Characteristics of salinity in the semi-enclosed Saro Estuary, Takalar, Indonesia

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Abstract. Narrowing in the semi-enclosed estuary due to sediment deposits can disrupt shipping lanes and flooding in the upstream area. Because of water circulation in the estuary, both the flow of freshwater from rivers and saltwater from the sea is obstructed. When contaminants originating from Watersheds flow into bays, they can accumulate and continue to degrade water quality. The purpose of this study was to describe the salinity distribution of the semi-closed river estuaries to the high and low tidal conditions. This research is field research at the Saro river, Takalar, Indonesia. The results show that there is a narrowing at the mouth of Saro estuary due to the presence of barrier berm across the estuary and shallow channels due to sedimentation so that seawater is trapped in the back-barrier region at during the tide. Water salinity in the Saro estuary's back-barrier region occurs up to point SL 6 or 0.67 km from the estuary to the upstream of the river. Distribution of salinity in the Saro estuary's back-barrier area can be classified as strongly stratified to well-mixed. At the SL 6 sample point, the salinity values ranged from 30 - 34.7 ppt, which means seawater, even though the conditions are at the lowest tide.

1. Introduction
River estuaries are the downstream part of a river connected to the sea. In this coastal area, seawater meets freshwater from the river and is influenced by environmental conditions such as waves, tides, river discharge, currents, sediment material, salinity, etc. In the semi-enclosed estuary, the river mouth narrows because sediment deposits can disrupt shipping lanes and cause flooding in the estuary's upstream area [1]. It can also cause water circulation in the estuary. The flow of fresh water from rivers and saltwater from the sea is hampered; once contaminants from the watershed flow into the bay, it will accumulate and continuously degrade water quality [2]. The seawater interference process depends on the height of the tides, the cross-sectional area of the mouth of the estuary, and the length of the wave. At high tide, seawater will enter the river for a certain distance. The intrusion of seawater in rivers causes rivers to have high salinity. Reducing the oxygen concentration of water, including river cliffs, is also affected by seawater [3]. Likewise, at low tide, seawater that comes out of the river takes a long time because of the mouth's narrowing.

The interaction between freshwater and seawater in the estuary will affect the distribution of salinity. Due to the difference in density between saltwater and freshwater, there will be a mixture between the two. Besides that, there are driving factors in tides that affect the salinity value [4]. Tidal currents affect salinity shifts along the estuary, which move upstream at high tide and downstream at low tide. The
salinity level concentration is significant, mainly when the water in the estuary is used for human consumption. High salt concentration in water can harm human health [5]. This problem can also affect the natural cycle of the estuary ecosystem, especially the area's biodiversity. The uncertainty of climate change, rapid population growth, and current industrial progress also affect river water quality. Furthermore, human activities such as dredging and river port activities can cause salt intrusion problems that impact water resources quality and threaten marine species. Therefore, salt intrusion studies need to be carried out to ensure the quality of incoming water can be consumed by humans [2].

Several previous studies related to semi-enclosed estuary [6][7][1][8], estuary channel maintenance method [2], water quality in semi-closed estuary type [6], salinity characteristics of estuary [3] [7], investigation of estuarine seawater intrusion [9], distribution and distribution patterns of salinity in estuaries [10] [11] [12], temperature and salinity distribution tidally in confluence river [13], and analytical and numerical modeling of estuary salinity [4] [6] [14].

It makes the writer interested in researching The Salinity Characteristics of Semi-Enclosed Estuary. This study aimed to test the water salinity level during tidal conditions and analyze the relationship between depth, distance, and salinity with the research location in the Saro river, Takalar, Indonesia.

2. Study area and Methods

2.1. A Study area

This study's study area was carried out in the Semi-Enclosed Estuary in the Saro River, Takalar, South Sulawesi, Indonesia, with the existing conditions, as shown in Figure 1. Located at Latitude 119° 21'39.508"E and 5° 20'36.455"S. The width of the mara's mouth is 40 m, the width of the estuary is 58 m, the average river width is 50 m. With varying depths from 0.2 m to 1.9 m. The study area is towards the sea 500 m from the estuary's mouth. The room towards the upstream, which is reviewed, is 2.2 km to obtain data on the exact location of the seawater's mixing and freshwater determined.

![Figure 1. Semi-enclosed Saro Estuary](image-url)

2.2. Methods

Field data collection was carried out from 4 July 2020 to 5 July 2020. The time for data collection was predetermined, namely: high tide, towards high tide, low tide, and towards low tide from the tide chart. The measuring instrument used is CastAway CTD with data collection from the boat, as shown in Figure 2.
The salinity data collection points were carried out at 9 points in the river estuary given the notation SL 1 to SL 9 as shown in Figure 3. The salinity data collection coordinates are as follows: SL 1 119° 22'4.631"E, 5° 21'0.683"S; SL 2 119° 22'6.473"E, 5° 20'54.119"S; SL 3 119° 22'4.154"E, 5° 20'45.256"S; SL 4 119° 21'57.623"E, 5° 20'50.098"S; SL 5 119° 21'48.684"E, 5° 20'54.732"S; SL 6 119° 21'50.635"E, 5° 20'48.081"S; SL 7 119° 21'50.499"E, 5° 20'42.192"S; SL 8 119° 21'45.672"E, 5° 20'39.067"S; SL 9 119° 21'40.072"E, 5° 20'36.696"S. Furthermore, the salinity data were interpolated based on their depth, to obtain the salinity distribution at high tide and at low tide. The salinity distribution is then input into the estuary salinity distribution map.

3. Results and Discussion

3.1. Salinity Distribution

Figures 4 and 5 show the Saro Estuary's vertical salinity distribution during High tide and Low tide. At high tide, the patterns displayed, the Saro Estuary mixing mechanism almost all can be classified as well-mixed with salinity range 30-34.7 ppt. Since the distribution of saline water is almost evenly mixed.
from the bottom to the surface, except at SL 1-3, which can be classified is strongly stratified. Well-mixed and strongly stratified Strong tidal forcing and weak river discharge result in vertically mixed estuaries. Mean salinity profiles in diverse estuaries are practically uniform, and mean flows are unidirectional with depth. In Figure 5, there is a significant weakly stratified at SL 4 to SL 9 at SL 1 to SL 3, brackish water dominant at low tide conditions. Weakly stratified or partially mixed estuaries result from moderate to strong tidal forcing and weak to average river discharge [10].

Figure 4. Vertical salinity distribution of the Saro Estuary at high tide

Figure 5. Vertical salinity distribution of the Saro Estuary at low tide

Figure 6-7 shows the horizontal salinity distributions of the Saro Estuary at the tide. It can be seen in high tide, the salinity values scattered up to the point SL 4 sampling location 1.63 km distance from the estuary's mouth. At low tide, the salinity values scattered down to the point SL 7 sampling location 0.48 km.
Figure 6. Horizontal salinity distributions of the Saro Estuary in high tide.

Salinity at high tide, the marked reed color is the most elevated salinity, and the green color indicates the lowest salinity value. The high salinity value spreads 30.28 - 35.28 ppt extending upstream of the river, almost reaching point SL 3, meaning that the influence of saltwater from the sea is enormous at that distance. Meanwhile, from point SL 3 to SL 1, the color marking shows a yellow to green color with a salinity value range of 10.63 - 25.42 ppt, which means that the water condition is brackish water. The salinity distribution pattern of Muara Saro at low tide is based on Figure 7. The marking is green at
the SL 1 sample point, with a salinity value range of 4.01 - 5.45 ppt. It shows that it is freshwater. The sample points SL 2 to SL 9 go to the estuary, marked in green to red with a salinity value range of 5.46 - 18.3 ppt, which indicates the type of brackish water.

Based on Figure 6-7, it shows that there is a significant difference between river salinity values at the tide and low tide, between saline water and brackish water. In contrast, the vertical salinity distribution is also very substantial. At high tide at all points in the depths, it tends to be uniform, with seawater's salinity. At low tide, it has various values for brackish water categories, except at points 6 to 8, due to the influence of the back-barrier region at the mouth of the estuary. Tends to be saline water. Because seawater has a greater specific gravity, it will quickly move upstream through the riverbed. In this case, the freshwater flow above seawater between saltwater and freshwater occurs in the salt wedge. The lower layer's salinity is the same as the salinity of seawater. In contrast, the upper layer is freshwater [3].

3.2. Influence semi-enclosed estuary to Salinity
At here is a narrowing at Saro estuary's mouth, then the presence of barrier berm across the estuary and shallow channels due to sedimentation, so that seawater is trapped in the back-barrier region at during the tide. Water salinity in the Saro estuary's back-barrier area occurs up to point SL 6 or 0.67 km from the estuary to the upstream of the river. As shown in the vertical salinity distribution at point SL6 and SL 8 at high tide, towards low tide, low tide, and towards high tide, are shown in Figures 11 and 12.

![Figures 8. Vertical salinity distribution of the Saro Estuary at point SL6](image)

Figure 8-9 shows that the distribution of salinity in the Saro estuary's back-barrier region can be classified as strongly stratified to well-mixed. At an average depth of 1 m from the water’s surface, a pattern is almost the same, has high salinity. At the SL 6 sample point, the salinity values ranged from 30 - 34.7 ppt, which means seawater, even though the conditions are at the lowest tide. At the SL 8 sample point, closer to the estuary's mouth, the salinity was between 29.5 - 34.7 ppt, lower by 0.5 ppt. Conditions high tide, towards low tide, low tide, and towards high tide cannot flow seawater in the estuary to the sea. Back-barrier regions are affected by ecological processes, such as mixing, deposition,
neutralization, and oxidation and reduction, due to various materials from chemical weathering, plant and soil organic matter, and anthropogenic sewage mixing fresh and seawater. The Back-barrier regions, causing the seawater to be isolated from the main waterway in the estuary, cause high salinity [10] [15]. Because the seawater's salt content is more significant, seawater tends to move on the water's bottom while freshwater is on the surface [3] [16].

Figures 9. Vertical salinity distribution of the Saro Estuary at point SL8

4. Conclusions

Based on the discussion results, conclusions can be drawn; at the mouth of Saro estuary, there is a narrowing due to barrier berm across the estuary, and shallow channels due to sedimentation seawater are trapped in the back-barrier region at during the tide. Water salinity in the Saro estuary's back-barrier area occurs up to point SL 6 from the estuary to the upstream of the river. Distribution of salinity in the Saro estuary's back-barrier region can be classified as strongly stratified to well-mixed. At the SL 6 sample point, the salinity values ranged from 30 - 34.7 ppt, which means seawater, even though the conditions are at the lowest tide. The Back-barrier regions, causing the seawater to be isolated from the main waterway in the estuary, causing high salinity

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