurunan muka tanah di kota Semarang. *Prosiding SNST Ke-4 Tahun 2013*. https://www.researchgate.net/publication/303138051