Estuary zone based on sea level salinity in Ciletuh Bay, West Java

D M Tunjung\textsuperscript{1}, S Supriatna\textsuperscript{1*}, I P Ash Shidiq\textsuperscript{1*}, M D M Manessa\textsuperscript{1*}
\textsuperscript{1} Department of Geography, Faculty Mathematics & Natural Sciences, Universitas Indonesia
dennisamt2@gmail.com

Abstract. The Estuary area is an area where there is a mixture of seawater with fresh water from the mainland. This estuary area is unique because seawater mixing with fresh water causes brackish water formation with fluctuating salinity. The fluctuation in salinity is influenced by the depth and shape of the water bed and the season. This study analyzes the estuary area (zone) in Ciletuh Bay, West Java, based on the rainy and dry seasons associated with bathymetry. The salinity value is obtained from Sentinel-2A image processing, using the salinity estimator algorithm's calculation, namely the Cilamaya Algorithm. The results showed that the mapping of the distribution of salinity forms the estuary boundaries, and the variables of rainfall and bathymetry affect the distribution of salinity values. The shallower the water, the lower the salinity level. Conversely, the deeper the waters, the higher the salinity level. The statement is due to the influence of freshwater entry into the sea, which is also related to rainfall (season), affecting fluctuations between saltwater and freshwater.

1. Introduction
The Estuary area is a meeting area between land and sea, a crucial component of a watershed in a complex and dynamic coastal area [1]. The mixing of seawater masses with freshwater makes the estuary area unique, namely by the formation of brackish water with fluctuating salinity [2].

The changes in salinity are influenced by the depth and shape of the water bed and the season. Each water has a different depth and bottom shape, which causes the salinity distribution pattern to be different. Land influence causes the salinity value level, such as mixing with freshwater carried by rivers [3]. Rising in salinity occurs due to the reduced power of freshwater input from the ground [4]. The effect of the entry of freshwater will decrease as the depth of the sea escalates. Upsurge rainfall in the tropics associated with global climate change can also affect the metabolic conditions' dynamics in the estuary surface water [5]. Estuaries in temperate and tropical climates are influenced by the source of CDOM (chromophoric dissolved organic matter) rivers mixed with seawater, indicating a negative relationship between CDOM and its salinity levels [6].

Knowledge of waters zoning needs to be studied to preserve the estuary area. Determining the zoning of waters by direct measurements in the field is difficult, so sensing data is much more effective. Sea surface salinity measurements can be identified using remote sensing technology. Remote sensing technology is the most effective method for observing coastal formations and the seafront [7]. Secret sensing satellite techniques can be applied to monitor salinity in coastal environments. That freshwater
discharge not only affects salinity levels and patterns under normal conditions but is also very important in restoring salinity patterns to normal conditions after storm disturbances [8].

This study analyzes the estuary area (zone) in Ciletuh Bay, West Java, based on the rainy and dry seasons associated with bathymetry. Ciletuh Bay is an area with high eel resources; eel is a type of fish that mostly lives in the tropics [9-11]. Salinity affects these organisms' habitat, seawater tides, oxygen content, water currents, waves, freshwater disturbances, and bathymetry [12]. Estuary zoning can be determined by analyzing the distribution of salinity [13].

2. Methodology

The research location is on the south coast of Java Island to be precise 106°03’8"E - 106°05’0"E and 07°01’0"S - 07°02’2"S. This research is based on a spatial and temporal approach based on the interpretation of satellite images processed by Sentinel-2A imagery based on wet months and dry months. The Sentinel-2A image used is the Sentinel-2A level 1C image recorded on April 9th, 2020, and July 18th, 2020. Estuary zoning is determined by analyzing its salinity distribution using a salinity estimator algorithm, namely the Cilamaya Algorithm [14]. The Cilamaya algorithm was generated from research on the use of remote sensing technology through the use of multi-temporal data from Sentinel 2A satellite imagery to map the surface salinity distribution of Muara Cilamaya (North Coast of Java Island) [14] with the algorithm equation as follows:

\[
\text{Salinity (ppt): } 139.566970 + (86.21318 \times LN \text{ Band 2}) - (24.62518 \times LN \text{ Band 4})
\] (1)

Where:
- LN = Natural Logarithm
- Band 2 = Blue Waves
- Band 4 = Red Waves

The salinity value generated from the algorithm is classified based on the salinity classification Venice System (1958) [15]. The amount less than 0.5‰ placed in the freshwater classification or Limnetic zone, 0.5-5‰ placed in the Mexo-oligohaline classification, 5-18‰ placed in the Mexo-mesohaline classification, 18-30‰ placed in the Mexo-polyhaline classification, 30-40‰ placed in the Euryhaline classification, more than 40‰ in the Hyperhaline classification. Estuary waters have a lower salinity than oceans and higher than freshwater. The range is from 5 to 30 ppt [13]. The salinity value is dynamic, which always changes due to physical phenomena such as rainfall, sea, tidal currents, and sea level so that these factors can affect the salinity value around [9]. In this study, estuary zoning areas based on the rainy season and the dry season is analyzed correlated with bathymetric data. The season determination is based on Oldeman classification, which states that a wet month is a month with rainfall > 200 mm/month, and a dry month is a month with precipitation < 100 mm/month [2,14].

3. Results and discussion

In the Ciletuh estuary, the monthly average rainfall in 2020, January to May 2020 has an average monthly rainfall above 200 mm/month, which indicates the rainy season, while June to July 2019 has a moderate rain monthly below 100 mm/month, which marks the dry season [16] (figure 1).

Figure 1. Graph of average monthly rainfall in January – July 2020.
The Cilamaya algorithm was applied to determine the distribution of surface salinity during the rainy season (April 9th, 2020) and the dry season (July 18th, 2020) in the Ciletuh estuary area. Statistical methods were tested and produced that the sea surface's salinity could be predicted accurately through remote sensing with more than adequate accuracy for many physical and ecological applications [17]. Changes in Spatio-temporal surface salinity in the sea are affected by freshwater flow analyzed using Meris imagery, MODIS, and river discharge data [18].

Figures 2, 3, and 4 show the calculations using the Cilamaya algorithm model on the Ciletuh estuary to distribute sea surface salinity data.

**Figure 2.** Graphic distribution of sea surface salinity of Ciletuh Estuary with Cilamaya Algorithm (a) April 9th, 2020 (rainy month), and (b) July 18th, 2020 (dry month).

**Figure 3.** The results of the analysis of sentinel 2A satellite images to determine the salinity level using the Cilamaya algorithm. In the rainy season in 2020, the salinity value obtained is in the range of 0.5 to 31 ppt. In the dry season in 2020, the salinity value obtained is from 0.5 to 33 ppt.

**Figure 3.** Distribution of Ciletuh Bay salinity based on Cilamaya Algorithm on (a) April 9th, 2020 (rainy month), (b) July 18th, 2020 (dry month).
Figure 4. Zoning Salinity of Ciletuh Bay Based on Cilamaya Algorithm on (a) April 9th, 2020 (rainy month), (b) July 18th, 2020 (dry month).

Based on estuaries’ zoning determination, April and July 2020, have four classes [15], namely Mexo-oligohaline, Mexo-mesohaline, Mexo-polyhaline, and Euryhaline. However, in the dry month, the euryhaline zone is more expansive than in the rainy month (table 1). In the dry month, the euryhaline site formed is mostly near the coast of Ciletuh Bay (figure 4).

| Zone             | April (Rainy Month) | July (Dry Month) |
|------------------|---------------------|------------------|
| Mexo-oligahaline | 1.06 Ha             | 11.64 Ha         |
| Zone               | April (Rainy Month) | July (Dry Month) |
|-------------------|---------------------|------------------|
| Mexo-mesohaline   | 181.10 Ha           | 277.62 Ha        |
| Mexo-polyhaline   | 2748.12 Ha          | 2625.12 Ha       |
| Euryhaline        | 39.84 Ha            | 55.75 Ha         |

The lowlands occupy around Ciletuh Bay and the Cimandiri River watershed, with slopes of 2° - 10° apart [19]. The characteristics of the seabed slopes around the coast are dominated by flat to almost flat. Ciletuh Bay has a depth variation in the range of 0-50 m (figure 5).

At a depth of 5 m, both during the rainy and dry seasons, salinity distribution in Ciletuh Bay is dominated by salinity with a range of values between 0.5 to 5 ppt (Mexo-oligohaline Zone) and 5 to 18 ppt (Mexo-mesohaline Zone) near the coast of Ciletuh. At a depth of > 10 m, both in the rainy season and the dry season, salinity distribution in Ciletuh Bay is dominated by salinity with a value range between 18 to 30 ppt (Mexo-polyhaline zone), which spreads more offshore.

![Figure 5. Bathymetry of Ciletuh Bay.](image)

Figure 5. Bathymetry of Ciletuh Bay.

![Figure 6. Cross-sectional of Sea Region at Ciletuh Bay on (a) April 9th, 2020 (rainy month), (b) July 18th, 2020 (dry month).](image)

Based on these results, apart from the rainy season and the dry season, it was found that the depth level affects the salinity distribution in Ciletuh Bay. The depth and shape of the bottom of the waters are different, causing the salinity distribution pattern to be different [3]. The shallower the water, the lower the salinity level. Conversely, the deeper the waters, the higher the salinity level. In shallower waters, freshwater intrusion can spread to the bottom of the water, resulting in low salinity [20]. This increase in salinity is due to the reduced influence of freshwater input from land [4]. The effect of freshwater entry into the sea is also influenced by the amount of rainfall (season). Freshwater that enters the waters...
has a lower water mass so that the water mass will be above the water mass with high salinity [21]. In
the rainy season, the amount of rainfall in this month is higher than in the dry season or included in the
dry season; this rainfall will affect the fluctuation between saltwater and freshwater. This rainfall affects
the discharge of river water that enters the es
tuary. The salinity value near the river mouth tends to be
lower, and the more offshore the salinity value is higher due to the reduced influence of freshwater from
the river.

4. Conclusions
The salinity fluctuation in the Ciletuh Bay estuary is influenced by
the season and water depth. The
shallower the water, the lower the salinity level. Rainfall (season) also affects the salinity distribution
due to the amount of freshwater that enters. Conversely, the deeper the waters, the higher the salinity
level. The low salinity area (0.5–5 ppt, 5–18 ppt, and 18–30 ppt), which dominates at a depth of 0 - 40 m, is the Ciletuh Bay area. The Mexo-polyhaline zone dominates the estuary of Ciletuh Bay.

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