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Salinity as an Ecological Indicator for Mangrove Rehabilitation in the East Kalimantan Province

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Abstract
The mangrove forest ecosystem serves as a habitat for a wide range of microorganisms. However, the environmental quality of mangrove forests is currently experiencing disturbances. One of the ecological factors influencing mangrove growth is salinity, which plays a crucial role in the growth, resilience, and distribution of mangrove species. This study aims to examine variations in salinity conditions in the mangrove habitats of East Kalimantan Province. The study was conducted in the province's mangrove forests using a census method, applied methodically across the mangrove areas. Salinity measurements were carried out through a census method, with prior mapping based on spatial data processing. The study results reveal salinity variations in several regions: Berau Regency: 10.42–29.00%, Bontang City: 22.58–27.50%, Kutai Kartanegara Regency: 6.63–32.36%, East Kutai Regency: 6.30–30.08%, Paser Regency: 8.05–28.13% and North Penajam Paser Regency: 3.00–18.45%. Based on the measurements, the environmental conditions of the mangrove forests in East Kalimantan Province largely support mangrove growth, although some locations have suboptimal salinity levels. This study on salinity conditions is part of efforts to assess the ecological state of mangrove forests to support successful rehabilitation and mangrove planting.
Keywords: *Environmental Quality, Mangrove Forest, Salinity Condition, Salinity Diversity, Spatial Spread*

1. INTRODUCTION

The mangrove forest ecosystems in East Kalimantan Province represent a critical ecological zone with a strategic role in sustaining environmental equilibrium and supporting the socio-economic livelihoods of coastal communities. (Audina & Sembiring, 2024). Covering a vast area, these mangroves serve not only as habitats for diverse flora and fauna but also as natural coastal defenses against shoreline erosion and the adverse effects of climate change. The Mahakam Delta, located within this province, constitutes one of the largest and most ecologically significant mangrove regions in Indonesia, functioning as both a biodiversity hotspot and an efficient carbon sink. Additionally, the mangrove forests of East Kalimantan possess considerable potential for development as sites for educational tourism and conservation-based initiatives. (Alongi, 2008).

Mangroves have a global temperature tolerance range; however, factors such as rainfall, salinity levels, tidal patterns, wave action, and river currents play a crucial role in determining the distribution, extent, and biomass of mangroves at regional and local scales. Mangroves provide shelter for small fish, fish larvae, and shellfish from predators (Taufiq et al., 2024), making them a key component of coastal ecosystems from ecological, social, and economic perspectives (Basyuni et al., 2018). Moreover, mangroves act as vital natural buffers that mitigate coastal erosion (Wiryanto et al., 2017). Despite their ecological importance, global mangrove ecosystems have experienced substantial reductions in area, especially within tropical regions (Gerona-Daga & Salmo III, 2022).

The primary issue concerning mangroves in East Kalimantan involves significant ecosystem degradation due to land conversion for various human activities (Matatula et al., 2018). The main drivers of this degradation include the conversion of land for aquaculture, plantations, mining, and settlements. This degradation has resulted in a decline in both the quality and extent of mangrove forests. (HUSODO et al., 2017). For example, in Berau Regency, land conversion has reduced the mangrove ecosystem area from 62,307.42 hectares in 2013 to 60,011.59 hectares in 2023, with most areas experiencing vegetation cover degradation below 50% (Sulistyorini et al., 2018). Additional factors, such as reclamation, coastal infrastructure development, and environmental pollution, have also contributed significantly to the decline and degradation of mangrove forest ecosystems. (HUSODO et al., 2017).

Salinity is a key environmental parameter affecting mangrove growth. As defined by Poedjirahajoe (2007), salinity denotes the concentration of dissolved salts in water, typically measured in parts per thousand (%). Mangrove species generally inhabit environments with salinity ranging between 11 25%, characteristic of saline to brackish water conditions. Salinity critically influences mangrove physiological processes, stress tolerance, and species distribution patterns. Consequently, a detailed assessment of salinity gradients within mangrove ecosystems in East Kalimantan Province is imperative. This study

aims to quantitatively analyze spatial and temporal variations in salinity within mangrove habitats across the region.

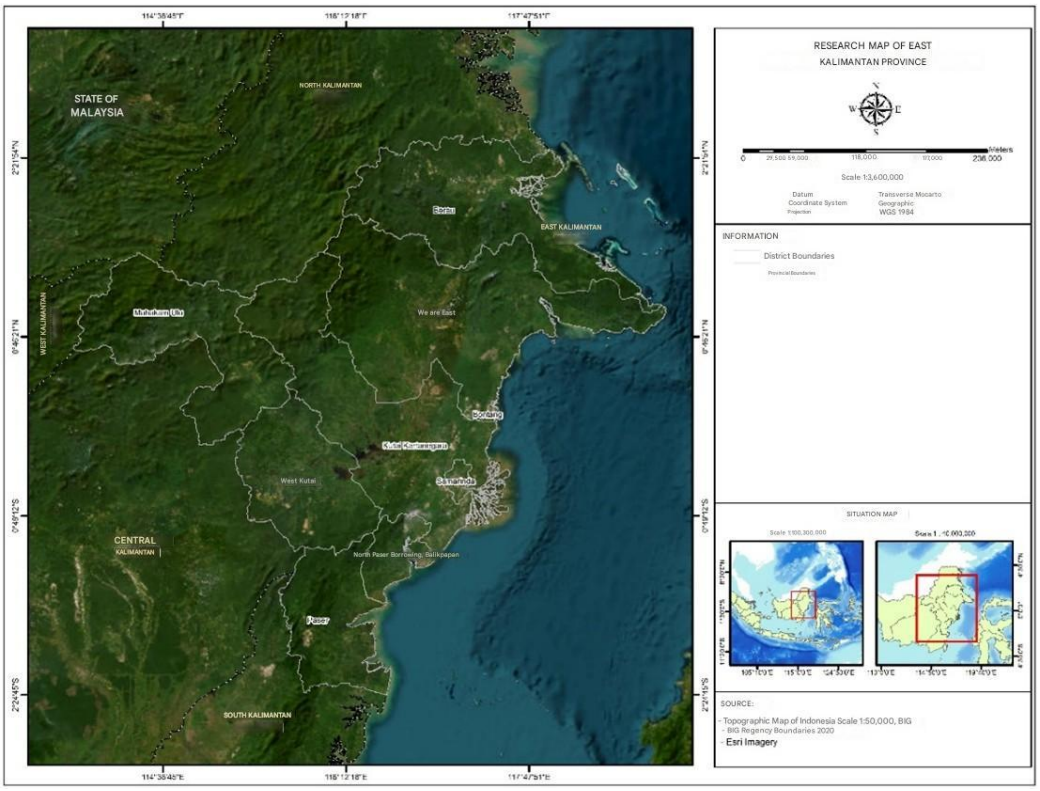

Figure 1: Salinity Data Sampling Location Map

2. METHOD

This study was conducted in the coastal region of East Kalimantan Province, which is characterized by extensive mangrove forest ecosystems. The research employed a census method based on indicative data, encompassing the entire area of East Kalimantan Province. This approach was utilized to obtain salinity measurements at predetermined sampling points identified through indicative mapping.

Salinity measurements were conducted using a salinometer. The collected data were analyzed using interpolation methods to generate salinity distribution maps. In this process, salinity data were classified into several categories based on the measured salinity ranges. (Ady, 2017). The classification consists of:

Oligohalin: Low salinity (0,5-5%)
Mesohalin: Moderate salinity (5-18%)
Polihalin: High salinity (>18-30%)
Hypersalin: High salinity (>40%)

The classification results were then mapped onto the RBI map and processed using interpolation to produce a spatial distribution map of salinity coverage.

3. RESULTS AND DISCUSSION

Salinity Diversity of Mangrove Forests in East Kalimantan Province. The condition of water bodies within a coastal ecosystem significantly influences the productivity and functioning of that ecosystem.

Table 1 Diversity of Salinity Conditions in Mangrove Forests of East Kalimantan Province

Berau	Bontang	Kukar	Kutim	Paser	PPU
Salinity (%)	Salinity (%)	Salinity (%)	Salinity (%)	Salinity (%)	Salinity (%)
27,67	22,58	12,00	18,47	24,15	17,10
21,83	27,50	6,63	26,30	21,73	17,53
14,28	-	22,70	6,30	24,01	9,05
27,25	-	8,47	23,58	24,60	17,49
12,70	-	7,92	17,43	28,13	16,73
26,00	-	20,33	22,00	19,83	10,87

Berau	Bontang	Kukar	Kutim	Paser	PPU
Salinity (%)	Salinity (%)	Salinity (%)	Salinity (%)	Salinity (%)	Salinity (%)
12,67	-	32,36	18,79	15,13	13,20
24,36	-	18,70	28,67	8,05	18,45
29,00	-	13,90	29,03	21,00	17,80
18,05	-	25,50	22,15	22,60	8,80
15,20	-	8,76	10,37	24,18	3,00
19,11	-	14,05	20,16	12,55	3,00
10,42	-	17,73	25,10	20,78	-
17,08	-	-	30,08	15,19	-
-	-	-	26,70	25,89	-
-	-	-	11,20	-	-
-	-	-	17,35	-	-

Basri, (2023) Stated that habitat factors significantly influence the composition of mangrove ecosystem components, and changes in habitat quality can disrupt the growth of mangroves present in the area. The salinity conditions of mangrove forests along the coastal areas of East Kalimantan Province exhibit salinity values ranging from 3% to 32.36%. The diversity of salinity conditions along the mangrove coastlines of East Kalimantan Province is presented in Table 1.

Berau Regency Environmental factors have a significant influence on the growth and productivity of mangrove ecosystems. (Marpaung et al., 2022) explained that salinity levels play a crucial role in determining mangrove growth. Meanwhile, categorized these conditions into three groups: edaphic factors, climate, and canopy structure. The salinity distribution map in Berau Regency can be seen in Figure 2.

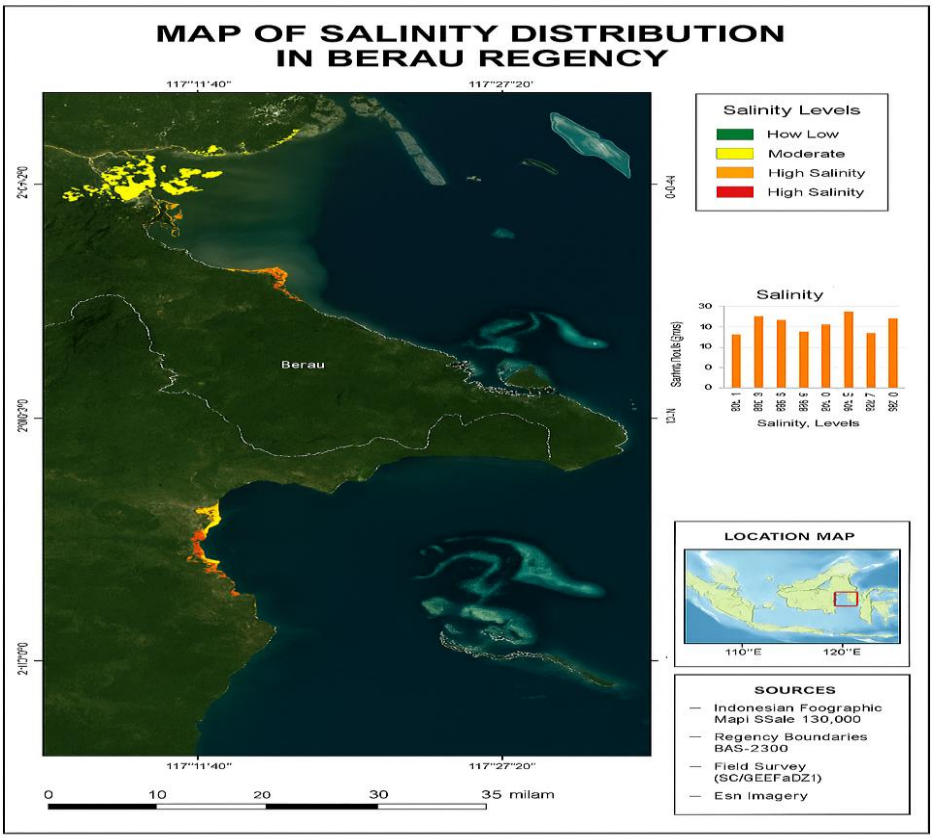

Figure 2: Salinity Distribution Map in Berau Regency

Salinity measurements in the mangrove forests of Berau Regency ranged from 10.42% to 29%, distributed across 14 locations. This salinity range remains within the limits that support mangrove growth. This finding aligns with (Matatula et al., 2019), who stated that mangroves thrive well in estuarine areas with salinity between 10% and 30%, and some mangrove species are capable of surviving

in even higher salinity levels. The salinity diversity in the mangrove forests of Berau Regency is illustrated in Figure 3.

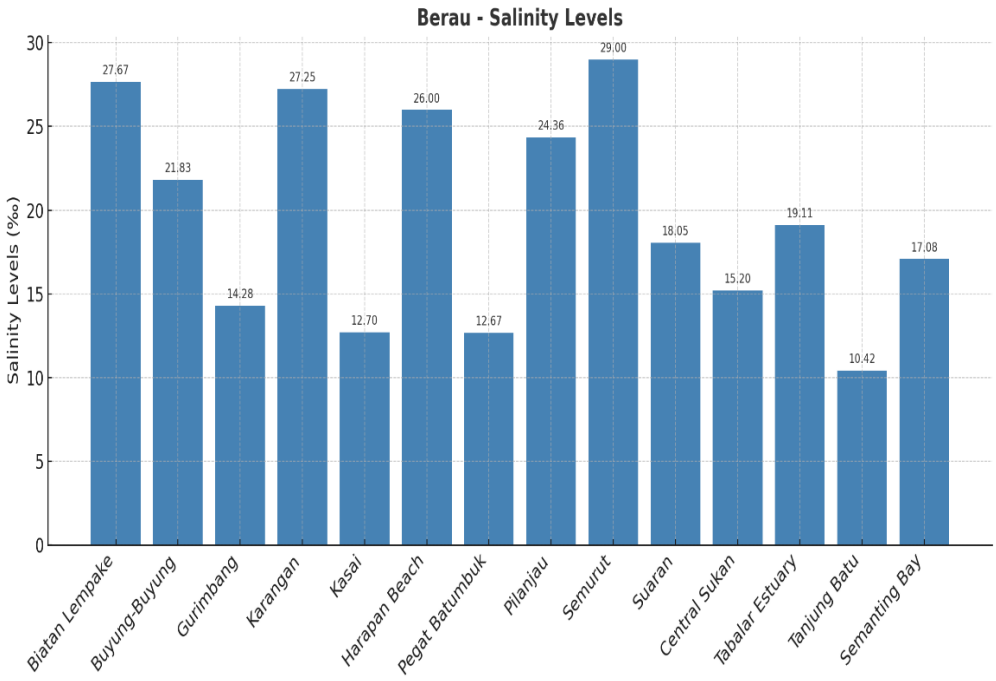

Figure 3: Diversity of Salinity Conditions in Mangrove Forests of Berau Regency

Bontang City. The salinity distribution map in Bontang City can be seen in Figure 4.

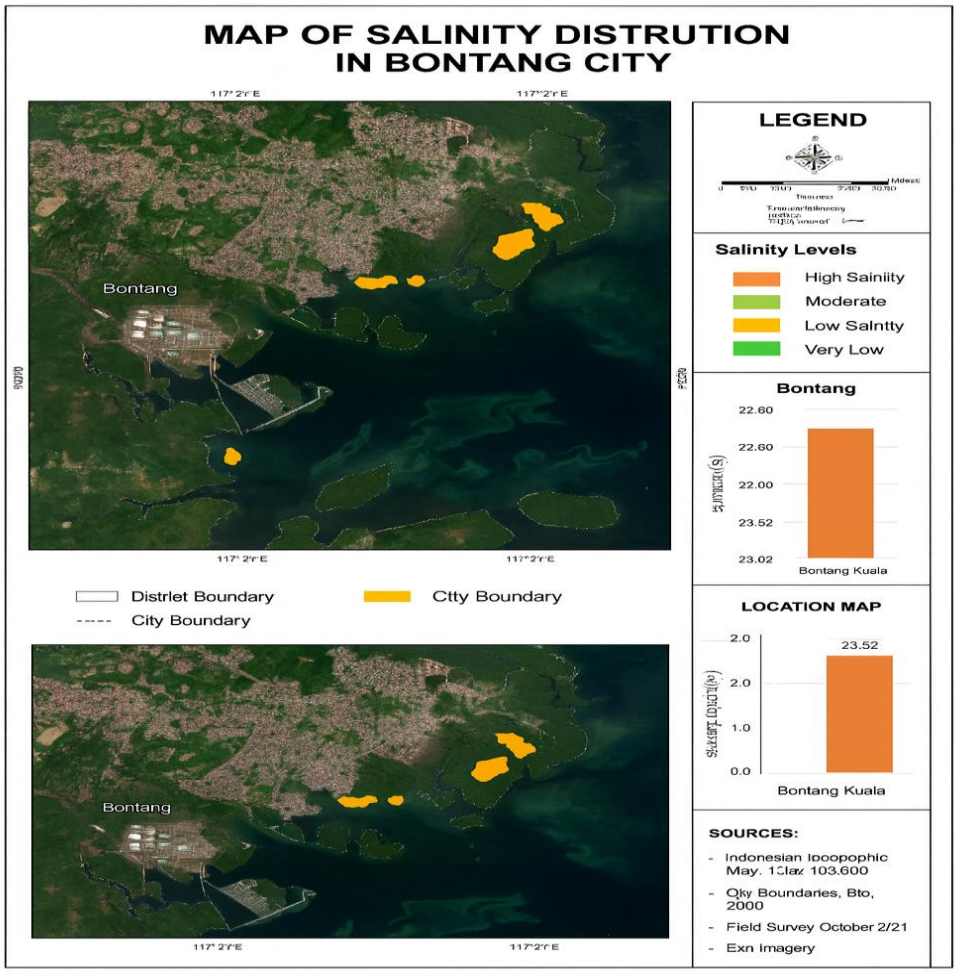

Figure 4: Salinity Distribution Map in Bontang City

The salinity in the mangrove ecotourism forest ranges from 22.58% to 27.50%. Compared to salinity values in other mangrove forests, the salinity levels in Bontang's mangrove forest are above average. This mangrove area in Bontang also serves as a popular tourist destination. Salinity is a key factor influencing mangrove growth. The salinity values observed in Bontang remain within the marine water quality standards for ports and marine tourism, as stipulated in the Indonesian Minister of Environment Regulation No. 22 of 2021. These values reflect relatively stable conditions that support the mangrove ecosystem. The diversity of salinity conditions in the mangrove forests of Bontang City is illustrated in Figure 5.

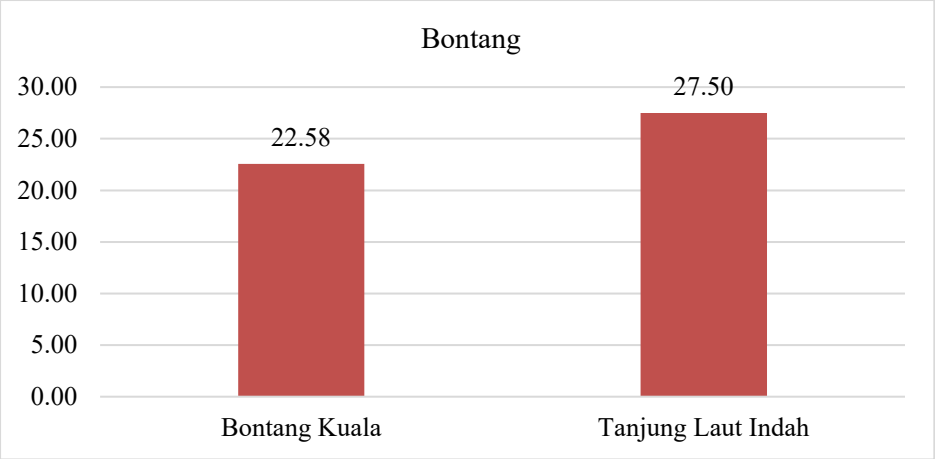

Figure 5: Diversity of Salinity Conditions in Mangrove Forests of Bontang City

Kutai Kartanegara Regency. The mangrove forests in Kutai Kartanegara Regency exhibit variable salinity levels, ranging from 6.63% to 32.36%. This variation is attributed to their location within the Mahakam Delta region. The delta, formed by sediment deposits at the estuary of the Mahakam River, extends towards the Makassar Strait in East Kalimantan. The delta covers approximately 100,000 hectares of land and 50,000 hectares of water bodies, administratively encompassing five districts: Muara Jawa, Samboja, Muara Badak, Sanga-Sanga, and Anggana.

The Mahakam Delta is also known for its natural resource potential, including significant oil and natural gas reserves located in the Peciko and Tunu fields, operated by the French multinational company Total E&P Indonesia. Prior to the 1997 Asian financial crisis, much of this area was still covered by mangrove forests. However, extensive portions have since been converted into shrimp aquaculture ponds, resulting in the loss of mangrove vegetation across ten islands within the region. The salinity distribution map in Kutai Kartanegara Regency can be seen in Figure 6.

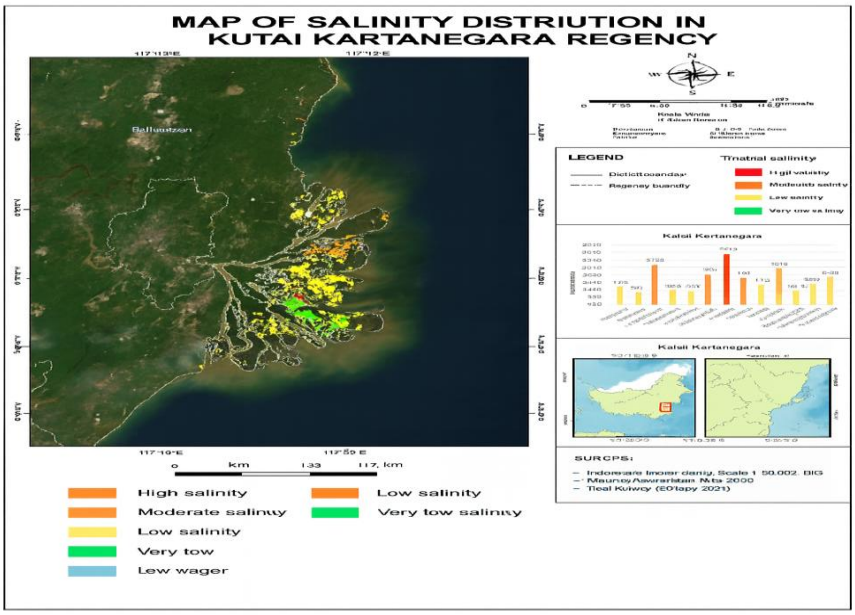

Figure 6: Salinity Distribution Map in Kutai Kartanegara Regency

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The Mahakam Delta represents a confluence of freshwater from inland areas and seawater from the Makassar Strait, heavily influenced by tidal dynamics. The surface sediments comprise a variety of materials such as clay, sand, mud, and gravel. Geologically, the delta exhibits a complex structure with stratigraphic layers dominated by carbonate sediments and siliciclastic delta deposits, reflecting responses to sea-level fluctuations. The variability of salinity values in the mangrove forests of Kutai Kartanegara Regency is illustrated in Figure 7.

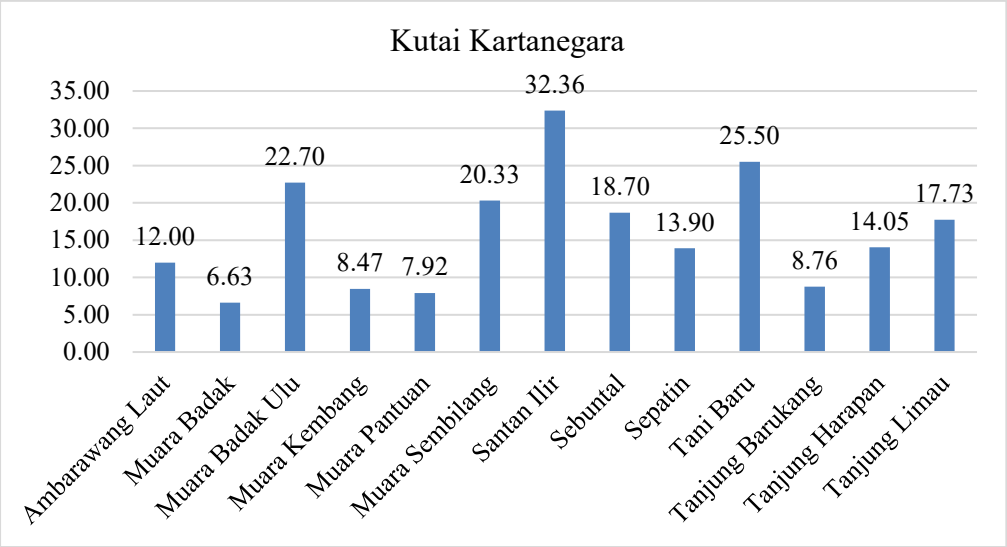

Figure 7 Diversity of Salinity Conditions in Mangrove Forests of Kutai Kartanegara Regency

Kutai Timur Regency. The salinity distribution map in Kutai Timur Regency can be seen in Figure 8.

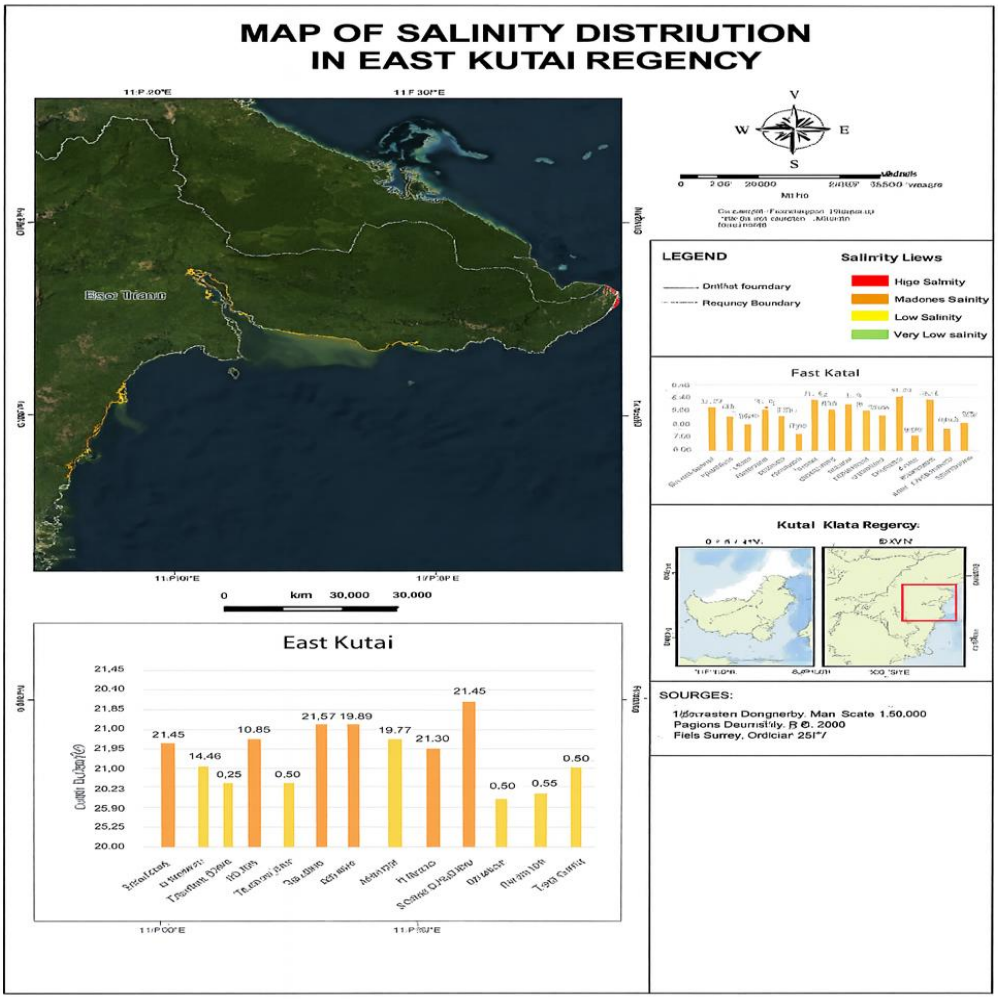

Figure 8: Salinity Distribution Map in Kutai Timur Regency

The environmental conditions of mangrove forests in Kutai Timur Regency are experiencing ecological pressure in their growing habitats. Salinity levels in the mangrove forests of this region range from 6% to 30.08%. These salinity conditions greatly influence the growth of mangrove forests in Kutai Timur Regency. This is consistent with Hastuti & Budihastuti, (2016), who stated that salinity conditions significantly affect mangrove life, as mangrove species are capable of surviving and growing in brackish water environments with varying salinity levels. The diversity of salinity values in the mangrove forests of Kutai Timur Regency is illustrated in Figure 9.

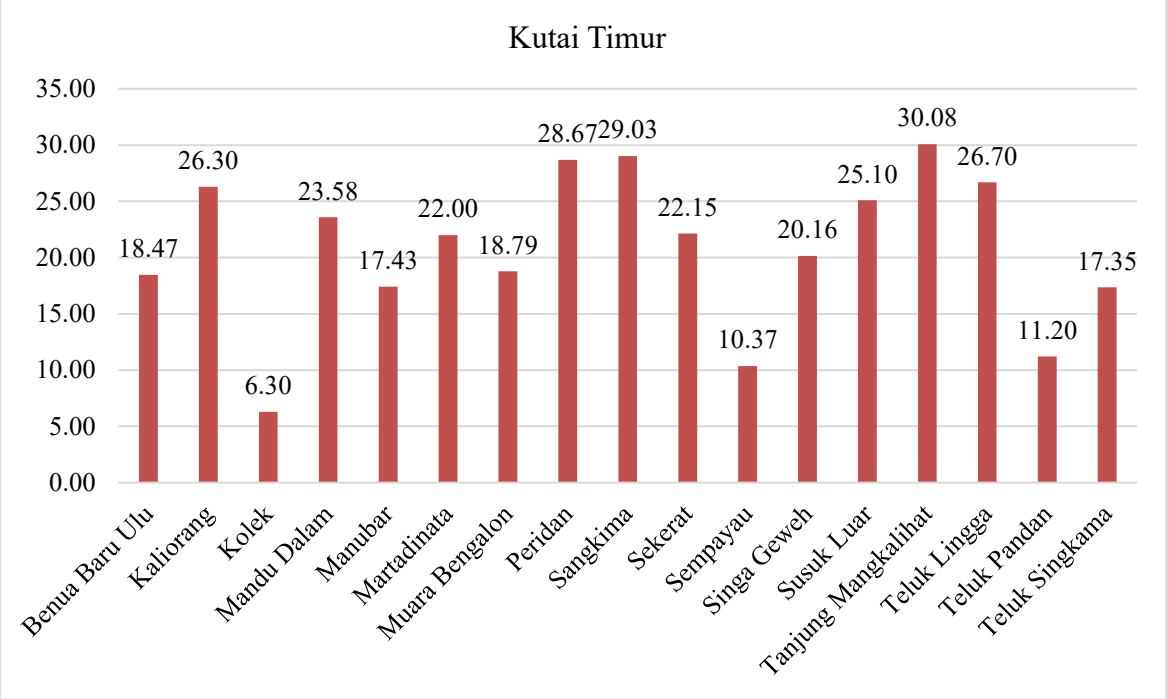

Figure 9: Diversity of Salinity Conditions in Mangrove Forests of Kutai Timur Regency

The mangrove forests in Kutai Timur, particularly within the Kutai National Park area, stretch along 65 kilometers of the eastern coastline and serve as a critical ecosystem for maintaining coastal environmental balance. A study conducted from April to May 2021 by (Rahayu et al., 2024) Identified seven mangrove species from four families, with Black Mangrove (Rhizophora mucronata) as the dominant species. The species diversity index (H') in primary mangrove forests was recorded at 1.06, higher than that of secondary mangrove forests, which had an H' value of 0.38. This indicates that primary mangrove forests possess greater biodiversity.

However, the mangrove ecosystem in this region is under considerable pressure due to human activities such as land conversion for aquaculture and the expansion of residential areas. Data from the East Kalimantan Forestry Service in 2004 indicated that forest resource degradation covered an area of 6.4 million hectares, including damage to mangrove ecosystems.

Paser Regency. When environmental conditions are favorable, they significantly support the regeneration process, particularly during the seed germination stage of mangroves. (Hastuti & Budihastuti, 2016). Mangroves themselves represent one of the coastal ecosystems currently facing threats in terms of both area coverage and environmental quality. (HUSODO et al., 2017). Good water quality in a given aquatic environment is crucial to support the life of various organisms within it. (Katili et al., 2020). The mangrove ecosystem is characterized by its distinctive and complex nature, involving interactions among various species of flora and fauna that are closely linked to their surrounding environmental conditions. (Pamungkas et al., 2024). The salinity distribution map in Paser Regency can be seen in Figure 10.

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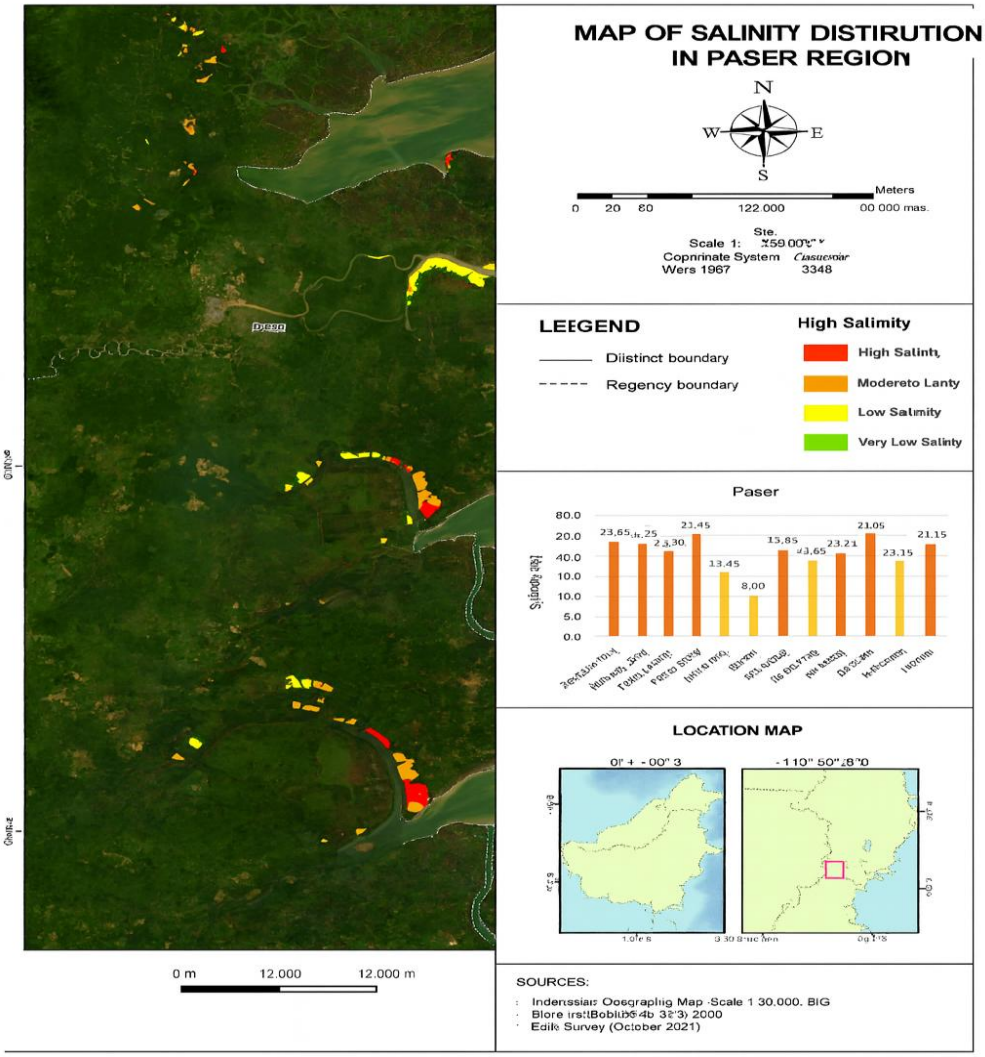

Figure 10: Salinity Distribution Map in Paser Regency

In Paser Regency, salinity levels in mangrove habitats range from 8.05% to 28.13%. These values remain within the suitable range for mangrove plant growth. (Matatula et al., 2019). The mangrove forests in this region, particularly within the Teluk Apar Nature Reserve, harbor high biodiversity and play a vital role in maintaining the balance of coastal ecosystems. The variation in salinity levels in this area results in diverse mangrove vegetation zonation. However, this ecosystem is currently under threat from various human activities. Therefore, sustainable conservation efforts, including active community participation, are essential to ensure its preservation. The diversity of salinity in the mangrove forests of Paser Regency is illustrated in Figure 11.

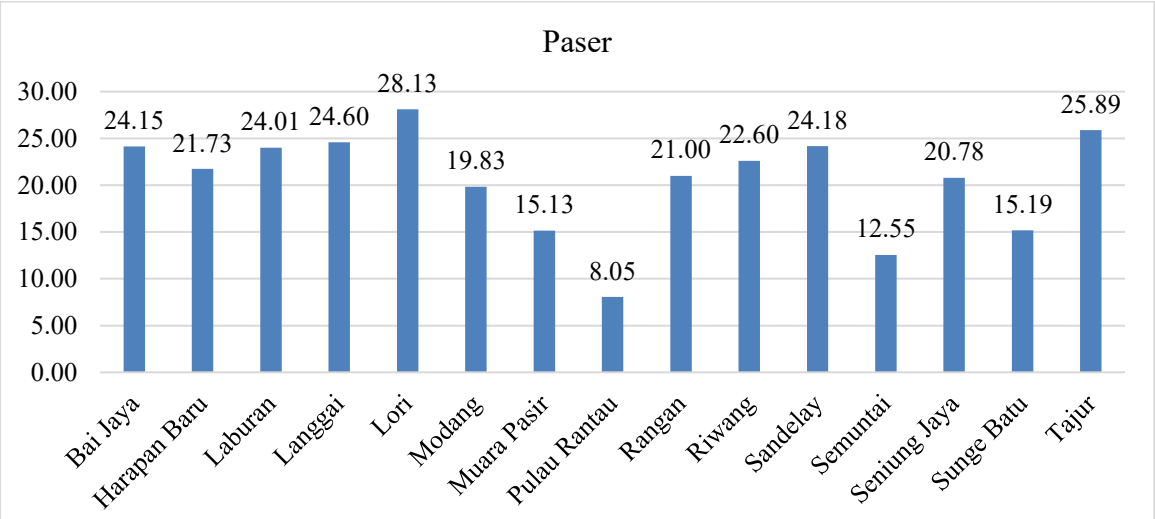

Figure 11 Diversity of Salinity Conditions in Mangrove Forests of Paser Regency

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Penajam Paser Utara Regency Salinity conditions are an environmental factor that significantly influences mangrove growth. (MAYALANDA et al., 2014). While several mangrove plant species exhibit high adaptive mechanisms to salinity, the absence of freshwater supply can lead to extreme soil and water salinity levels, potentially threatening the survival of mangrove vegetation (Dahuri, 2003).

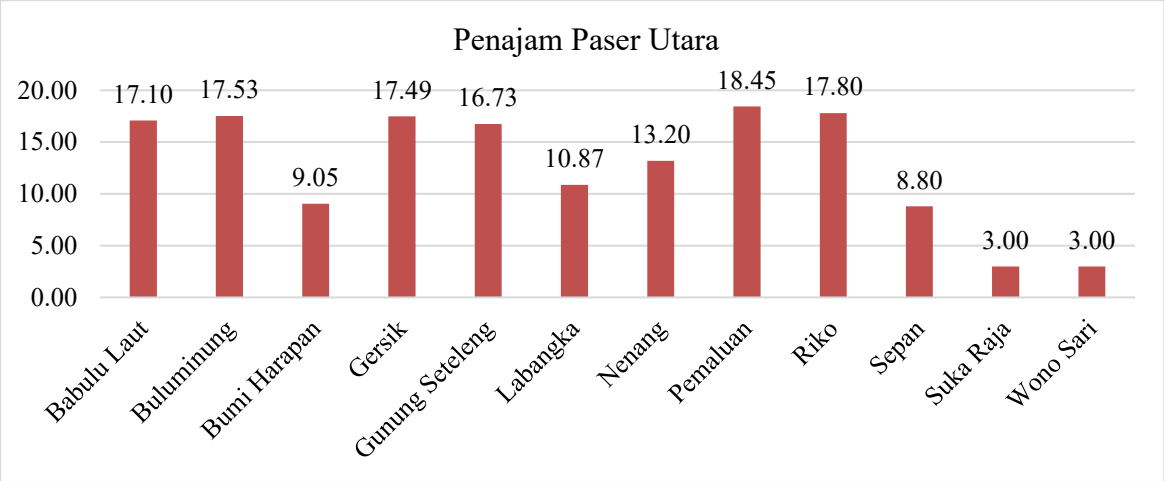

Figure 12 Diversity of Salinity Conditions in Mangrove Forests of Penajam Paser Utara Regency

Based on Figure 12, salinity levels in the mangrove forests of North Penajam Paser Regency range from 3.00% to 18.45%. Mangroves exhibit tolerance to a wide range of salinity levels; however, extreme fluctuations can adversely affect the health of the ecosystem. Certain mangrove species, such as Avicennia marina and Aegiceras corniculatum, display high salinity tolerance, while other species may be more sensitive to changes in salt concentration. (Irwanto et al., 2024). The salinity distribution map in Paser Regency can be seen in Figure 13.

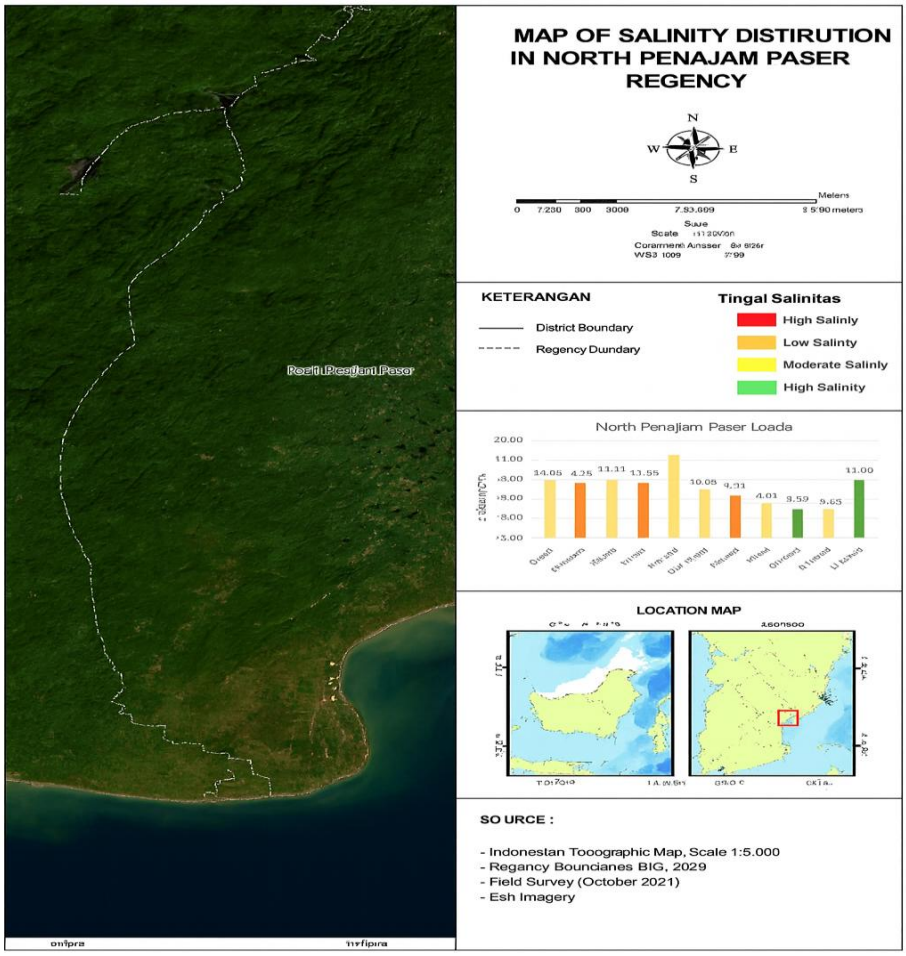

Figure 13: Salinity Distribution Map in Penajam Paser Utara Regency

Spatial Distribution of Salinity Conditions. The data obtained indicate a variation in salinity levels across the mangrove forest regions distributed throughout East Kalimantan Province. Salinity levels are influenced by several factors, including circulation patterns, evaporation, precipitation, and river discharge. In mangrove ecosystems, the water salinity is classified as brackish, as these areas are typically located in estuarine zones, where seawater and river water converge. The field research findings indicate that the distribution of salinity conditions across mangrove forest areas in East Kalimantan Province serves as a key reference indicator.

The physical condition of the environment plays a critical role in the management of mangrove forests, considering that mangrove habitats are highly dynamic and continuously undergo changes, either rapidly or gradually. These changes may result from various factors such as storms, freshwater inflow, and sedimentation, which alter environmental intensity. Therefore, understanding the physical conditions of the environment is essential to assess whether a body of water is in a healthy or degraded state. Waters are considered healthy if they can support the life of organisms within them. Salinity is one of the key environmental variables influencing the growth of mangroves and other organisms in the ecosystem (Nugroho et al., 2022).

According to Siahaan (2016), mangrove forest encroachment activities that take place in each ecosystem can cause changes in the physical condition of the environment. Salinity is affected by several factors, including circulation patterns, evaporation, precipitation, and river flow. In mangrove ecosystems, the salinity of the water tends to be brackish because it is located in the estuary area, which is the confluence of seawater and river water.

Based on field research findings, the spatial distribution of salinity conditions in East Kalimantan Province serves as a benchmark for assessing the environmental conditions supporting mangrove growth. This distribution is instrumental in formulating the ecological characterization of mangrove forest environments in East Kalimantan, as part of broader efforts to support effective mangrove forest management. A spatial map delineating the environmental conditions of mangrove forest growth areas in the province is urgently needed. According to Zulfikhar et al., (2017)Ongoing forest fragmentation has led to a decline in both the number and size of mangrove forest patches.

The spatial salinity condition map illustrates the spatial distribution using a color scheme: red indicates hypersaline areas (>40%), orange represents polyhaline areas (18–30%), yellow denotes mesohaline areas (5–18%), and green marks oligohaline areas (0.5–5%). These salinity zones are distributed across six regencies/cities with mangrove forest areas, as shown in Figure 14.

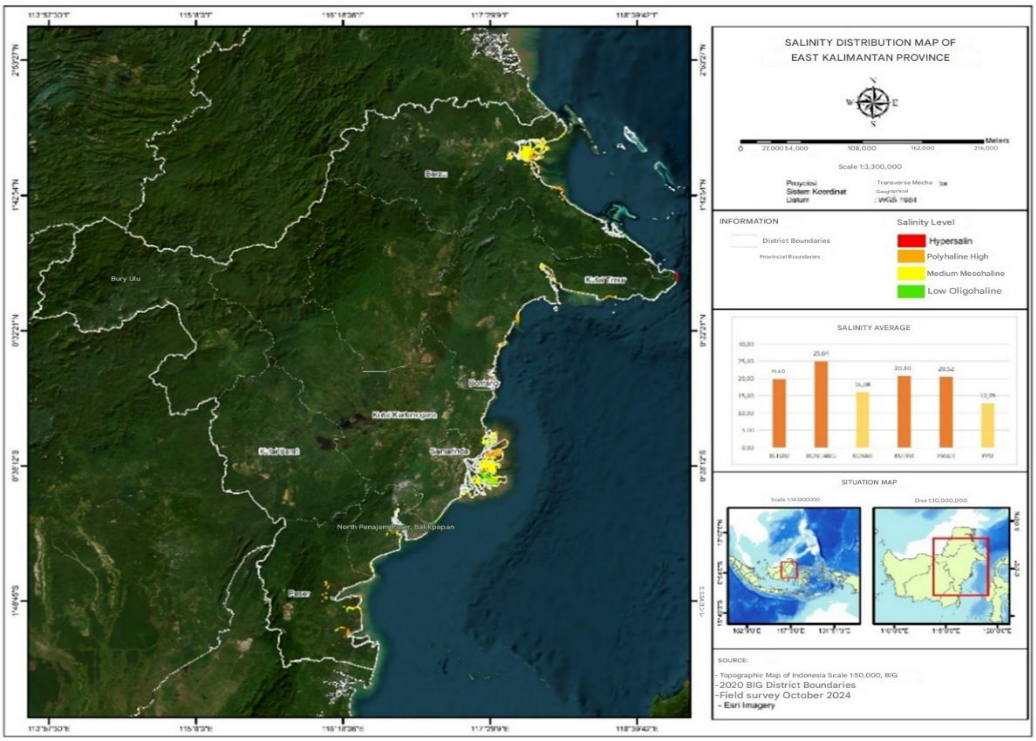

Figure 14 Spatial Distribution Map of Salinity in Mangrove Forests of East Kalimantan Province

4. CONCLUSION

Salinity has a significant influence on mangrove growth, particularly in the context of rehabilitation efforts in East Kalimantan Province. Mangroves are plants tolerant to high salinity levels; however, extreme salinity can inhibit their development. Research indicates that the success of mangrove rehabilitation depends largely on selecting sites with salinity levels suitable for specific mangrove species. Additionally, factors such as water currents, tidal patterns, and soil quality also play crucial roles in supporting mangrove growth. By understanding the relationship between salinity and mangrove growth, rehabilitation programs can be more effective in restoring healthy mangrove ecosystems that function as coastal protectors and habitats for diverse species.

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