Adaptive Urban Design Principles for Land Subsidence and Sea Level Rise in Coastal Area of Tambak Lorok, Semarang

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Abstract. In recent years, the upward trend of sea level rise caused by climate change continues to increase. This condition threatens urbanization that occurs in urban areas, especially in coastal area. Coastal is a strategic location for various activities such as ports, recreation, fisheries and agriculture, but it is vulnerable to changes caused by community and natural activities. Semarang is one of the coastal city located in the north of Central Java. Dense and slum settlements are dominating the coastal area of Semarang, one of them is fisherman’s settlement in Tambak Lorok. This area has been undergoing land subsidence for a long time and is now threatened by sea level rise due to climate change. The purpose of this study is to formulate adaptive urban design principles on land subsidence and sea level rise in Tambak Lorok, Semarang. This study is carried out with qualitative method using the approach of research and development in building a formula that applies to the conditions formed by land subsidence and sea level rise. The design principles formulated from this study are general principles that serve as guidelines for designing coastal areas that adaptive to land subsidence and sea level rise. We believe, the adaptation of urban space can reduce the impact of the disaster and create a resilient coastal area to reduce the risk of natural-induced disasters.

1. Introduction

Sea level rise (SLR) poses a threat to people living in low elevation coastal zones (land up to 10 m height above mean sea level) [1], as well as community and natural systems that support this area. In the Fifth Assessment Report (AR5), the Intergovernmental Panel on Climate Change (IPCC) projected, the upper end of the range of possible global average SLR, to reach 98 cm by the end of this century in accordance with changes of MSL in 1986-2005 [2]. Extreme seawater conditions arise as a combination of average sea level, astronomical waves, storm surges (driven by tropical storms), and dynamic wave components (especially in open coastlines) that lead to run-ups on the coast and overtopping built and natural coastal defenses, such as embankments, sea walls, or sand dunes.

Coastal is a strategic area for various activities such as port, recreation, fisheries, agriculture, industry, settlements, and etc. Behind all the advantages, coastal area are vulnerable to changes caused by coastal activities. Residents living in coastal areas are also vulnerable because they rely on natural resources in coastal areas. Changes in sea level will adversely affect coastal communities by increasing the flood risk and/or coastal and cliff erosion, and that will also have ecological and...
economic impacts on valuable marine ecosystems (such as productive estuaries, coastal wetlands and coral reefs). One of the cities located in coastal area is Semarang. Semarang is the capital of Central Java which is located on the North coast of Java Island. The topography of Semarang consists of two plains, the lowlands and coastal areas in the North; and hilly areas in the South. The North, which consists of city center, port, airport and train station, is a relatively flat area. This section has a relatively higher population and more industrial and business areas compared to the South.

The main problems found in Semarang are land subsidence and tidal flooding. Tidal flooding is defined as a flood that hit areas with low elevations in coastal areas, including estuaries and deltas, which are inundated by brackish water or sea water. Inundation due to rob is one of the environmental problems faced by cities located in coastal areas such as Semarang. Tidal flood inundation is also influenced by various modifications of landforms by human activities. Modifications to the landforms of coastal plains such as reclamation greatly affect the possibility of coastal disasters. Tidal flooding inundation area in Semarang has the potential to expand with the phenomenon of land subsidence. Not to mention the threat SLR as one of the impacts of climate change. If these conditions continue without intervention or prevention, it can be ascertained that there will be a decline in environmental quality which directly reduces the quality of life of the coastal communities of Semarang. There needs to be an adaptation effort to reduce negative impact from the upcoming disaster. The purpose of this study is to formulate adaptive urban design principles on land subsidence and sea level rise in Tambak Lorok, Semarang. These adaptive principles can be considered by the government in redesigning Tambak Lorok area in accordance with its physical and socio-economic conditions while also anticipating the future disasters.

Adaptation to disasters and climate change is mentioned in the New Urban Agenda (NUA) article on disaster mitigation, which is to strengthen the city’s resilience to reduce the risks and impacts of disasters. Take actions to address climate change by reducing greenhouse gas emissions [3]. Not only in NUA article, on Sustainable Development Goals (SDGs) No. 13 is also mentioned about the urgency to take action to combat climate change and its impacts by regulating emissions and promoting the development of renewable energy. The Government has sought to integrate SDGs indicators into the RPJMN, as well as climate change. One of the general policy directions of the RPJMN 2015-2019 is about improving environmental quality, mitigating natural-induced disasters and handling climate change. Plans related to disaster adaptation and mitigation have been integrated in various cross-cutting programs with the aim of reducing GHG emissions by 26% and improving climate resilience in the regions [4].

2. Study Area

The study area is located in Tambak Lorok which located in Tanjung Mas Subdistrict, North Semarang and has long been known as a fisherman village. Semarang coastal cultivation is very productive because of abundant sea resources. This situation attracted fishermen from around Central Java to settle around Tanjung Mas. Since the 1980s, local community have turned open spaces in the form of fish pond and swamps into settlements. City stakeholders also built infrastructure such as transportation (ports, stations and airports), industrial, and commercial zones in coastal areas to support the growth of Semarang. The existence of fishing villages for decades shows culture and behavior that are familiar with sea phenomena such as high tide and coastal flooding. The existence of fishing settlements is also closely related to fishing locations, distribution and coastal areas, where these areas must be easily accessed by the public with a good transportation system and road network, enriched with various economic, social and cultural activities without having to damage environmental conditions.
3. Methodology

The methodology used in this paper is qualitative using triangulation method. Triangulation refers to the use of multiple method or data sources in qualitative research to develop a comprehensive understanding of phenomena [5]. Data sources used in this study are collected from literature studies, government policies through planning document and regulations, and existing conditions from the study area. Literature study focuses on the land subsidence, SLR, and adaptive measures in respond to disaster. Literature study is carried out by describing the cause and effects of land subsidence and SLR caused by climate change, both large scale and site specific. The resulting findings are then further elaborated into the criteria for designing adaptive urban areas by evaluating government policy and existing conditions.

4. Land Subsidence

Land subsidence is a gradual and/or sudden change in land shape to a lower level due to the movement of soil constituent material. Some causes of land subsidence include consolidation of soil layers, underground mining, groundwater extraction and building loads [6]. Land subsidence due to excessive use of ground water is also experienced by several major cities in Asia such as Tokyo, Osaka, Shanghai, Bangkok, and etc [7]. According to that paper, land subsidence occurred in Bangkok was due to excessive use of groundwater and the structure of Bangkok's soil layer which contains a thick layer of soft clay. The impact of this land subsidence includes increased risk of flooding, settlement problems on soil and building structures, coastline regression, and sea water intrusion into the aquifer layer. This problem is very important because the city is located in a low-lying topography. At present, some of the eastern region of the city has sunk more than 1.0 m below the mean sea level. During rainfall, water needs to be drained by pumping through drainage channels. Recent mitigation measures adopted include groundwater management systems, expansion of tap water supply, and strict groundwater law enforcement, which has resulted in a sharp decline in groundwater use. However, land subsidence will continue for a long time because the soil layer consolidation process still continues.

Land subsidence in North Semarang is believed to be caused by a combination of natural consolidation of young alluvium soil, extraction of groundwater and excessive building and structural loads [8]. In coastal areas, around Tanjung Mas Harbor, the coastline development is quite fast with a rate of around 4 to 16 m / year in the period 1695 to 1991. Since 1695 until now, the development of the coastline has reached around 2-3 km in certain locations [9]. According to Bemmelen [10], muddy sedimentation in the coastal areas of Semarang occurred at least 500 years ago. Therefore, it can be estimated that the consolidation of natural coastal young alluvium soils will have a significant contribution to the relatively large decline in the coastal areas of Semarang. In addition to the relatively young natural alluvium consolidation, the land subsidence in Semarang is also partly due to the extraction of excessive groundwater. Groundwater extraction in the city of Semarang has risen sharply since the early 1990s, especially around industrial estates. According to Marsudi [11], the number of wells registered in 1900 was 16, increasing to 600 wells in 1990 and 1050 wells in 2000.
Due to the excessive extraction of groundwater, the groundwater level in Semarang during the 1980s and 1996 periods experienced a significant up to 1.2 to 2.2 m/year. Suhelmi [12] concludes that land subsidence played an important role in increasing the inundated area in Semarang from initially 2,162 ha to 3,896 ha in just 10 years.

5. Sea Level Rise
Rising sea level is one of the consequences of climate change, both for the community, the built area, and the environment. Sea level also changes when there is a mass exchange between reservoir, ice or terrestrial and oceanic atmosphere. In the ice age, water is stored in the form of a large ice sheet in the highlands. Variations of the surface of the earth’s crust by water and ice change the shape of the earth as a result of the elastic response of the earth's lithosphere and mantle, thereby changing the level of soil and relative sea level. This change in mass distribution changes the gravitational field of the earth, thereby changing the surface of the sea. Relative sea level can also be affected by local tectonic activity and also by the release of soil when groundwater is extracted or sedimentation increases. Sea water density is strongly influenced by temperature. As a result, sea level will change if the ocean temperature changes (due to thermal expansion) without changes in mass.

Some of the initial impacts of SLR that can be identified are erosion, increased inundation due to coastal flooding and saltwater intrusion. Bird [13] illustrates that changes that occur on the coastline are not necessarily the result of rising sea levels. Erosion can only occur in stable water conditions due to soil structure that has not been consolidated and the deficit of shoreline-forming sediments. However, rising sea levels can accelerate and worsen erosion of the coast in areas that experience SLR. Nicholls [14] states that the direct effects of SLR are immersion and increased frequency of flooding in coastal areas, as well as saltwater intrusion. Long-term effects also occur because the coastline adjusts to new conditions, including increased erosion and saltwater intrusion into groundwater. Sea level rises relatively faster than the trend caused by climate change in regions that experience land subsidence. In many areas, human activity exacerbates land subsidence in vulnerable coastal areas, including most river deltas. Therefore, greater attention must also focus on non-climatic components of SLR, especially for beaches that are more vulnerable to land subsidence. The impact of human action tends to be greater where there is a high concentration of population and economic activity, and therefore, has higher potential impact.

Wdowinski [15] in his research on SLR in Miami Beach, Florida, expresses the same thing. The rate of floods increased dramatically due to SLR after 2006, where rain-induced flood increased by 33% and tidal-induced flood increased by 400%. The increase in flood due to SLR was affected by the gravity-dependent drainage system, until finally the Miami Government replaced the drainage system in 2014. The study also found the rate of SLR in Miami before 2006 was similar to the global rate of SLR, but the rate of SLR increased dramatically beyond the global rate after 2006. From various studies conducted in assessing the impact of SLR, all of them stated an increase in the intensity of floods, shoreline changes and sea water intrusion. Adaptive measures to reduce impacts of SLR should rely on local conditions, because not all locations experience the same rate of SLR and land subsidence.

6. Adaptive Measures
Adaptation and mitigation are two complementary strategies in responding to climate change and its impacts. Mitigation is the process of reducing emissions or limiting the release of greenhouse gases (GHG) into the atmosphere, so it can limit climate change in the future. Adaptation is the adjustment of the natural or community system to a changing or new environment. Adaptation to climate change refers to the adjustment of natural or human systems in response to climate stimuli, actual or expected stimuli, which are moderately harmful or exploit opportunities that might be beneficial (Figure 2). Various types of adaptation can be distinguished, including anticipatory and reactive adaptations, personal and community adaptation; and autonomous and planned adaptation [16]. Both adaptation and mitigation can reduce and manage the risk of climate change impacts on the built environment. However, behind all the benefits resulting from these two actions, adaptation and mitigation can also
pose risks. Strategic responses to climate change require consideration of climate-related risks related to the risks and benefits provided by adaptation and mitigation actions [17].

Figure 2. Adaptation and Mitigation Process (Adapted from Klein et al [18])

The basic principles of adaptation to the impact of land subsidence and SLR, such as permanent inundation, are adjustments to physical and non-physical aspects. Physical aspect focuses more on urban geometry, while non-physical focuses on activity, community awareness and education [19]. This study focuses on physical approaches on urban spaces and activities within them. The use of elevated buildings [20][21], green infrastructure - in the form of protection of natural elements, green roof, rain garden, naturalization of rivers, floodplains and blue infrastructure - in the form of rainwater harvesting and ponds retention are physical adaptation that can reduce the impact of flood and climate change disasters [19][21][23]. Some strategies that can be carried out in the land use are mixed land uses where the function of the building on the ground floor has a lower level of disaster vulnerability than the above. An example is putting residential above commercial functions such as shops, retail and café/restaurants. The ground floor can be used as a commercial area, but the function can change into boat storing when the sea level rises and there is a permanent inundation [22].

Planning for building mass and intensity in coastal areas has a different approach compared to other regions. The narrow shape of the parcel and perpendicular circulation path to the coastline can reduce the damage to the structure by giving way to incoming water. Building relocation located in the coastline, or commonly called coastal borders, is needed to preserve coastal ecosystem and provide a safe space from the threat of tidal waves which can also cause erosion. This coastal border can serve as a buffer area of the waves which can be reduced further with coastal vegetation, such as mangrove forests [23]. In the context of the Water Sensitive Urban Design (WSUD), open space in an adaptive area is designed to be able to accommodate multiple functions. One of the main functions that needs to be accommodated in the open space includes water catchment areas, evacuation area, and as a temporary water retention area [24]. Vegetation in the open spaces has a major role to increase the absorption capacity of the soil by using native plants, because native plants have higher compatibility with the local soil, and deep-rooted vegetations [23]. The main consideration in designing circulation and parking in flood-prone areas is safety and security. Several design principles of circulation and parking include parallel road orientation to the topographic form or water body, circulation to the evacuation point must be easily defined, the addition of alternative pathways at a certain height as an evacuation attempt, [21][23][25] and public parking areas are located in area that have a high level of flood vulnerability [25].
Table 1. Summary of the urban design principles taken from literature.

| Element                  | Principle                                                                 | Source                        |
|--------------------------|---------------------------------------------------------------------------|-------------------------------|
| Land Use                 | Mixed land use, with lower level function having low vulnerability to disaster | RIBA, 2009                   |
| Intensity and Building Mass | Narrow parcel and perpendicular to shoreline                             | Watson, 2011                  |
|                          | Use of elevated building mass                                             | Liao, 2016                    |
| Open Space               | Multi-function open space                                                 | Morgan, 2013                  |
|                          | Use of native vegetation                                                  | Watson, 2011                  |
|                          | Use of deep-rooted vegetation                                             |                               |
| Circulation and parking  | Parallel to topography and shoreline                                      | Mendez, 2014                  |
|                          | Provide clear and easily defined evacuation route on different heights    | Watson, 2011                  |
|                          | Communal parking space located in more vulnerable zone                    | Communities and Local Government, 2009 |

7. Design Criteria

Evaluation of the existing conditions using the principles formulated through literature review is done in order to formulate the design criteria for Tambak Lorok, Semarang. During the analysis of secondary data using aerial photograph, a change on the Eastern side of the study area, that was previously fishpond, was found. High tide and SLR caused fishpond to be inundated permanently (Figure 3). In Sayung Subdistrict located adjacent in the East of Semarang, Utami [26] also states that SLR caused changes to the coastline and increased permanent inundation in coastal areas.

![Figure 3. Coastal erosion on study area (Courtesy of Google Earth)](image)

Evaluation of the existing condition is carried out by observing the study area using urban design elements by Shirvani [27]. The elements used in this observation are elements related to the principles formulated in the previous chapter such as land use, building mass and intensity, open space, and circulation and parking. As one of many settlement that support economic activities in North Semarang Subdistrict (port and industrial area), land use in Tambak Lorok is dominated by residential. According to the projection of sea level rise carried out by DKP [28], some areas in the Tambak Lorok will experience permanent inundation in 2100. In areas that will experience permanent inundation, land use on the ground floor must be in accordance with the flood zone classification [22]. Residential
will be placed on the second floor, so this area will have mixed land use. Restrictions on land use are to ensure that activities in the flood prone zone are not disturbed by inundation due to SLR.

Tambak Lorok is a densely populated settlement with a total population of 8,319 people divided into 5 RWs. Form of settlements that exist in this area are mostly attached houses that stand 1-2 floors high. As an adaptation effort to land subsidence, the inhabitants always increase the height of their houses by 1-1.5 meters every 5-10 years. Green open space is nowhere to be found because of high Building Coverage Ratio (BCR). In addition to the high BCR, there are still many buildings located directly adjacent to the sea (Figure 4). The absence of buffer area causes residents who live in these houses to be displaced during high tide and sometimes it damages their houses. Buildings in the coastal area should be located behind the coastal border which is 100 meters from the highest tide [29]. The building mass in this area must also be oriented towards the shoreline with narrow shape, clear distance between the buildings to ensure optimal sunlight and air circulation, and act as a water passage during high tide; and have open spaces. To get optimum open space, BCR can be further reduced to minimum 80% by increasing the Floor Area Ratio (FAR). Residential buildings located on the ground floor must also be elevated according to the projected inundation and the rate of land subsidence.

Based on RTRW Kota Semarang 2011-2031, Tambak Lorok must have at least 20% of green open space. Tambak Lorok, which is part of North Semarang Subdistrict, is also included in the tidal flood and abrasion prone area [30]. The city development document suggests creating blue and green infrastructure in the form of retention ponds and mangrove forest. The provision of retention pond must be at a lower elevation than other regions to utilize the natural properties of water. While open space with evacuation function must be at a higher elevation and easily accessible, for example in the middle of the study area which stands 6 m above sea level. According to Martuti's research [31] on mangrove diversit, in Tugurejo Village, there are several mangrove varieties both planted by the community and those that grow naturally. The most common types of mangroves are *Rhizopora mucronata* and *Avicennia marina*, both types are believed to be suitable and can be planted in the study area which has the same soil structure as Tugurejo Village. On the circulation and parking element, most road network in the region are already perpendicular to the coastline. However, it still needs additional evacuation route that is accessible and safe from potential inundation.

**Table 2. Summary of the design criteria in Tambak Lorok, Semarang.**

| Element            | Principle                                      | Design Criteria                                      |
|--------------------|------------------------------------------------|------------------------------------------------------|
| Land Use           | Mixed land use, with lower level function having low vulnerability to disaster | - Land/building function according to the vulnerability zone classification  
                      |                                                 | - No residential function on the ground floor in high-vulnerable zone  
                      |                                                 | - No permanent structures on coastal border zone  
                      |                                                 | - Maximum BCR of 80%  |
| Intensity and Building Mass | Narrow parcel and perpendicular to shoreline | - Land/building function according to the vulnerability zone classification  
                      |                                                 | - No residential function on the ground floor in high-vulnerable zone  
                      |                                                 | - No permanent structures on coastal border zone  
                      |                                                 | - Maximum BCR of 80%  |
| Element                          | Principle                      | Design Criteria                                                                 |
|---------------------------------|-------------------------------|---------------------------------------------------------------------------------|
| Use of elevated building mass   |                               | Residential building located on high-vulnerable zone must be elevated according to the potential inundation height |
| Open Space                      | Multi-function open space     | - Provision of minimum 20% green open space                                    |
|                                 |                               | - Floodable open space on lower elevation                                       |
|                                 |                               | - Evacuation area located in higher elevation                                  |
| Use of native vegetation        |                               | Provision of green belt in the form of mangrove forest consists of *rhizophora mucronata* and *avicennia marina* |
| Use of deep-rooted vegetation   |                               |                                                                                  |
| Circulation and parking         | Parallel to topography and shoreline | Road and streets are mostly perpendicular to the shoreline                     |
|                                 | Provide clear and easily defined evacuation route on different heights | Provision of evacuation route to the higher grounds                             |
|                                 | Communal parking space located in more vulnerable zone                    |                                                                                  |

8. Conclusion

Land subsidence and SLR are global phenomena that happen due to both natural and human activities. These phenomena will continue to pose challenges in many different coastal environments, one of them is in Semarang. Semarang has long been experiencing land subsidence, especially in North Semarang District, and is now threatened by upcoming SLR. In responding to these conditions, several design criteria formulated in the previous chapter can improve the adaptability of Tambak Lorok settlement. Some design criteria that can be carried out are land use in accordance with the flood zone, moving dwellings to the upper floors, building narrow building plots, to multifunctional open spaces.

Without intervention on the urban scale, Semarang is likely to experience economic losses and decrease in environmental and social qualities. Adaptation in urban planning/design can reduce risks and create resilient coastal area while on the same time making mitigation efforts to reduce the occurrence of disasters. This action is also in accordance with SDGs number 13, namely take action to combat climate change and its impacts, which also has been integrated into RPJMN 2015-2019.

Suggestion for further research on adaptive area in coastal area of Tambok Lorok, Semarang, is a research using non-physical adaptation approaches on the local community. Community participation aspects, that consist of public awareness of disaster and climate change, willingness and ability to adapt, can be explored.

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