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Algorithm Model for the Determination of Cimandiri Estuarine Boundary using Remote Sensing

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ABSTRACT. Estuarine zone is a typical ecosystem, because this areacontinuously receives organic materials from the river and sufficient light illuminating the water. It has also salinity level from *mesohaline* to *eurihaline*. The zone must be protected from waste discharge (liquid or solid) coming from domestic and industrial activities along the riverside. The determination of estuarine boundary still cannot be confirmed until now due to the transformation of existing water dynamics changes over time according to the season changes. One of technologies in the determination of estuarine boundary is using remote sensing technology.The advantage of this technology is on its temporal and spatial resolution. Some research have been done in tropical water of Northern Java Coast and Makassar Strait, however none has been done in tropical high seas such as in Cimandiri Estuary. The algorithm model resulted from this research is different with existing algorithm. Estuarine boundary will be made based on salinity level. This model can also be used for different area and used by stakeholder and local government in order to protect estuary in sustainable way.

INTRODUCTION

Indonesian archipelago has many estuaries because of a lot of river, wetlands, coastal, gulf, and shallow sea. Coastal areas in Java, Sumatra, Kalimantan, and Papua which have high rainfall cause a part of the sea around the mainland and will become a part with salinity differences. Estuary can be divided in two types, positive and negative estuary [1]. Positive estuary is an estuary threat which has more water from river and rainfall than evaporated water. Therefore, the salinity where is surface lower than the ocean, while negative estuary is vice versa plenty of evaporation than the existence of water from stream and rainfall, so it is called hyper saline. The increasing of storm in tropical region related with global climate change can affect metabolism dynamics of surface water in estuary [2].

Interaction between fresh water and salt water (estuary area) determines the water circulation and mixing process that raised by the difference of the density between two types of water. The density of sea water depends on salinity and temperature, though the range of salinity in estuary is relatively large and the temperature is low. Therefore, the temperature has a slight effect against the density of sea water. This condition generally causes the organism diversity to diminish in this region [3].

Estuary area is usually formed in the end of the great rivers to the sea which have a flat coast. Mixed water between fresh water and seawater make this region unique to the formation of brackish water with salinity fluctuation. River stream continuously carry minerals, organic materials, and sediments from upstream to the end of the river (sea), and the reverse flow of water from the sea to the estuary due to ocean current. The accumulation of nutrient will affect productivity in the territorial water of estuaries. Therefore, the biological productivity in estuaries is higher (1500g/m2/year) than productivity in the ocean (125 g/m2/year) and beside productivity in freshwater (400 g/m2/year) [4].

Estuary area is an important habitat for a large amount of fish and shrimp to breed that, some fish also migrate to the estuary area for spawning. Another characteristic that causes this ecosystem becomes important is, on its role as a nutrient trap, but if the ground water has been pollute, not only nutrients but also pollutants, such as oil, pesticides, and heavy metals [5]. Supriharyono [3] suggested that the physical and chemical conditions which could affect

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organisms in the estuarin eecosystems such as salinity, temperature, and sediment. York *et al.* [6] stated that food chain in the estuarine area of San Francisco is less efficient than previous estimates, so providing low support for areas with a high tropical elements. Food chain in this case is not efficient (low) with a high abundance of fish, including at the mouth of delta which have a low salinity zone.

Recently, remote sensing technology still cannot detect the content of salinity in the water. This technique that can draw boundary line of salinity by finding the association of salinity that can be detected by satellite imagery. Estuarine boundary which ahead to the ocean can be associated with the sediment in estuaries, because the sediment is an outcome from the influence of the river that has low salinity (fresh water) so there is a sediment area with brackish water salinity. The boundary on land can be associated with mangrove land cover and other agricultural land, because the habitat of plants is located in brackish area.

Lenkopane *et al.* [7] revealed that Salinity fluctuations occur on estuary due to the impact of tidal effect. Significantly, interaction between salinity value, stream dynamics, and groundwater zone at aquifer area of estuary can change easily than the dynamics at riparian zone (the meeting zones of land and sea) [7].

Based on research background above, this research focused in determining salinity area (zone) using remote sensing technology. These results were used to observe algorithm equation models from field data and remote sensing image processing.

This research was conducted at Cimandiri Estuary, Sukabumi, West Java. Geomorphologically, Cimandiri Estuary is considered as estuaries formed by tectonic processes combined between the formation of Cimandiri Fault and Pelabuhanratu Bay. From the hydrographic point of view, Cimandiri Estuary is classified as partially mixed estuary or medium stratification, due to the number of inflow stream from river and the tidal movement from ocean are nearly equal.

METHODS

Mantas *et al.* [8] stated that Satellite image of Landsat-7 ETM+ (Enhanced Thematic Mapper Plus) can be used to estimate the concentration of chlorophyll-a, turbidity, and salinity. Reflectance values and in situ data are automatically recorded to be sampled. ETM data is also used to identify local water colour index and to see the relative difference on the reflection value of the three band spectrum in that range.

Estuarine boundary can be determined by a statistical model to see the difference in daily surface salinity at a resolution of 1 km in the Chesapeake Bay analyzed by MODIS (Moderate Imaging Spectroradiometer)image. Eight statistical method were tested and the result showed that the sea surface salinity can be accurately predicted by remote sensing in which the accuracy result is more than adequate for manyphysical and ecological applications [9]. Based on the results of his research, Qing *et al.* [10] described that the spatio-temporal changes in sea surface salinity was affected by the flow of fresh water analyzed using MERIS (Medium Resolution Imaging Spectrometer), MODIS, and river flow data. In the area of the Yellow River, China, it was found that the biggest influence on the change of surface salinity was near river mouth and the relatively small impact was on the region away from the river mouth.

In this study, data processing will be started after the data field and the results of Landsat 7 ETM+ or Landsat 8 OLI (Operational Land Imager) are achieved. Processing of the data in this study includes:

1. The first step: is conducting remote sensing image data processing in the laboratory of remote sensing using software Envi Ver. 4, which identifies sedimentation using remote sensing data from the algorithm of Total Suspended material (TSM). The results of this image data processing are classifications of salinity level, which are 0-16 ppt, 16-30 ppt, and>30 ppt. These results are transformed from image data (raster) into digital maps (vector). Besides the algorithm of Wouthuyzen [11] is also used by the following Equation 1:

$$Salinity(ppt) = -142.72(-61{,}128X3 + 79{,}129X2 - 34{,}022X1 + 4.885) + 32.702 \quad (1)$$

(Where: X = blue chromaticity = (Band-1 / (band-1 + band-2 + band-3))
Landsat images taken started on February 17, 2014 until August 15, 2015. Eight landsat images in 2014 and six in 2015.

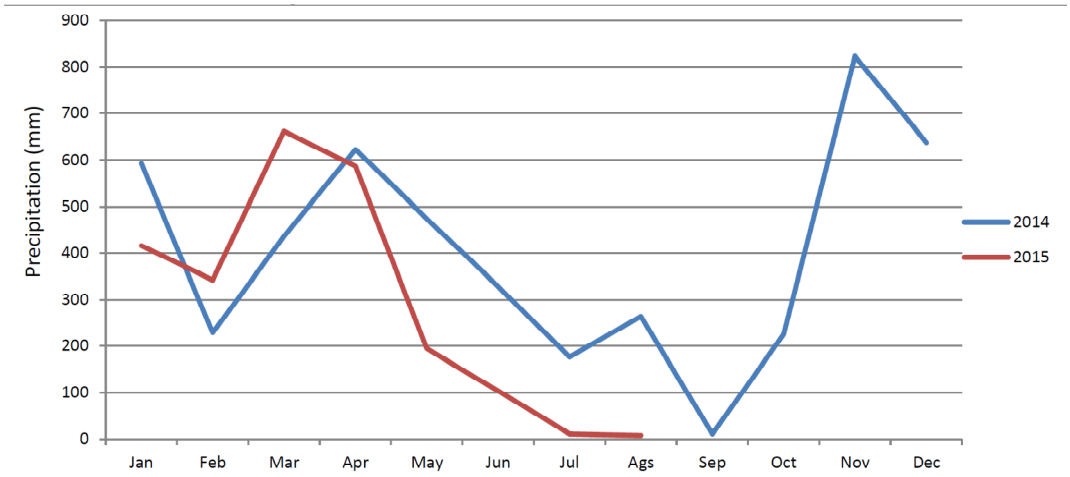


FIGURE 1. Average monthly rainfall at stations around the Cimandiri River basin (Jampangkulon Station, Selabintana, Cisolok, and Sukabumi)

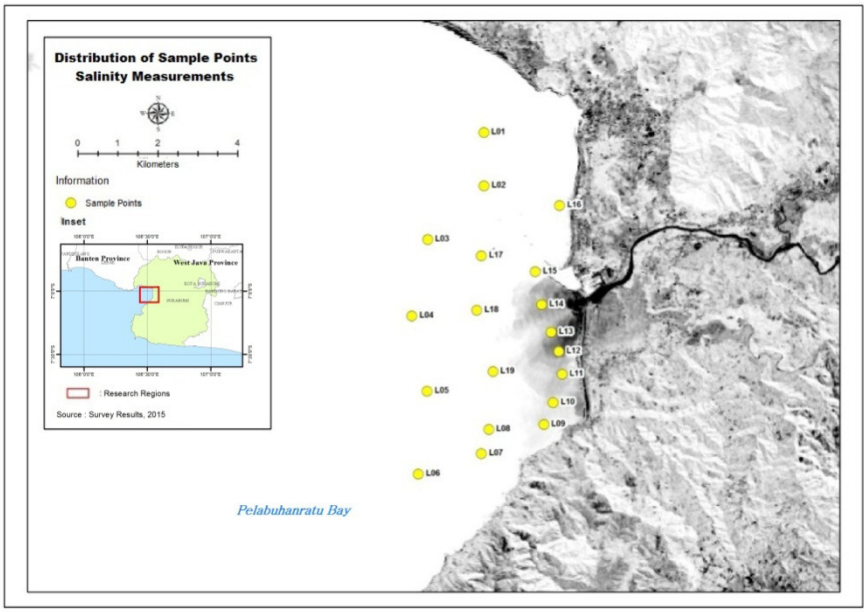


FIGURE 2. Distribution of Sample Points

2. The second step: is using field sampling tabulation. Surface water salinity data is processed into field result tables. The same classifications as above (salinity 0-16 ppt, 16-30 ppt, and> 30 ppt) were made on the table. The final result of this processing is map on salinity. The survey was conducted during the rainy season (in the wet month) and dry season (in the dry month). The first survey was conducted on June 12, 2015 and the second survey was conducted on August 15, 2015. On June 12, 2015, monthly rainfall still reaches 133.33 mm at rainfall stations around Cimandiri River basin. On August 15, 2015, it's only 8 mm of rainfall, then the first field sampling (dated June 12, 2015), is still in the wet months (rainy season) and the second field sampling is in the dry months (dry season). More clear explanation can be seen in Fig. 1.
3. The third stage: is processing data from the results of image processing and processing the field results to get Cimandiri Estuarine limit. This processing produces new algorithms with the approach of the field surveys results and it can be compared to the existing algorithm. So we get the salinity zone of the tropical region estuary on the southern coast of Java. The new algorithm is used to analyze the level of salinity in the waters of all the processed images (February 17, 2014 - August 15, 2015) as shown in Fig. 2.

TABLE 1. Distribution of Sample Points Location

No. Sample	Longitude (x)	Latitude (y)	Salinity in situ (ppt) June 12, 2015	Salinity in situ (ppt) August 15, 2015
L01	10,652,089	-699,051	31.0182	31.5031
L02	10,652,100	-700,272	31.2174	31.2191
L03	10,650,822	-701,493	30.1695	31.0628
L04	10,650,468	-703,237	28.9372	31.9325
L05	10,650,822	-704,947	30.4826	31.9146
L06	10,650,630	-706,835	30.0777	31.1896
L07	10,652,058	-706,360	30.5525	31.8135
L08	10,652,225	-705,809	29.7173	31.1864
L09	10,653,474	-705,699	30.3451	31.5219
L10	10,653,684	-705,192	23.3605	30.0891
L11	10,653,886	-704,552	23.1663	29.6582
L12	10,653,807	-704,035	23.1845	26.2866
L13	10,653,632	-703,599	24.1899	25.0249
L14	10,653,416	-702,965	23.3227	26.8522
L15	10,653,268	-702,222	25.3723	28.2619
L16	10,653,815	-700,710	31.2395	31.2169
L17	10,652,045	-701,858	31.2064	31.2089
L18	10,651,942	-703,101	26.0233	29.9864
L19	10,652,315	-704,491	25.0215	29.1568

Source: Field Survey, 2015

4. The end stage is zoning the estuary limit during the rainy season and the dry season by performing overlay analysis on Landsat 7 ETM+ image.

RESULTS AND DISCUSSION

The results obtained by using the algorithm of Wouthuyzen [11] showed a mismatch between salinity values obtained from satellite image and measurement results in the field. The possible cause is differences in the geographical situation of the sites. The algorithm of Wouthuyzen [11] is used in closed waters such as Jakarta Bay, while Pelabuhanratu Bay is the open water facing the Hindia/Indonesian Ocean. Because of that, we need a new equation for measurement of salinity resulted from Landsat 8 OLI in Pelabuhanratu Bay in order to be more precise compared to the result from field survey.

In acquiring new equation or new algorithm, reflectance values of each pixel of the sample points on the band 2, 3, and 4 must be calculated first. The regression values of these reflectance values are then calculated in order to obtain a new algorithm for measuring salinity. After obtaining the new algorithm, the salinity predictive value of each image starting from the date of February 17, 2014 until August 15, 2015 need to be calculated.

Sample points in the Table 1 format were changed into spatial digital format so that it can be overlaid with the image. Conversion of digital number band 2, 3, and 4 from Landsat 7ETM+ & 8 OLI Image to be an image reflectance using the following Equation 2 below:

$$\rho\lambda' = M\rho Qcal + A\rho \tag{2}$$

where:

$\rho\lambda'$ = TOA reflectance has not corrected by angle of the sun
$M\rho$ = Scale Factor (Band-specific multiplicative rescaling factor)
$A\rho$ = Additional Factor
$Qcal$ = Pixel Value (Digital Number)

Calculated results ofeach pixel reflectance values in band 2, 3, and 4 on sample points as shown in Table 2. Calculation results of the equation or new algorithm through regression analysis. The result obtained by using regression analysis shows r value is 0.821 or the influences from each variable against the salinity are 82%. The result of significance value is less than 0.05 as shown in Table 3, so this equation can be used to analyze or describe salinity variables. So, the new Equation 3 obtained is:

$$Y = 29{,}983 + 165{,}047B2 - 260{,}227B3 + 2{,}609B4 \tag{3}$$

where:

Y = Salinity (ppt)
B2 = Blue waves
B3 = Green waves
B4 = Blue waves

The new algorithm is called as "Cimandiri Algorithm", it is used to calculate salinity values in Pelabuhanratu Bay, so the result of salinity on each samples point approaching the real values from the result of field measurements. Crop the image that has been calculated for salinity values which suitable with research regions in Cimandiri Estuary as shown in Fig. 3.

Reclassifing the salinity values to be classified with 1 interval. Starts from 15 that is the smallest value untill the value higher than 30‰. Salinity with the value 15 is the start salinity value for brackish area. Meanwhile, the salinity over 30 including to sea water category.

TABLE 2. Reflectance Values of Sample Points

Code	B2	B3	B4
L01	0,07780	0,04672	0,02418
L02	0,07732	0,04508	0,02356
L03	0,07972	0,04898	0,02622
L04	0,08366	0,05466	0,03030
L05	0,08750	0,06218	0,34280
L06	0,07980	0,05048	0,28420
L07	0,08470	0,05820	0,03108
L08	0,08580	0,06130	0,33180
L09	0,08752	0,07570	0,04202
L10	0,08738	0,07702	0,04506
L11	0,08688	0,07784	0,05018
L12	0,08740	0,08180	0,06280
L13	0,08730	0,07900	0,06016
L14	0,08774	0,07834	0,05880
L15	0,08650	0,06608	0,03870
L16	0,08550	0,06500	0,03212
L17	0,08330	0,05354	0,02944
L18	0,08804	0,06774	0,03866
L19	0,08800	0,06774	0,03736

Source: Interpretation Results, 2015

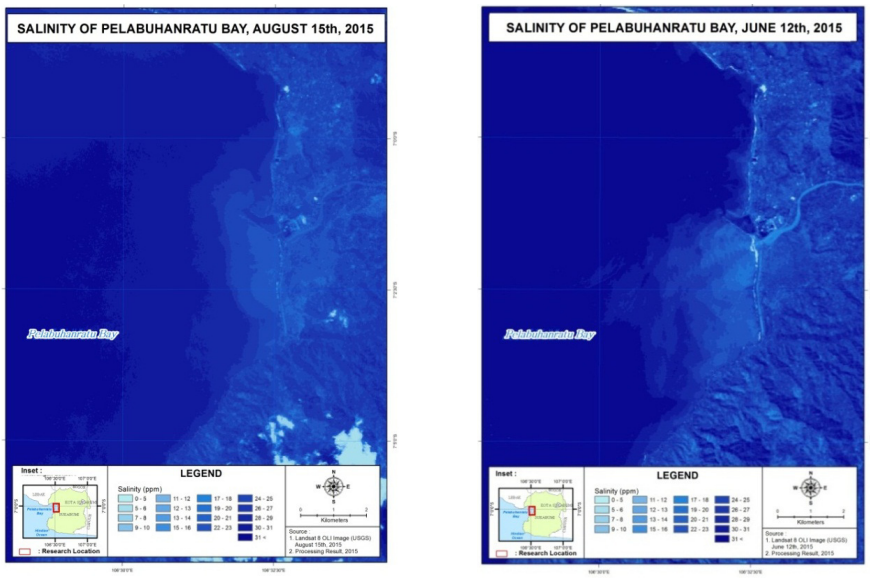
TABLE 3. Pixel Classification Values (Value)

No	Class	Pixel Classification Values (Value)
1	0 - 15	1
2	15-16	2
3	16-17	3
4	17-18	4
5	18-19	5
6	19-20	6
7	20-21	7
8	21-22	8
9	22-23	9
10	23-24	10
11	24-25	11
12	25-26	12
13	26-27	13
14	27-28	14
15	28-29	15
16	29-30	16
17	30 <	17

Source: Interpretation Results, 2015

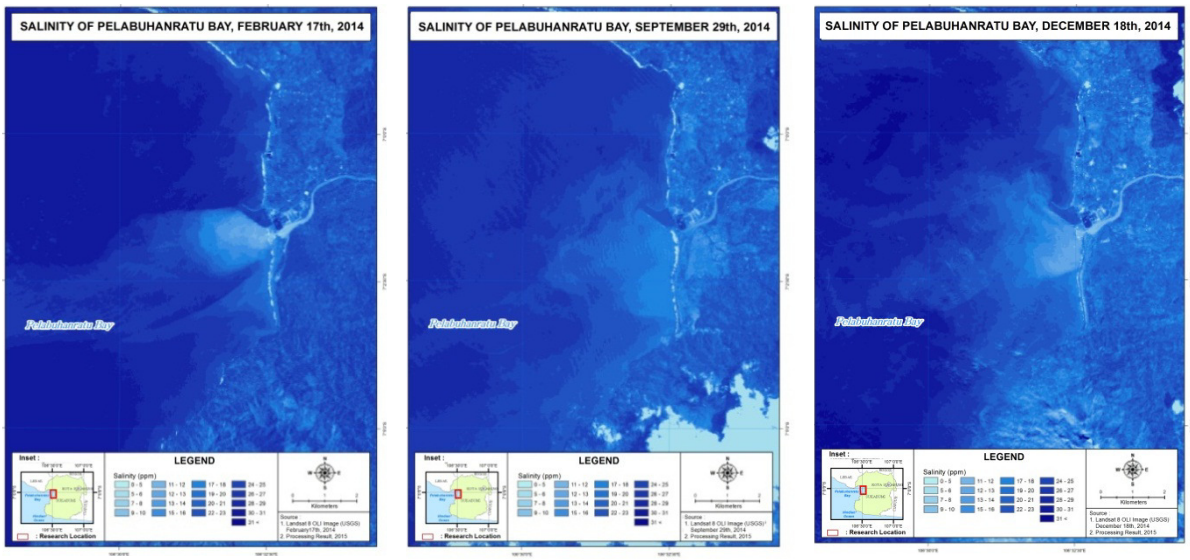
Here are some of the image processing results on the date when the rainy season of 2014 (Fig. 4(a)), the end of the 2014 rainy season, dry season of 2014 (Fig. 4(b)), the rainy season in 2014 to 2015 (Fig. 4(c)), the end of the 2015 rainy season, and the dry season in 2015 (Figs. 5(a) and 5(b)).

The average ofsalinity in each area is <16 ppt in 179.19 ha, and 16-30 ppt in 926.5 ha of area. Details per season, in rainy season, waters area with salinity <16 ppt is 339.89 ha and waters area with salinity between 16-30 ppt is 1,083.67 ha. In dry season, waters area with salinity <16ppt is 9.24 ha and water area with salinity between 16-30 ppt is 384.67 ha. In rainy season, the water area with salinity <16 ppt and 16-30 ppt wider than during the dry season. It is caused by the amount of insipid water entering into the larger waters during the rainy season compared to the dry season. More clear explanation can be seen in Fig. 6.



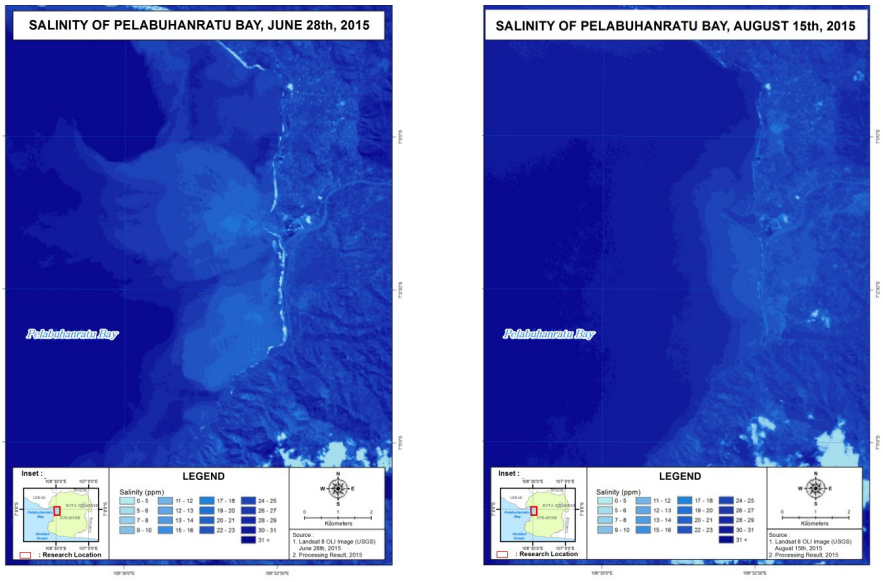
(a) (b)

FIGURE 3. Salinity level from image processing results using Cimandiri Algorithm On June 12, 2015, (b) August 15, 2015



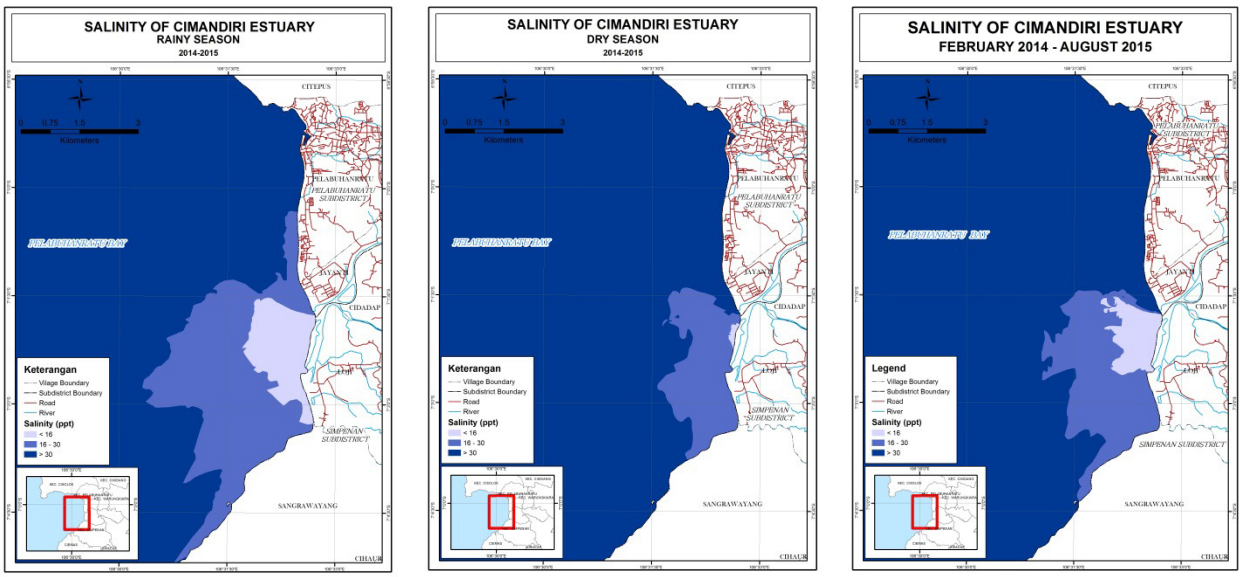
(a) (b) (c)

FIGURE 4. Salinity level from image processing results using Cimandiri Algorithm when the rainy season of 2014 (a), dry season of 2014 (b), the rainy season in 2014 to 2015 (c)



(a) (b)

FIGURE 5. Salinity level from image processing results using Cimandiri Algorithm when the rainy season of 2015 (a), dry season of 2015 (b)



(a) (b) (c)

FIGURE 6. Salinity level from spatial analysis results when the rainy season in 2014 to 2015 (a), dry season in 2014 to 2015 (b), and during 2014 to 2015 (c)

CONCLUSIONS

Based on several analysis in this study it can be concluded that the algorithm Wouthuyzen [11] cannot be used in open seawater such as Pelabuhanratu Bay water including Cimandiri Estuary. Cimandiri Algorithm is generated from the new approach of the field results in rainy and dry seasons.

In rainy season the water area which has alow salinity levels (<16 ppt and16-30 ppt) wider than the dry season. Areas with low salinity (<16 ppt and 16-30 ppt) on February 2014-August 2015 is Cimandiri Estuary region.

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