Cilamaya estuary zonation based on sea surface salinity with 2 Sentinel-2A satellite imagery

S Kaffah, Supriatna and A Damayanti

Department Geography, Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Indonesia, Depok, 16424, Indonesia

Corresponding author’s email: ysupri@sci.ui.ac.id

Abstract. Estuaries act as transitional areas on the coastal zone that connect highly saline ocean environments with fresh river systems. This dynamic aquatic ecosystem is created by deep fluctuations in water quality and salinity levels. Cilamaya estuary supports a highly diverse marine ecosystem that is underutilized due to knowledge deficiencies of its variable rates of salinity. The aim of this study is to show the difference zone of estuary based on the sea surface salinity in the different time, so that Cilamaya Estuary areas can be utilized optimally for resource management. Sea surface salinity is obtained using algorithmic calculations based on the Sentinel-2A imagery. Salinity levels are studied based on the rainy and dry seasons. The higher salinity occur on the dry seasons, while on the rainy seasons have a lower salinity. Estuary areas experience 0.5-30 %o salinity placing it within the three zoning classes of the Venice System; Mexo-oligohaline; Mexo-mesohaline and Mexo-polyhaline.

Keywords: Estuary zonation, Cilamaya, sea surface salinity, Sentinel-2A imagery

1. Introduction

Estuary is a transitional area on the coastal zone that connect the river environment and marine environment, and thus this area is influenced by the character of river (e.g.: the amount of fresh water and sedimentation carries) and by the character of the ocean on the other side (e.g.: tides, waves, salinity and currents) [1]. This thing then make estuary area is included in the category of naturally productive ecosystem [2]. Estuary is a particular and complex ecosystem which contains of diverse kinds of habitats, especially fish. The function of estuary for fish life is as a spawning area, parenting area, food storage, and migration paths [3].

Estuary area is a dynamic aquatic system. Mixed water between fresh water and high-saline water make this area unique to the formation of brackish water with salinity fluctuation [4]. This fluctuating level of salinity can be cause by several factors, there are rainfall, currents, and tides [5]. This will affect to water quality, water utilization, agricultural, and also environment and aquatic ecosystem in general, especially in estuary area [6].

Cilamaya estuary is an area with a high potential of marine ecosystem richness, which consist of squid, shrimp, crab, and fish [7]. To explore the potential of marine ecosystems in this area, knowledge of the ocean is needed, especially the estuary area. To find out the estuary area is to know the zoning of the estuary area. The distribution of salinity is one of the parameters that can be used in determining the zone of estuary [5].
Along with the technological development, salinity can be analyzed through remote sensing [8]. Wouthuyzen et al. have mapped the distribution of surface salinity of Jakarta Bay indirectly through ocean color sensing (CDOM) with Landsat 7-ETM imagery [9]. Supriatna et al. [4] also have mapped the distribution of surface salinity indirectly with Landsat 8-OLI in Cimandiri Estuary. In this study, the distribution of surface salinity obtained by using Sentinel-2A Imagery.

Sentinel-2 Imagery marks 13 spectral bands, with range from visible and near-infrared (NIR) to the short-wave infrared (SWIR) domains, with the range of ground spatial resolutions from 10 to 60 m [10]. It give the benefits in the global monitoring by giving the availability of the endurance of the subsequent project with the likelihood to resolve complicated and tiny-scale features near the coast areas [11]. Sentinel-2A just released in November 2015, so there have not been many studies especially about surface salinity using this imagery. According to this background, this research focused in determining the salinity area (zone) using remote sensing technology. The results of this study are used to observe the algorithm equation model from in-situ data and remote sensing processes, so that it can be used to determine the estuary zone, that the boundary waters of Estuary Cilamaya and its surroundings can be utilized optimally for resource management.

2. Method
This research was conducted in Cilamaya Estuary, Sub District of Cilamaya Wetan, Karawang, Jawa Barat. It is located at 6°9’59” – 6°13’30” S dan 107°35’12” – 107°39’ E. The Sentinel-2A imagery used was 48MYU, at the recording of April 15th, 2018, March 31st 2018, and September 27th, 2018. Sea surface salinity in-situ data was taken with refractometer. Sample points of in-situ data is shown in figure 1. The result of the in-situ data that have been obtained are then processed together with Sentinel 2A-Imagery to obtain a new algorithm for estimating surface salinity. The results of the algorithm calculations are then used as a reference to see the distribution of surface salinity at different imagery recording times.

2.1. Atmospheric and radiometric correction
Radiometric correction aims to change the DN (Digital Number) to the ToA (Top of Atmhosperic) radians or reflectance using parameters available in image metadata. Furthermore, geometric correction is a process to correct pixel with a wrong coordinates [12]. Sentinel-2A imagery which available is Level 1-C, meaning it has been corrected geometrically and radio metrically in the form of To a reflectance values [13]. So that, the reflectance and geometric value does not need to be proceeded first and immediately conducts atmospheric correction. Atmospheric correction for Sentinel-2A images uses the Sen2Cor plugin found in ESA SNAP 5.

2.2. Sea surface algorithm
In obtaining a new equation or a new algorithm for the distribution of surface salinity, the spectrum of visible light is used. The used of visible light is because the measurement of sea surface salinity with remote sensing can be obtained from the translation of sea colour data. Sea colour is defined as electromagnetic waves coming out of the surface of the water at visible wavelengths (0.4–0.7 μm) [14]. In Sentinel 2A imagery, the visible light spectrum appears to be Band 2 (blue waves), Band 3 (Green Waves), and Band 4 (Red Waves) [13]. The first thing to do in obtaining this algorithm is to get the reflect value of each pixel in the sample point in the visible light spectrum. It can be done by using Extract Multi Value to Points tools on ArcGIS. After that, regression test is performed. The results of the test then become a new algorithm for estimating the distribution of salinity using Sentinel 2A Imagery.

2.3. Estuary zoning
Estuary zoning was obtained by classifying the value of salinity distribution based on the classification (table 1) [15]. Sea Surface Salinity distribution is obtained by using Sentinel 2A image processing
with the algorithm equation that has been made. Before calculating the imagery with algorithm, the separation of land and water is done first. After that, enter the algorithm equation that has been obtained by using the Raster Calculator tools on ArcGIS. In this study, the estuary zoning was studied based on different seasons, rainy and dry seasons. The determination of the season refers to Oldeman which states that wet months are months with rainfall > 200 mm/month, and dry months are months with rainfall < 100 mm/month [16]. To determine precipitation in this area is used from BPS data which shown in figure 2 [17].

3. Results and discussion

3.1. Sea surface salinity algorithm
The result of regression test show that the band combination that has highest R2 value is band 2 and band 4. So in this study, only band 2 and band 4 that are used to obtained a new algorithm for sea surface salinity. The relationship between reflectant value from Band 2, Band 4 and in situ data on September 27th, 2018 shown in figure 3.

Calculation results of the equation or new algorithm through regression analysis. The result obtained by using regression analysis shows R value is 0.79, or the influences from each variable against the salinity is 79 %, with significance value < 0.01. The new algorithm is named “Cilamaya Algorithm”. This algorithm then can be used to identify distribution sea surface salinity with

![Figure 1. Distribution of sample points.](image)

| Salinity ‰ | Zona                      |
|------------|---------------------------|
| < 0.5 ‰   | Limnetic (freshwater)     |
| 0.5–5 ‰   | Mexo-oligohaline (brackish)|
| 5–18 ‰    | Mexo-meshohaline (brackish)|
| 18–30 ‰   | Mexo-polyhaline (brackish)  |
| 30–40 ‰   | Euryhaline (seawater)      |
Sentinel 2A-imagery, especially in Cilamaya Estuary. The new equation to obtain sea surface salinity with Sentinel 2A-imagery is;

\[ Y = 139.566970 + (86.213184 \times \ln \text{Band 2}) - (24.625188 \times \ln \text{Band 4}) \]  \hspace{1cm} (1)

where, \( Y \) = Salinity, Band 2 = Blue Waves, Band 4 = Red Waves.

3.2 Estuary zonation based on sea surface salinity

The algorithm model that has been obtained is then applied to determine the distribution of surface salinity during rainy seasons (March 31\textsuperscript{st}, 2018) and dry seasons (April 15\textsuperscript{th}, 2018 and September 27\textsuperscript{th} 2018). From the results obtained that in dry seasons, the level of salinity in the Cilamaya estuary is higher than the level of salinity in the rainy seasons. The distribution of sea surface salinity in rainy seasons majority scattered on range 18–25 ppt, but in the rainy seasons the range is between 30–35 ppt. It is caused by the amount of rainfall in the rainy seasons that can carry the freshwater from river into the estuary area. Whereas in dry seasons the amount of rainfall is low so that fresh water from the river is not carried to the estuary which cause a high level of salinity in this area. The graphic and distribution of the distribution of sea surface salinity of Cilamaya Estuary as shown in figure 4 and figure 5.

![Figure 2. Monthly precipitation of Cilamaya Wetan](image)

![Figure 3. Relationship between in situ data of sea surface salinity on September 27\textsuperscript{th} 2018 with (a) Band 2, and (b) Band 4 Sentinel 2A imagery.](image)
Salinity distribution values are then classified to get the estuary zoning area. The classification results with Venice System classification are shown in figure 6. From the results of the distribution of salinity in figure 5, it can be seen that in the rainy seasons the salinity is quite fluctuating, which can affect the estuarine zoning. On March 31st, 2018, there were 3 estuary zones namely
Figure 6. Zonation of Cilamaya Estuary on (a) March 31st, (b) April 15th, and (c) Sept 27th 2018.

Mexo-mesohaline with an area of 269 ha, Mexo-polyhaline with an area of 3775 ha, and Euryhaline with an area of 5088 ha.

Contrast with the result on the rainy seasons, figure 4 and 5 showed that on the dry seasons the salinity level is relatively stable. On September 27th 2018, there are only 2 estuary zones, namely Mexo-polyhaline with an area of 194 ha and Euryhaline with an area of 8937 ha. The same thing happened on April 15th, 2018, the results of classification there were only 2 estuary zones, Mexo-polyhaline with an area of 718 ha and Euryhaline with an area of 8413 ha. This indicates that on dry seasons, there are only 2 estuary zones, which are Mexo-polyhaline and Euryhaline, with the mexo-polyhaline region being tighter than Euryhaline.

From the results, it was found that the closer the sea, the more stable the salinity level is, and it belongs to Euryhaline and Hyperhaline zone. It is because the distance is further from the river, so that there is just little or no fresh water carried by the river into this zoning. On the other hand, the closer to the land, the more fluctuating the salinity level is, and it belongs to Mexo-mesohaline and Mexo-polyhaline zone. As with the explanation of distribution of salinity, the difference in estuary zoning between rainy and dry seasons is caused by the amount of fresh water entering into the ocean waters during the rainy seasons compared to the dry seasons.

4. Conclusion
Based on the results of this study, the R2 of model is 0.79, with significance value < 0.01. It was found that the Sentinel-2A imagery can be used to determine the distribution of surface water salinity using the obtained algorithm. The algorithm is named Cilamaya Algorithm. In the rainy season, the level of salinity is lower than in the dry season. Furthermore, the variety of estuary zoning is more varied in the rainy season than in the dry season. It is caused by the amount of fresh water entering into the ocean waters during the rainy season is higher compared to the dry seasons. Based on several analysis, found that estuary has a 3 types of zonation, there are Mexo-mesohaline, Mexo-polyhaline, and Euryhaline. This zonation can be used as a reference for resource management in the estuary area.

Acknowledgments
This work was financially supported by Universitas Indonesia under research grant PITTA 2018 with grant contract number contract number 2236/UN2.R3.1/HKP.05.00/2018.
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