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Original Paper

Disaster Mitigation Based on Regional Vulnerability Analysis of South Labuhanbatu Regency for Risk Reduction Planning

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ABSTRACT

Disaster mitigation is a systematic effort to reduce disaster risks through pre-disaster planning, vulnerability reduction, and capacity building to support sustainable development. In South Labuhanbatu Regency, geographic conditions, climate change, and land-use dynamics, particularly lowlands, dense river networks, high rainfall, and extensive oil palm plantations, increase the risk of flooding and environmental degradation. Therefore, mitigation efforts must be specific, based on a vulnerability analysis that integrates environmental aspects into spatial planning strategies. Data analysis was conducted spatially using GIS through map digitization and georeferencing, land use classification, and overlay analysis between physical conditions of the region, land use, and disaster potential. Spatial analysis shows that is dominated by flood hazards, covering 34,224.8 Ha (9.59%) of the total area, mainly in Kampung Rakyat, Kotapinang, Sungai Kanan, and Torgamba, while Silangkitang is not flood-prone. Flood vulnerability is closely related to lowland areas along the Barumun Watershed, where peatland conditions and oil palm–dominated land use reduce infiltration and increase surface runoff. Landslide hazards are limited to Torgamba and Sungai Kanan due to hilly terrain and land clearing, while active fault intensity varies spatially, with the highest levels in Silangkitang, highlighting the importance of integrating geological risk into spatial planning.

ARTICLE INFO

Keywords:
Disaster, Mitigation, Vulnerability, Planning, South Labuhanbatu

1. INTRODUCTION

Disaster mitigation is a series of systematic efforts undertaken to reduce the risks and impacts of disasters, whether natural, non-natural, or human-caused (Kristian et al. 2024). Mitigation focuses not only on post-disaster management but also emphasizes the pre-disaster phase through planning, reducing vulnerability, and increasing community and regional capacity (Sapountzaki, 2022). In the context of sustainable development, disaster mitigation is a crucial instrument for protecting human life, economic assets, and ecosystems. Modern disaster mitigation approaches place regional vulnerability analysis as a key component of risk reduction planning (Palliyaguru et al. 2014). Vulnerability encompasses physical, social, economic, and environmental aspects that determine the extent of losses when a disaster occurs. Areas with high vulnerability tend to experience greater impacts, even if the hazard intensity is relatively the same. Therefore, vulnerability analysis is an essential basis for developing targeted mitigation strategies based on local conditions.

Djalante (2018) state that Indonesia is a country with a high level of disaster risk due to its geographic location, geological conditions, and massive land-use dynamics. Climate change, land conversion, and development pressures exacerbate the potential for disasters such as floods, forest fires, droughts, and landslides (Alcántara-Ayala, 2025). In recent decades, the trend of disaster occurrences has shown an increase in both frequency and impact on communities and the regional economy. This condition is also reflected in North Sumatra, including South Labuhanbatu Regency. This regency is characterized by lowland to undulating terrain, with a dense river network and relatively high rainfall. This combination of natural factors makes the region vulnerable to hydrometeorological disasters, particularly flooding and inundation, especially during the high-intensity rainy season (Hoyos et al. 2019).

In addition to natural factors, environmental pressure in South Labuhanbatu Regency is increasing due to the dominance of oil palm plantations. Much of the regency is surrounded by large-scale and smallholder oil palm plantations, which are transforming natural land cover. The conversion of forests and wetlands to plantations has resulted in reduced water absorption capacity, increased surface runoff, and the degradation of the region's ecological function. The presence of massive oil palm plantations also contributes to the increased risk of other disasters, such as land fires during the dry season and environmental degradation (Noojipady et al. 2017). Poorly managed drainage systems in plantation areas and surrounding settlements exacerbate the potential for flooding, while the community's economic dependence on a single commodity increases socio-economic vulnerability when disasters occur (Douglas, 2017).

In this context, disaster mitigation cannot be implemented in a general or uniform manner, but must be based on a comprehensive regional vulnerability analysis. Vulnerability mapping allows the identification of priority areas, the most vulnerable community groups, and the main factors causing disaster risk (Morrow, 1999). This information is crucial to support spatial planning, infrastructure development, and natural resource management that are more adaptive to disaster risks. An effective mitigation strategy in South Labuhanbatu Regency requires integrating structural and non-structural approaches. The structural approach includes strengthening flood control infrastructure, improving drainage systems, and rehabilitating the environment. Meanwhile, the non-structural approach includes developing risk-based policies, increasing community capacity, providing disaster education, and strengthening local institutions for disaster risk reduction.

However, to date, disaster mitigation studies based on regional vulnerability analysis in South Labuhanbatu Regency are still limited and have not been optimally integrated into regional

development planning. Many disaster management policies and programs are reactive and not fully based on comprehensive vulnerability data (Beccari, 2016). This situation has the potential to increase losses when disasters occur in the future. Therefore, research on disaster mitigation based on regional vulnerability analysis in South Labuhanbatu Regency is crucial and urgent. This research is expected to provide a scientific basis for more effective, contextual, and sustainable disaster risk reduction planning. Furthermore, the research results can serve as a reference for local governments and stakeholders in formulating more disaster-resilient development policies.

2. METHOD, DATA, AND ANALYSIS

The research was conducted in South Labuhanbatu Regency, North Sumatra Province. This area was selected because of its land use characteristics dominated by oil palm plantations and its physical condition, which makes it vulnerable to hydrometeorological disasters. Geographically, South Labuhanbatu Regency is located between 1°26'00" – 20'15'55" North Latitude and 99°40'00" – 100°26'00" East Longitude, with an area of 356,900 hectares, comprising 5 sub-districts and 52 villages/2 definitive sub-districts.

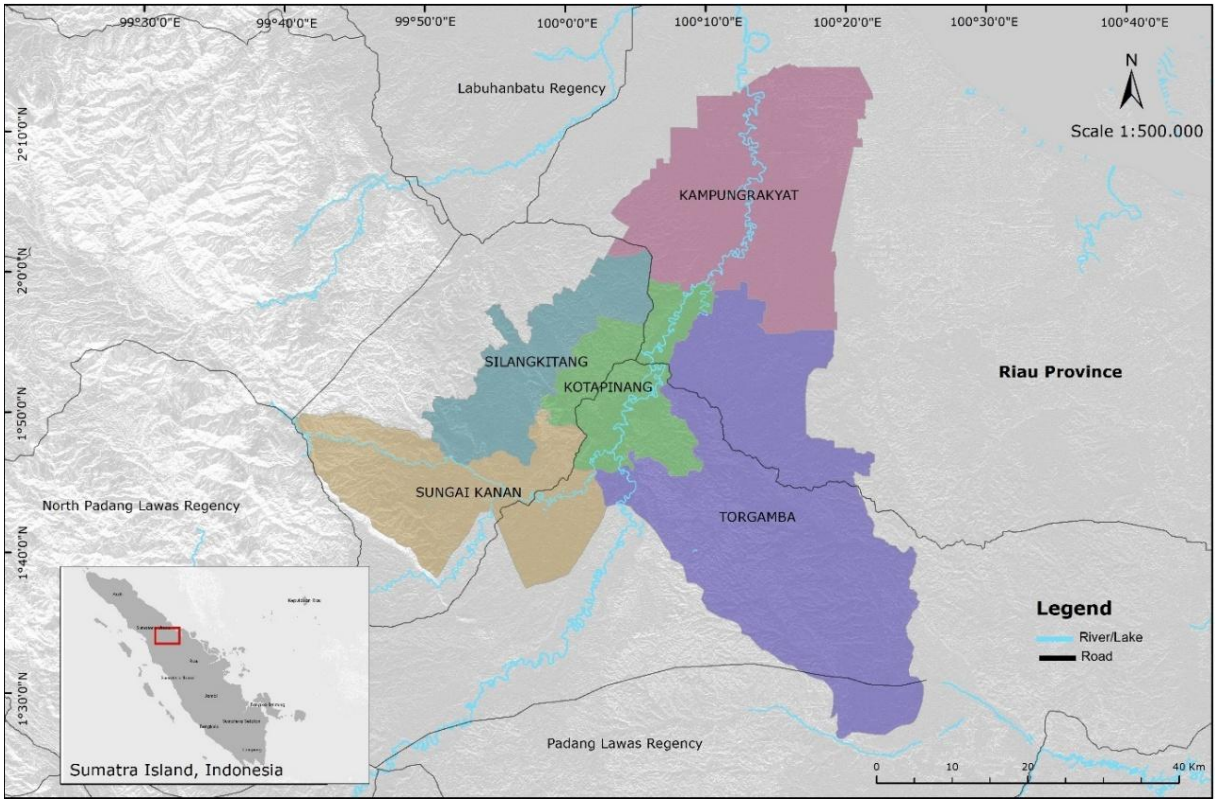

Figure 1. Research Map Location

2.1. Data Types

The data types used in this study consist of spatial and nonspatial data. Spatial data is used to describe the physical conditions and spatial layout of the region, while nonspatial data is used as supporting data to understand the social characteristics, policies, and existing conditions of the region. The combination of these two data types aims to produce a comprehensive regional vulnerability analysis.

2.2. Data source

The main data source in this study is the Layout of the Regional Spatial Plan (RTRW) of North Sumatra Province for 2017–2037 (Regional Regulation Number 2 of 2017). The RTRW map is used as the basis for analyzing the suitability of spatial use and disaster mitigation planning, with a map scale of 1: 350,000. In addition, supporting data is obtained from related agencies, official government publications, and the results of relevant previous studies and research.

2.3. Data Analysis

Data analysis was conducted using a spatial analysis approach utilizing a Geographic Information System (GIS). The spatial analysis stages included map digitization and georeferencing, land use classification, and mapping of regional vulnerability elements (Ştefan, 2018). The processed spatial data was then analyzed using an overlay to identify the relationship between land use, the physical condition of the region, and disaster potential (Costache et al. 2020).

Next, a regional vulnerability analysis was conducted, considering physical and spatial parameters, such as proximity to river networks, land slope, and land use patterns. The results of this analysis were used to identify zones with low, medium, and high levels of disaster vulnerability. This vulnerability classification served as the basis for compiling a regional vulnerability map for South Labuhanbatu Regency.

The results of the spatial analysis were then interpreted descriptively to support the formulation of disaster mitigation strategies. This interpretation was carried out by linking the vulnerability mapping results to spatial planning policies and actual land use conditions. Therefore, this research is expected to produce recommendations for disaster risk reduction planning that are region-based and aligned with applicable RTRW policies

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3. RESULT AND DISCUSSION

The comprehensive research findings related to the vulnerability analysis of the South Labuhanbatu Regency area obtained through a spatial approach, include the identification of the distribution of potential disasters, the level of vulnerability between regions, and their relationship to physical characteristics and spatial utilization, while also discussing the effectiveness of the analysis results on disaster mitigation planning and sustainable risk reduction strategies, especially in supporting the implementation of spatial planning and spatial planning policies that apply at the regional and local levels.

3.1. Regional Disaster Risk

The results of the spatial analysis of disaster vulnerability in South Labuhanbatu Regency based on sub-district boundaries, which detail the area and percentage of floods, landslides, and the distribution of active cesarean as a basis for disaster risk reduction and mitigation planning.

Table 1. Disaster risk analysis results

Subdistrict	An area (Ha)	Flood (Ha)	(%)	Landslide (Ha)	(%)	Active Cesarean	(%)
Torgamba	118.500	6.842,3	19,98	12.450,0	68,9	Low	10
Kotapinang	52.300	8.964,7	26,19	0	0	Currently	15
Sungai Kanan	61.200	7.103,5	20,75	5.600,0	31,1	Currently	25
Kampung Rakyat	64.900	11.314,3	33,08	0	0	Low	10
Silangkitang	60.000	0	0	0	0	High	40
Total	**356.900**	**34.224,8**	**100**	**18.050,0**	**100**		**100**

The analysis results show that the total area of flood-prone areas in South Labuhanbatu Regency reaches 34,224.8 Ha or approximately 9.59% of the total area of the regency (356,900 Ha). Flood vulnerability is unevenly distributed among sub-districts, with the largest contribution coming from Kampung Rakyat Sub-district covering 11,314.3 Ha (33.08%), followed by Kotapinang Sub-district covering 8,964.7 Ha (26.19%), Sungai Kanan Sub-district covering 7,103.5 Ha (20.75%), and Torgamba Sub-district covering 6,842.3 Ha (19.98%). In contrast, Silangkitang Sub-district does not show any indication of being a flood-prone area. This distribution pattern shows that areas along the main river channels and lowlands have a higher level of flood vulnerability.

The most flood-prone area is Kampung Rakyat District, with a disaster area of 11,314.3 hectares, out of a total flooded area in the Regency, calculated using geometry of 34,224.8 hectares. This is influenced by the area still being classified as a peatland area. According to Indonesian Peatland Data sheet 0717, Kampung Rakyat District has many areas with peatland status. Therefore, wet and inundated areas are still a regular disaster in this area. Meanwhile, overflow water from upstream to downstream in the areas on either side of the river is very difficult, such as areas without vegetation or bare (Daulay et al. 2023).

Landslide vulnerability in South Labuhanbatu Regency was only identified in two sub-districts, namely Torgamba and Sungai Kanan, with a total landslide-prone area of 18,050.0 Ha. Torgamba is the area with the highest level of landslide vulnerability, covering an area of 12,450.0 Ha or 68.9% of the total landslide-prone area, while Sungai Kanan has an area of 5,600.0 Ha or 31.1%. The absence of landslide potential in Kotapinang, Kampung Rakyat, and Silangkitang sub-districts indicates that topographic factors and geological conditions play a significant role in shaping landslide vulnerability patterns in the study area.

The distribution of active cesareans in South Labuhanbatu Regency shows variations in intensity levels between sub-districts. Silangkitang Sub-district has the highest proportion of active cesarean distribution, at 40%, indicating a relatively greater potential for geological vulnerability compared to other sub-districts. Sungai Kanan and

Kotapinang Sub-districts each have active cesarean distribution levels of 25% and 15%, respectively, while Torgamba and Kampung Rakyat Sub-districts are classified as having low active cesarean intensity, at 10% each. These findings emphasize the importance of considering geological disaster aspects in spatial planning and infrastructure development, especially in areas with high active cesarean intensity.

The results of the spatial analysis are presented in the form of a disaster hazard map that depicts the distribution of potential flood, landslide, and active cesarean hazards in South Labuhanbatu Regency as a basis for disaster risk reduction and mitigation planning.

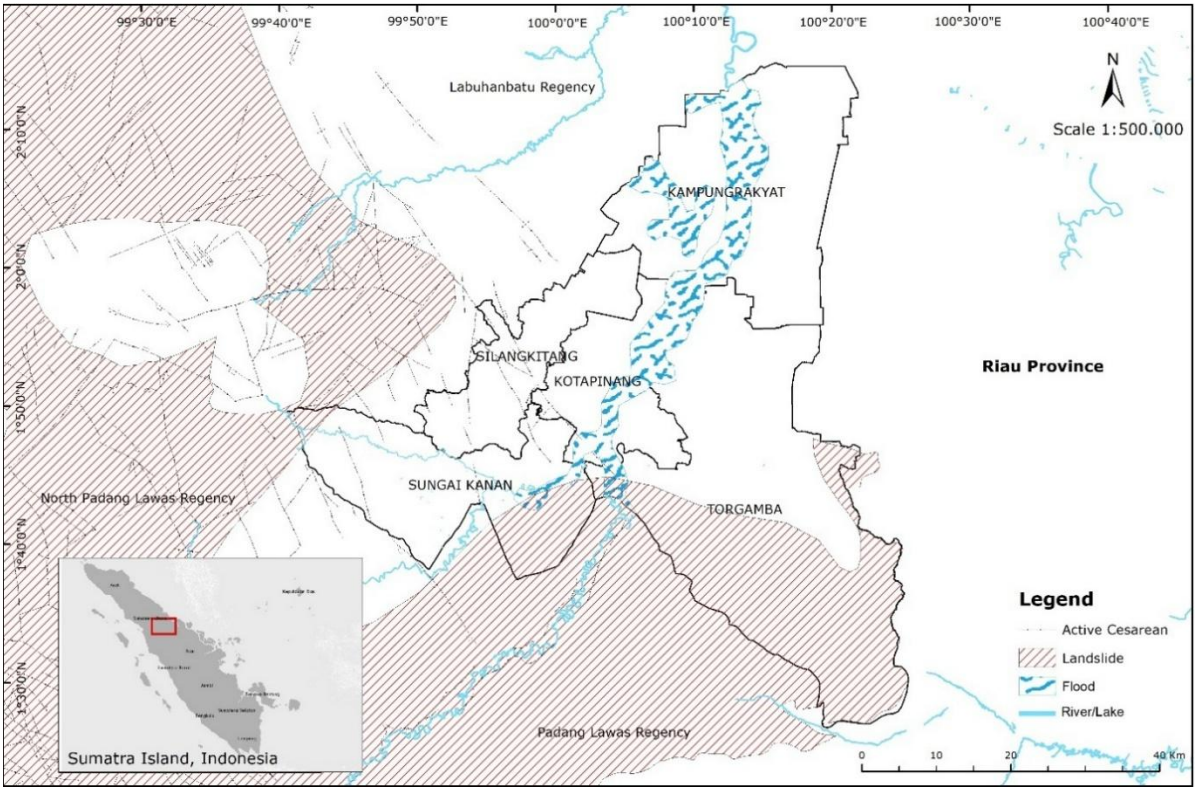

Figure 2. Disaster Hazard Map

The South Labuhanbatu Regency Disaster Hazard Map shows that flooding is the most common and frequent disaster, with a disaster-prone area of 34,224.8 hectares. Flooding in South Labuhanbatu is a recurring disaster in the regency. As reported by Sumatra Bisnis, 15 cities/regencies in North Sumatra, including Asahan Regency and South Labuhanbatu, are at moderate risk for flooding in February 2021.

Data from the National Disaster Management Agency (BNPB) shows that 2,862 disasters occurred throughout 2017. Of these, nearly 99 percent were hydrometeorological disasters, namely disasters influenced by weather and surface runoff, including flooding, with 979 occurrences. This is due to the fact that South Labuhanbatu is classified as a peatland area. Therefore, wet and inundated areas remain a frequent disaster in this region. Meanwhile, runoff from upstream to downstream in areas on either side of the river is very difficult, such as areas without vegetation or bare areas.

In South Labuhanbatu Regency, there are many rivers that flow from south to north and unite into the Barumun River, often referred to as the Barumun Watershed. Therefore, based on the results of the river potential study and the consideration of the criteria above, the designated river boundary area is: the Barumun River. Besides the Barumun River, there are other smaller rivers such as the Kanan River, Aek Raso, Aek Kabaro, and Aek Tasik.

3.2. Distribution of Flood, Landslide, and Active Cesarean

The South Labuhanbatu Regency Disaster Hazard of areas with potential flooding, moderate landslides, and active cesareans across several sub-districts. Based on spatial analysis, flood-prone areas are primarily concentrated along the main river basin, stretching from Kampung Rakyat Sub-district to Sungai Kanan Sub-district and parts of Kotapinang Sub-district. This pattern indicates that areas with high proximity to the river network have a significant level of flood vulnerability, particularly in lowland areas.

Kotapinang and Kampung Rakyat Sub-districts exhibit relatively high levels of flood vulnerability due to their downstream location with dense river flow and intensive land use activities. This condition is exacerbated by changes in land cover dominated by oil palm plantations, which reduce water absorption capacity and increase surface runoff. As a result, these areas are prone to inundation and river overflow during periods of heavy rainfall.

Meanwhile, a moderate level of landslide potential has been identified in the southern part of South Labuhanbatu Regency, particularly in Torgamba District. The undulating to hilly terrain, coupled with land clearing activities and minimal soil-retaining vegetation, are the main factors increasing landslide vulnerability in this area. Although the vulnerability level is categorized as medium, potential impacts on settlements and infrastructure still need to be anticipated through appropriate mitigation planning.

In addition to disaster risk, the map also shows the presence of active cesareans that traverse several parts of the regency. The presence of these active cesareans indicates the potential threat of

geological disasters, such as earthquakes, which must be considered in spatial planning and infrastructure development. Areas near active cesarean lines require stricter spatial use regulations to minimize the risk of damage and loss of life (Comelsen, 2015).

Overall, this disaster hazard map provides a comprehensive spatial overview of the vulnerability of South Labuhanbatu Regency to various types of disasters. This information serves as an important basis for disaster risk reduction planning, particularly in determining priority mitigation zones, controlling spatial use, and strengthening regional and community capacity (King et al. 2016). Thus, the integration of the results of this map into spatial planning and regional development policies is expected to increase regional resilience to future disasters.

3.3. Characteristic Disaster Mitigation

Disaster mitigation in South Labuhanbatu Regency needs to be designed contextually, taking into account the region's biophysical characteristics, which are dominated by lowlands, dense river networks, limited hilly areas, and land use dominated by oil palm plantations. These conditions make flooding a primary threat, followed by landslides in areas with certain slopes and the potential for geological disasters due to the presence of active cesareans. Therefore, the proposed mitigation strategy must integrate structural, non-structural, and socio-institutional approaches.

From a biophysical perspective, flood mitigation needs to focus on watershed management and controlling land use in floodplain areas. Possible measures include river normalization and maintenance, improving drainage systems in residential and plantation areas, and rehabilitating vegetation supporting rivers to increase water infiltration capacity (Rowiński et al. 2018). Meanwhile, landslide mitigation is focused on the Torgamba and Sungai Kanan sub-districts through slope strengthening, limiting land clearing in vulnerable zones, and implementing soil and water conservation techniques. In areas crossed by active cesareans, controlling infrastructure development and implementing earthquake-resistant building standards are crucial mitigation measures (Okem et al. 2024).

From a socio-economic and cultural perspective, the people of South Labuhanbatu Regency largely rely on plantations and agriculture for their livelihoods, with settlement patterns developing along river and main road access. This situation increases community exposure to flooding and demands a community-based mitigation approach. Strengthening community capacity through disaster education, local wisdom, and organizing disaster-prepared communities is a key aspect in reducing disaster risks and impacts (Diansasnita et al. 2024).

The mitigation efforts proposed in this study align with South Labuhanbatu Regent Regulation Number 39 of 2018 concerning disaster management, particularly the preparedness phase. This regulation emphasizes that preparedness activities include the development and testing of emergency response plans, testing of early warning systems, providing and preparing basic supplies, organizing and training emergency response mechanisms, preparing evacuation routes and locations, and compiling and managing accurate

disaster data and information. Implementation of this regulation provides a strong institutional foundation for disaster risk reduction efforts at the regional level.

One key mitigation strategy that needs to be strengthened is the development and testing of an early warning system that is adaptive to local conditions. This system serves to provide early information to the public before disasters occur, particularly floods and landslides (Fathani et al. 2016). Equipment used in an early warning system includes information-receiving devices such as hydrometeorological sensors, microcontrollers, and servers or computers for data processing. The use of simple yet effective technology is crucial for the system's sustainable operation in rural areas.

By integrating the region's biophysical characteristics, the socio-economic and cultural conditions of the community, and the regional regulatory framework, such as South Labuhanbatu Regent Regulation No. 39 of 2018, this disaster mitigation proposal is expected to significantly reduce disaster risk. A comprehensive, region-based mitigation approach not only plays a role in reducing disaster losses but also supports more resilient and sustainable regional development.

4. CONCLUSION AND SUGGESTION

The spatial analysis indicates that South Labuhanbatu Regency faces multi-hazard vulnerability dominated by flooding, followed by landslides and geological hazards related to active cesareans. Flood-prone areas cover 34,224.8 Ha or 9.59% of the total regency area (356,900 Ha), with the highest exposure occurring in Kampung Rakyat, Kotapinang, Sungai Kanan, and Torgamba sub-districts, while Silangkitang shows no flood susceptibility. Flood vulnerability is strongly associated with lowland areas along major river networks within the Barumun Watershed, where peatland conditions and land-use changes dominated by oil palm plantations reduce water infiltration and increase surface runoff. Landslide hazards are more spatially limited, occurring only in Torgamba and Sungai Kanan due to hilly topography, geological conditions, and land clearing activities. Active cesarean distribution varies across sub-districts, with higher intensity in Silangkitang and moderate intensity in Sungai Kanan and Kotapinang, emphasizing the need to integrate geological risk into spatial planning. The resulting disaster hazard map provides a crucial basis for disaster risk reduction, supporting integrated mitigation strategies aligned with biophysical conditions, socio-economic characteristics, and the implementation of Regent Regulation No. 39 of 2018.

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