https://jurnal.unimed.ac.id/2012/index.php/tgeo/article/view/65577
https://doi.org/10.24114/tgeo.v14i1.65577 (Vol. 14 No. 1 – 2025)
e-ISSN: 2622-9528 p-ISSN: 2301-606X

Spatial Study of Land Cover Change and Degradation of Environmental Carrying Capacity of Settlements in the Coastal Area of Belawan Bahagia 2004-2025

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Received:
May 07, 2025

Revision:
May 21, 2025

Accepted:
August 08, 2025

Abstract
Spatial thinking skills are essential in everyday life. These skills can be improved through geography learning. Various studies on efforts to improve spatial thinking skills through geography education have been conducted in Indonesia; however, none have specifically examined the various models, teaching materials, and learning outcomes. Through a comprehensive review of previous findings, this study was conducted to fill this gap. The results of this study can be helpful for teachers and researchers in further developing geography education. This study employs a qualitative research design, specifically a document study or literature review. Publish or Perish software is used in the process of exploring or conducting literature searches. Through the initial search process, a total of 61 documents were obtained. These documents were then reviewed individually, resulting in a total of 16 documents that met the inclusion criteria. The results of the study showed that the most widely applied geography learning model was Project-Based Learning, followed by Discovery Learning and EarthComm. The teaching materials used are Disaster and Disaster Management, Basics of Mapping, Remote Sensing, and Geographic Information Systems (GIS), Atmosphere, Hydrosphere, Lithosphere Dynamics and Its Impact on Life, and Potential of Indonesian Marine Waters. Through the application of the learning model, various improvements were obtained in several indicators of spatial skills. The Project-Based Learning model is the most successful approach in improving various indicators of spatial thinking skills, including Analogy, Aura, Pattern, Association, Form, and Analysis.

Keywords: Learning Model, Geography, Spatial Thinking Skills

INTRODUCTION

Coastal areas have a strategic role in national development because they integrate ecological, social, and economic aspects. According to Dahuri et al. (2001), coastal areas are transitional areas between land and marine ecosystems that are dynamic and vulnerable to change caused by natural factors and human activities. One of the main issues that often arises in coastal areas is land cover change, which directly impacts the environment's carrying capacity and the surrounding communities' quality of life.

Coastal areas have significant environmental challenges, including the impacts of land cover change and climate change (Turner et al., 2017). One of the main problems coastal areas face is land conversion, especially green open space (RTH), which is turning into residential land. If not properly regulated, this conversion process can reduce the environment's carrying capacity and increase its vulnerability to natural disasters, such as tidal flooding, which is increasing due to climate change and urbanisation (Sitorus, 2020).

Urban coastal settlements can be defined as part of the earth's settlements that are within the urban scope and inhabited by humans as a container with all the facilities and infrastructure to support the lives of residents, which become a unit and are located on land areas, including waterlogged and non-waterlogged areas that are still influenced by marine processes. The Coastal Zone is a crossing point between land, placing the coastal zone under pressure from various land- and sea-based activities and events. Abrasion, inundation, and flooding are phenomena that occur on land. Settlement development is one of the community's activities, including rice fields, pond development, and an influence on coastal ecosystems. The boundaries of land areas and water areas where earth activities or activities and land use still affect marine processes and functions (Damisi et al., 2014). Coastal areas are the meeting area between land and sea. Towards the land, coastal areas include parts of the land, both dry and submerged in water, which are still influenced by sea properties such as tides, sea breezes, and saltwater seepage. Coastal settlement is a residential environment located between land and sea, where there are livelihood activities by the group of settlers who dominantly utilise the potential in the coastal area in fulfilling their needs.

The criteria for environmentally sound settlements (SEBERLING) according to (Rachmat Mulyana, 2013) consist of: 1) Settlement patterns in each settlement land suitability class; and 2) Specifications of healthy house building technically, ecologically and economically in each settlement land suitability class which includes the type of house construction, waste management, liquid and solid waste, and yard utilisation. The relationship matrix between settlement land suitability class and settlement pattern, and house building specifications further became the SEBERLING settlement criteria for the downstream watershed zone.

Land cover change, especially land conversion from green open space to settlements, industry, and other infrastructure, has become a common trend in various coastal areas of Indonesia. This is in line with the opinion of (Turner et al., 1995), which states that land use change is one of the primary forms of pressure on environmental sustainability because it can disrupt the ecological function of the region.

Neighbourhood 19 of Belawan Bahagia Urban Village, located in the coastal area of Medan City, North Sumatra, is one of the areas that has experienced significant changes in its land structure and function in the last decade. Based on satellite image interpretation and spatial data processing results, this neighborhood's area increased from 4.9 hectares in 2014 to 5.03 hectares in 2025. This increase in area is primarily related to the expansion of residential land and the reduction of green open space (RTH). Based on research conducted by Putri (2023), Sea level rise has increased the frequency of tidal flooding in Medan Belawan Sub-district, including Belawan Bahagia Village. Studies show that several areas in coastal Sumatra, including Medan Belawan, are experiencing land subsidence due to overexploitation of groundwater and development activities (Pratomo et al., 2021).

During the 2014-2025 period, there was an increase in building area of 0.13 hectares, while green open space experienced a reduction of 0.37 hectares. This land conversion mainly occurred due to the increasing need for residential land in line with population growth. Data shows that the population in Belawan Bahagia Village increased from 1,142 people with 210 housing units in 2014 to 1,691 people and 354 housing units in 2025. This significant increase in population not only increases pressure on land but also has an impact on reducing the environmental carrying capacity of the area. This increase indicates pressure on the environment's carrying capacity, potentially worsening ecological conditions and increasing the risk of tidal flooding (Hutapea, 2021).

The apparent impact of this land cover change and population growth is the increasing incidence of tidal flooding. Based on data from the Regional Disaster Management Agency (BPBD) of Medan City, in 2014, the tidal inundation height in this area reached ±5-10 cm. However, by 2025, the height increased to ±20-30 cm. This phenomenon shows that the capacity and absorption capacity of the environment is significantly decreasing, along with the increase of settlement area and the reduction of water catchment area, therefore the increase is due to the high rate of land conversion that reduces water catchment capacity and increases surface flow, which exacerbates the potential for tidal flooding (Nasution, 2022). This phenomenon underscores the importance of spatial analysis to understand how land cover change affects the carrying capacity of the environment and its vulnerability to disasters.

According to environmental carrying capacity theory, an area cannot support human activities without experiencing ecological degradation (Odum, 2005). When human activities exceed this capacity, the environment deteriorates and becomes more vulnerable to natural disasters. Therefore, it is important to analyse land cover change, environmental carrying capacity, and its impact on disaster risks such as tidal flooding to design sustainable mitigation policies (Ginting, 2021).

Research by Harahap (2023) also emphasises the importance of green open spaces in reducing the impact of natural disasters, including tidal floods. It states that converting green open spaces into settlements can reduce the soil's ability to retain and absorb water, potentially worsening its vulnerability to tidal floods. Uncontrolled land conversion will reduce water absorption, thus increasing the frequency and intensity of flooding.

In the sustainable development framework, it is important to analyse land cover change and evaluate the environment's carrying capacity. Spatial analysis using Geographic Information Systems (GIS) is a practical approach to mapping and analysing land use dynamics and their implications for environmental conditions. According to Burrough and McDonnell (1998), GIS allows the integration of various spatial and thematic data to produce information that supports appropriate decision-making in regional planning.

This research aims to analyse land cover changes in the coastal area of Belawan Bahagia Urban Village between 2014 and 2025 and evaluate their impact on the settlement environment's carrying capacity. Through a spatial approach, this research is expected to provide a comprehensive picture of the area's existing conditions and the projected environmental impacts caused by land use change.

The results of this research are expected to be the basis for preparing spatial planning policies for more environmentally sound coastal areas. The information generated is also expected to increase various parties' awareness of the importance of coastal area management in an integrated, sustainable, and adaptive manner to climate change and development pressures.

RESEARCH METHODS

This research uses a quantitative descriptive approach with a Geographic Information System (GIS)- based spatial analysis method. The research site is located in Belawan Bahagia Urban Village, Medan Belawan Sub-district, Medan City, a coastal area with significant land cover change dynamics between 2014 and 2025.

The data used consisted of primary and secondary data. Primary data were obtained through field observations, visual documentation, and informal interviews with the community and village officials on environmental conditions and tidal flooding events. Secondary data included 2014 and 2025 satellite images (Landsat or Sentinel), land cover data from image interpretation, population data, number of houses from BPS Medan City, tidal water level data from BPBD Medan City, and administrative maps of the study area.

Data processing was conducted through visual interpretation of satellite images with manual digitisation to classify land cover types such as settlements, green open spaces, water bodies, and vacant land. Furthermore, an overlay analysis was

conducted between two periods to determine the extent and pattern of land cover change. These changes were then spatially analysed using QGIS/ArcGIS software to determine their relationship with environmental vulnerability, particularly tidal flooding.
In the natural aspect, this is aligned with the settlement land's carrying capacity and the settlement environment's capacity. To determine the carrying capacity of land with an approach for settlements or buildings, based on (Permen LH No. 17 of 2009 concerning Guidelines for Determining Environmental Support Capacity in Regional Spatial Planning) can use the following formula:

$$LTb = LB + LTp$$

Description:
LTb = Built-up land area (ha)
LB = Building land area (ha)
LTp = Land for infrastructure such as roads, rivers, drainage, and others (ha) can be assumed to be 10% of the building area.
Next,

$$DDLB = (\alpha \, Lw) / LTb$$

Description:
DDLB = Land carrying capacity for building
LW = Area (ha)
LTb = Built-up area (ha)
α = Maximum built-up area coefficient (By the Spatial Planning Law No. 26 on the Environment that 70% for urban land and 30% for green spaces.

Meanwhile, for rural areas, the assumption is that the remaining 50% is for the benefit of agricultural land and protected functions. Then, based on the results of calculating the carrying capacity of settlements with the building approach. The results of these calculations will be classified into three classes, which are detailed as follows.

DDLB <1 : Poor
DDLB 1-3 : Conditional/Medium
DDLB > 3 : Good

Another formula that can be used to calculate the carrying capacity of settlements is as follows:

$$DDPm = (LPm/JP) / \alpha$$

Description:
DDPm = Settlement carrying capacity
LPM = Settlement land area (ha)
JP = Total population
α = Coefficient of space requirement/capita (m2/capita) Status of settlement land carrying capacity. The standard area of space requirement/capita (m2 /capita) is 26 m2 or 0.0026 ha.

After obtaining the value of the carrying capacity of settlement land, the optimal number of residents can be calculated, namely:

$$Jpo = DDPm. JP$$

Description:
Jpo = Optimal population
DDPm = Settlement carrying capacity
JP = Total population

Data analysis was conducted quantitatively to describe the area's spatial changes and physical conditions, and qualitatively to interpret the environmental and social impacts of land conversion. This research is limited to the administrative area of Neighbourhood 19 of Belawan Bahagia Urban Village and the period 2014-2025, with the accuracy of image interpretation limited to medium resolution.

RESULTS AND DISCUSSION

Belawan Bahagia Urban Village is located in the coastal area of Medan City, North Sumatra, and is one of the areas that has geographical characteristics typical of coastal areas. Based on data from BPS Medan Belawan Sub-district, Belawan Bahagia Village has an elevation of about 3 metres above sea level (masl). With a very low altitude compared to sea level during tidal phenomena and proximity to the Malacca Strait, this area often experiences tidal flooding. Tidal floods are caused by seawater overflowing onto land, especially during the full moon phase or when extreme weather strikes.

Based on research conducted by Putri (2023), Sea level rise has increased the frequency of tidal flooding in Medan Belawan Sub-district, including Belawan Bahagia Village. Studies show that several areas in coastal Sumatra, including Medan Belawan, are experiencing land subsidence due to excessive groundwater exploitation and development activities (Pratomo et al., 2021). The more the land subsides, the higher the likelihood of seawater inundating these areas. Mangrove forests, which function as a natural barrier to sea waves, have been destroyed due to land conversion and industrial activities. The loss of mangroves makes coastal areas more vulnerable to the direct impact of tidal floods.

According to data obtained from the Belawan Bahagia Village Head Office, most of the population depends on fisheries, petty trade, and services related to marine activities. However, tidal flooding poses a significant threat to the survival and economy of the local community. When flooding occurs, saltwater submerges homes, roads, and public facilities, often bringing daily activities to a halt. Another factor that exacerbates this condition is the inadequate drainage infrastructure. Many drains are clogged with sedimentation or sewage, slowing the draining process when the tide recedes. In addition, land subsidence that occurs due to groundwater exploitation is also a cause of the increasing frequency and intensity of tidal floods.

Belawan Bahagia Urban Village, Medan Belawan Sub-district, is one of the areas in Medan City that is rarely dry, where every day it always experiences the phenomenon of tidal flooding. Tidal flooding usually occurs in the morning and evening. In this research location, the community is used to water entering their homes at high tide times, but this cannot be allowed to continue because it will have many negative impacts in various fields, especially health, which is certainly not suitable for the survival of the surrounding community.

Land Cover Change 2014-2025

Based on the results of satellite image interpretation in 2014 and 2025 (Figure 1 & 2), there were significant changes in land cover in Neighbourhood 19, Belawan Bahagia Village. The area increased from 4.9 hectares in 2014 to 5.03 hectares in 2025. Although this change in area is numerically small, functionally it shows a massive expansion of built-up land, especially for settlement needs.

The area of residential buildings has increased by 0.13 hectares in 11 years. Meanwhile, green open space (RTH) experienced a reduction of 0.37 hectares, most of which was converted into residential areas. This conversion indicates development pressure on ecological spaces that should function as environmental buffers. Research shows that mangroves (RTH) can offset sea level rise due to the ability of the root system to add sediment, making mangroves gradually migrate towards land when sea levels rise, and vice versa towards the sea when sea levels fall (Wood, 2020).

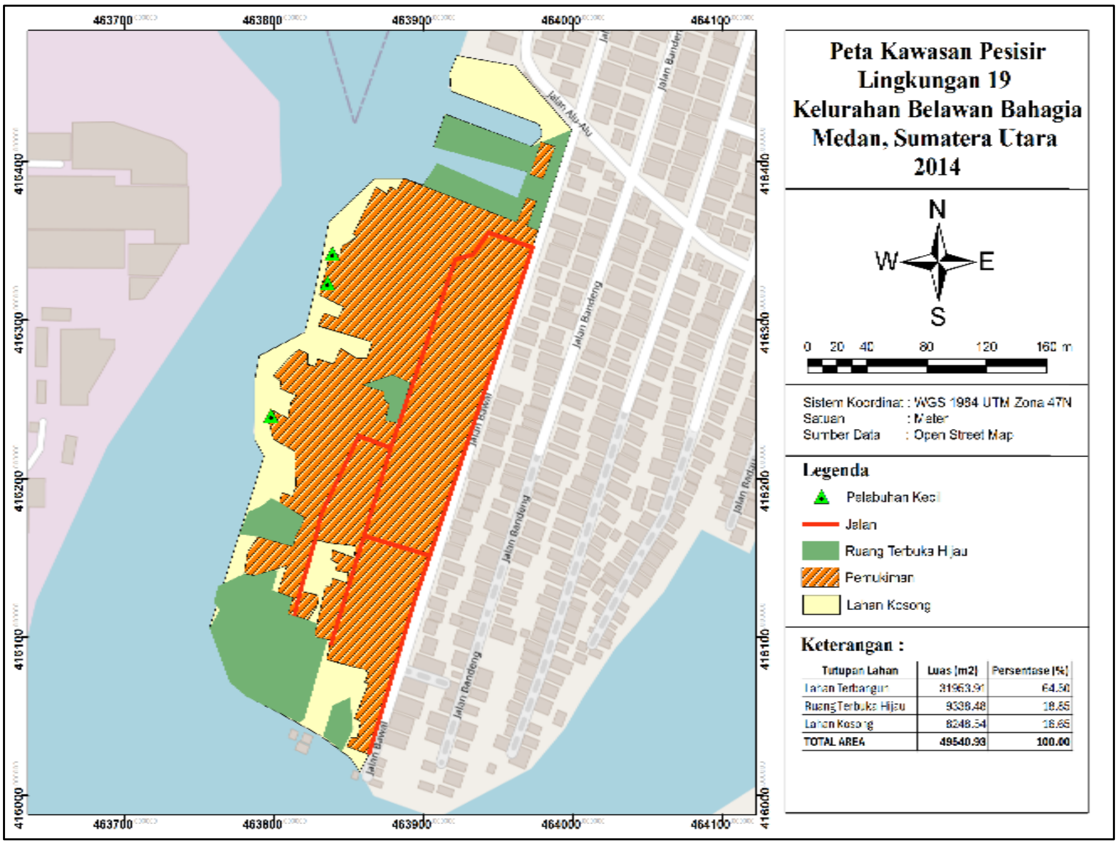

Figure 2. Situation Map 2014 (Source: Data Processing, 2025)

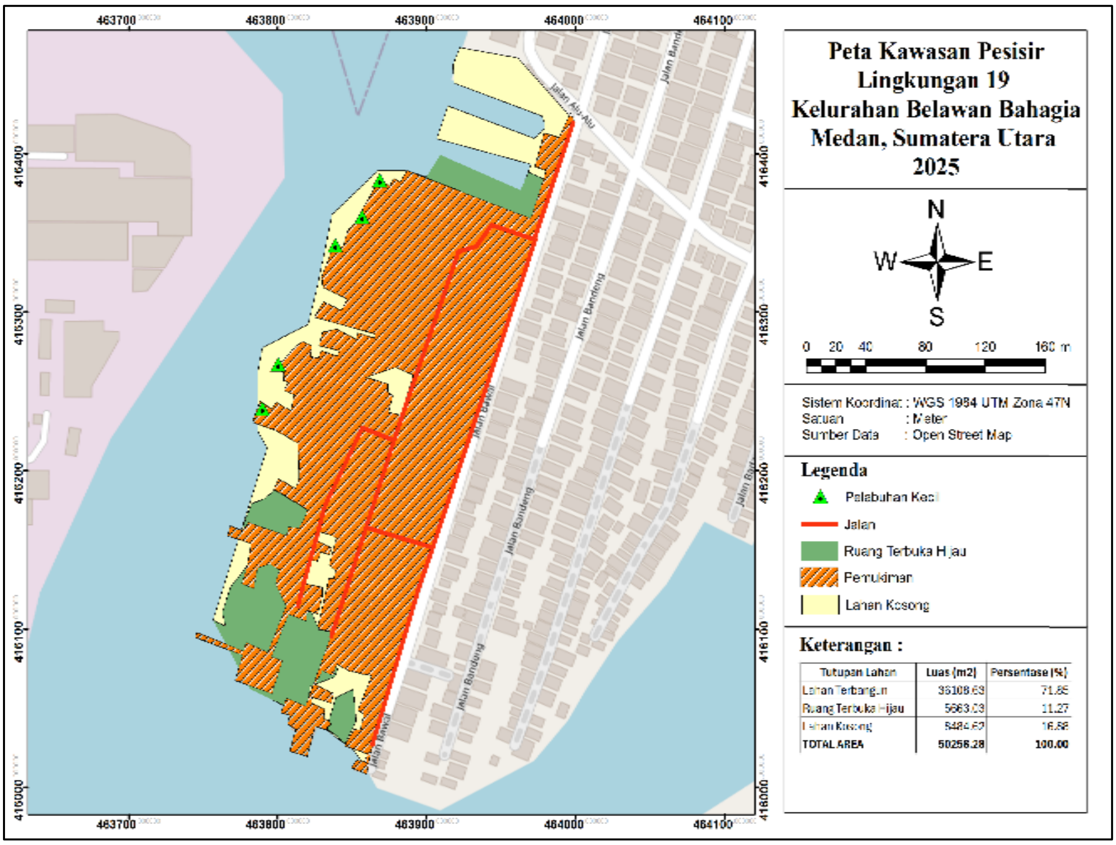

Figure 3 . Situation Map 2025 (Source: Data Processing, 2025)

Population and Household Growth

https://jurnal.unimed.ac.id/2012/index.php/tgeo/article/view/65577
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The research results in the field obtained for Settlement Support Capacity (DDPm) in 2014 amounted to 1.077 ha. So, the optimal population in this area is 1230 people. This year, the population still fulfils the capacity of 1142 people. However, this population is very close to the optimum population.

Based on research conducted in 2025, the settlement support capacity (DDPm) in 2025 is 0.81 ha. Therefore, the optimal population in this area is 1385 people. The population data for the area in Neighbourhood 19, Belawan Bahagia Urban Village, Medan Belawan Sub-district is 1691 people, meaning the area has already met capacity (Overpopulation). Government Regulation Number 57 of 2009. This regulation states the provisions regarding the direction of population mobility to achieve optimal population distribution. This is based on the balance between the population and the carrying capacity of nature, the capacity of the built environment, and the capacity of the social environment.

So, based on the field results and the applicable rules, the advice that can be given at this point is that managing the number of residents approaching JPO requires strategic intervention through family planning programmes, improving the quality of education and health, creating employment opportunities, and sustainable development planning. With these measures, the community can balance population and environmental carrying capacity and improve the overall quality of life.

Demographic data shows that the population of Belawan Bahagia Village increased from 1,142 people in 2014 to 1,691 people in 2025. The number of households also increased from 210 to 354 housing units. This population growth directly increases the need for residential land, facilities, and infrastructure and adds to the area's environmental burden. With the increase in population and building area, the pressure on the environment's carrying capacity is increasing. These changes not only result in the loss of ecological functions of green spaces but also reduce water catchment areas and increase the potential for inundation and flooding.

Impact on Rob Flooding

According to (Novalinda, 2022), there are several characteristics or characteristics of tidal floods, including occurring at high tide, the colour of the water is not too cloudy, does not always occur during the rainy season, and usually occurs in areas with lower land areas. Tidal flooding occurs due to human activities, among others, excessive groundwater use. This will cause the subsidence of the land surface and the clearing of mangrove forests. In addition, artificial flooding is also caused by several factors. These factors include:

1. Global Warming is a natural event that causes an increase in the world's average temperature. The increase in air temperature on Earth will, of course, impact the ice at the Earth's two poles. As a result of this cause of global warming, the two ice caps at the poles of the Earth melt in large quantities. The melting of the ice at the Earth's two poles, either a little or a lot, will affect the increase in the amount or volume of seawater. As a result, sea water will increase and the sea level will rise (this phenomenon is called the sea level rise phenomenon).
2. Over-utilisation of groundwater will cause the soil's surface to fall, especially in coastal areas that need much clean water. Of course, this will make residents around the coast look for extra sources of clean water, lowering the land surface in the coastal area. This drop in groundwater levels will cause tidal floods to come very easily.
3. Clearing of mangrove forests, the clearing of forest species such as mangrove forests. Mangrove forests have a function to hold water when the tide arrives. If these mangrove forests are cleared, then what will happen is that the waves that hit will not be able to be held back. Waves that cannot be protected will

be a threat to the occurrence of tidal floods.

4. The topography of an area is one of the factors that cause tidal flooding. This means that the condition of the natural area in an area with a type of land surface is below or low from the sea level. This situation will cause seawater to easily flow over the land or land surface, causing tidal flooding.
5. The phenomenon of land subsidence, land surface subsidence, or land surface lower than sea level will trigger tidal floods in a particular area. This shows that land subsidence is also automatically a factor that supports the occurrence of tidal floods. Changes in the use of swamp land, situ, rice fields, land that functions as a swamp or situ or rice fields, and so on, if converted into residential land, or other lands that can block water infiltration into the soil. In the long term (even quickly), this will cause flooding to occur very easily.

Based on the analysis of observations in the field, the topography in the area of the arrangement of the Belawan waterfront tourism area is generally relatively flat with a slope of 0 - 3%, especially in areas near the coast, thus the area of the Medan Belawan sub-district includes coastal areas that are influenced by tides, so that most of the water is brackish.

The main factors leading to increased tidal flooding include climate change, coastal reclamation, and groundwater exploitation that alter coastal ecosystems (Kodoatie & Sjarief, 2010). To overcome this problem, several environmentally-based approaches can be applied, such as using environmentally friendly materials, ecological engineering, adaptive spatial planning, and strengthening community participation. Environmentally friendly building materials, such as porous concrete and water-adaptive structures, can help reduce the impact of tidal flooding (Priyono et al., 2019). In addition, ecological engineering by constructing natural embankments based on mangrove vegetation and green infrastructure can increase water absorption and reduce the risk of seawater overflow (Setiawan, 2020). Adaptive spatial planning, considering zoning safe from tidal flooding and constructing buffer zones, is also important in mitigation (Sugandhy & Hakim, 2007).

The participation of coastal communities in the planning and implementation of mitigation strategies further strengthens the effectiveness of these efforts, as community-based approaches are more sustainable than top-down interventions (Adger, 2003). By applying this approach in an integrated manner, environment-based development can be a long-term solution in reducing the risk of tidal flooding and maintaining the sustainability of the coastal environment.

By taking a case study in Neighbourhood 19 of Belawan Bahagia Urban Village, Medan Belawan Sub-district, North Sumatra, the image interpretation results show that the area for green space in the area reaches 0.94 Ha (18.85%). Data on the height of tidal flooding in the area in 2014, according to BPBD Medan City, reached ± 5-10 cm. The image interpretation results show an increase in the area from 2014 to 2025, which is 0.13 ha, due to the construction of houses that go to sea. The original green space area of 0.94 ha (18.85%) of the total area became 0.57 ha (11.27%) of the total area. This has led to the worsening of tidal flooding conditions in the area. Based on data, the height of tidal flooding has reached ±20-30 cm.

Data from BPBD Medan City shows that in 2014, this area experienced tidal flooding, with water levels reaching ±5-10 cm. However, by 2025, the height of tidal flooding had increased to ±20-30 cm. This increase is caused by natural factors such as sea level rise and the decrease in soil absorption capacity due to the increase in built-up land and the reduction of green areas. Spatial analysis shows that areas that have experienced converting green space to residential land tend to have a higher risk of inundation. This indicates a correlation between the loss of ecological functions of open space and increased vulnerability to tidal disasters.

Evaluation of Environmental Supportability

To calculate the carrying capacity of residential land in the research area in 2014, the Built-up Land Area (LTb) was found to be 3.2 ha. Based on this data, the Land Support Capacity for Building (DDLB) is 1.07, by PERMEN LH No.17 of 2009 that DDLB = 1-3 is included in the conditional/medium category. To calculate the carrying capacity of the research area settlement land in 2025, the Built-up Land Area (LTb) was obtained at 3.6 ha. Based on this data, the Land Support Capacity for Building (DDLB) is 0.97. By PERMEN LH No.17 of 2009, that DDLB < 1 = bad.

Based on the results of research conducted by Fathyn & Yunus (2023), evaluating the carrying capacity of settlement land in Tapango District, Polewali Mandar Regency, to determine the capacity of land in supporting population growth. Recommendations from the results of his research are to optimise existing land use, pay attention to environmental aspects, and carry out sustainable development planning to increase DDLB. Then Zulkarnain (2019) analysed the carrying capacity of land for housing development in urban areas, focusing on identifying areas with poor DDLB, recommending conducting geotechnical analysis, and applying appropriate construction technology to improve land carrying capacity.

Based on the data obtained in the field, the DDLB of the area is in the exceeded/poor category. Evaluating this by the results of previous research provides suggestions for overcoming this. Some things that can be applied are as follows: First, it is necessary to conduct periodic evaluation and monitoring of land conditions, including geotechnical analysis to determine the capacity of the soil to support buildings. Second, it is recommended to conduct better spatial planning, considering the land's carrying capacity and the surrounding environment, and optimising the use of existing land to avoid development in areas with low DDLB capacity. Third, the use of appropriate construction technology, such as deep foundations or pile foundations, can be a solution to improve the durability of building structures on land with poor bearing capacity. Fourth, effective drainage management is also critical to prevent a decrease in soil bearing capacity due to water accumulation, which can cause damage to building foundations. These measures allow development in areas with low land bearing capacity to be carried out more safely and sustainably.

The calculation of land bearing capacity for buildings (DDLB) shows a decrease in the capacity of land to support the population. If the area of residential land is compared to the total population, the carrying capacity ratio shows a smaller value as the population increases and non-residential land shrinks. This indicates the area is under severe environmental pressure and beyond its carrying capacity.

Currently, the decline and even loss of mangroves and other types of vegetation along the coastline has increased the vulnerability of coastal areas to storm and tsunami damage (Danielsen et al., 2005). This makes strengthening mangrove greenbelts and other coastal forests critical to mitigating the impacts of future extreme events. In addition to reducing pressure on coastal hazards by protecting natural phenomena such as tidal flooding, coastal vegetation, such as mangroves, can provide benefits and resilience to local communities through ecosystem services. The ability of mangroves and other coastal plants to protect the coast from waves by reducing wave height as they pass through the vegetation has been widely studied. Tanaka et al. (2007) mentioned that the composition of mangrove forest species is strongly related to the ability to reduce wave energy. The study simulated vegetation drag and found that among mangroves (Rhizophora spp. and Avicennia spp.) and other coastal plants (Pandanus odoratissimus, Casuarina equisetifolia, Cocos acciden nucifera, and Anacardium acciden-tale), Rhizophora and Pandanus odoratissimus mangroves were the most effective at lowering water flow and reducing wave height. This is supported by Mazda et al. (1997) that Rhizophora spp. Forms a considerable friction against waves. Rhizophora has a characteristic root that emerges on the ground like a claw that can block waves and incoming wind energy, thus reducing the height of approaching waves. Aksornkoae et al. (1992) and Jayatissa et al. (2002) explained that Rhizophora apiculata-type trees have a complex root structure contributing to a high friction coefficient. Tanaka et al. (2007) found that Rhizophora apiculata and Rhizophora mucronata effectively protect against extreme waves such as tsunamis, based on observations in Sri Lanka and coastal areas in Andaman, Thailand. Therefore, the study also mentioned that a complex variety of species will have a better effect because different types and sizes of leaves, stems, and roots will produce different resistance levels. In this case, the width of the forest also matters.

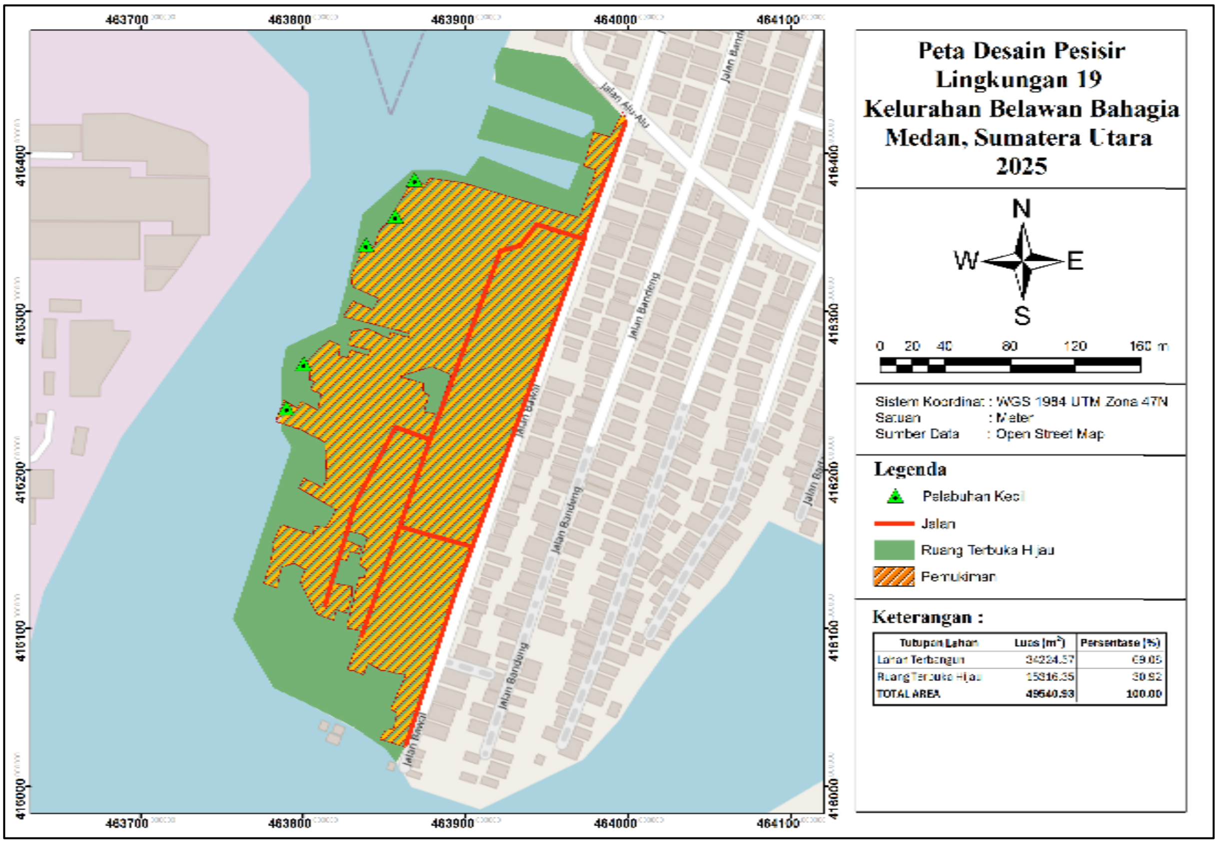

Figure 4. Study Area Recommendation Map (Source: Data Processing, 2025)

By taking a case study in Neighbourhood 19 of Belawan Bahagia Urban Village, Medan Belawan Sub-district, North Sumatra, an environment-based settlement concept for tidal flood mitigation can be developed, which is described as follows. The result of image interpretation shows that the area for green space in the area reached 0.94 Ha (18.85%). Data on the height of tidal flooding in the area in 2014, according to BPBD Medan City, reached ±5-10 cm. The image interpretation results show an increase in the area from 2014 to 2025, which is 0.13 ha, due to the construction of houses that go to sea. The original green space area of 0.94 ha (18.85%)

of the total area became 0.57 ha (11.27%) of the total area. This has led to the worsening of tidal flood conditions in the area. Based on data, the height of tidal flooding has reached ±20-30 cm.

The carrying capacity of settlement land for the above settlement recommendations refers to the Spatial Planning Law No.26 concerning LH that 70% of urban land (buildings) and 30% for green spaces. Settlement recommendations for urban coastal areas vulnerable to tidal flooding by planting mangrove forests along the coastline can be an effective and sustainable solution to reduce disaster risk and increase the carrying capacity of settlements. Mangrove forests function as a natural barrier that can absorb ocean wave energy, reduce the impact of tidal flooding, and prevent coastal erosion. The roots of mangroves growing along the coast dampen the force of waves and stabilise the soil, preventing land subsidence and infrastructure damage. In addition to their role in disaster mitigation, mangroves also provide significant ecological benefits, such as increasing biodiversity and supporting the local fishing industry. As a carbon sequestering ecosystem, mangroves contribute to reducing greenhouse gas emissions, supporting climate change mitigation efforts in coastal areas. Mangrove planting also plays a role in strengthening the carrying capacity of settlement land, maintaining soil stability, and increasing the sustainability of coastal city development. Implementing this site plan requires collaboration between the local government, community, and ecologists to create an optimal and sustainable mangrove ecosystem. Thus, the project protects the community from natural disasters, improves the quality of life, and strengthens the resilience of coastal areas in the long run.

CONCLUSION

This research shows that there have been significant land cover changes in the coastal area of Belawan Bahagia Urban Village during the period 2014 to 2025. This change was characterised by an increase in built-up land area of 0.13 hectares and a decrease in green open space (RTH) of 0.37 hectares. This land conversion was primarily caused by significant population growth, from 1,142 people to 1,691 people, and an increased in houses from 210 units to 354 units.

The land cover change directly impacted the decrease in environmental carrying capacity, marked by an increase in the intensity and height of tidal flood inundation from ±5-10 cm in 2014 to ±20-30 cm in 2025. The decline in the ecological function of green spaces as water catchment areas has exacerbated the region's vulnerability to tidal floods. Through a spatial analysis approach and image data interpretation, this research proves that the imbalance between physical development and environmental capacity will increase disaster risk and reduce the community's quality of life. Therefore, more adaptive, environmentally sound, and spatial data-based spatial planning is needed to ensure the long-term sustainability of coastal areas.

ACKNOWLEDGMENT

With tremendous gratitude, the author would like to thank all those who have provided support, assistance, and encouragement while preparing this research. Special thanks go to the Ministry of Education, Ministry of Science and Technology of the Republic of Indonesia, which has provided support in the form of scholarships during lectures until this journal can be completed, to the Regional Disaster Management Agency (BPBD) of Medan City, the PKP Office of North Sumatra Province, which has provided the data and information needed in this research. All parties cannot be mentioned one by one who have helped directly or indirectly. Hopefully, all the help and kindness given will be rewarded by God Almighty.

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