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Identifying Distribution of Chlorophyll-a Concentration Using Landsat 8 OLI on Marine Waters Area of Cirebon

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Abstract. Phytoplankton is a microscopic plant that has a function to produces oxygen and organic substances. It also plays a role as a main producer in the food chain of a marine ecosystem. Chlorophyll-a is a colour pigment most common in phytoplankton species, so that the concentration level of chlorophyll-a can be used as an indicator of the abundance of phytoplankton cells, and as a reference for predicting organic potency in the aquatic area. This research discusses about the spatial and temporal distribution of chlorophyll-a and its correlation with salinity and total suspended solid (TSS), in the seawaters of Cirebon, West Java. The goal of this research is to be a source of information for fishermen, and other stakeholders whose related subjects in the field of marine and fisheries to predict fertile water regions and can also be used as an indicator in discovering potential areas to catch pelagic fish in Cirebon seawaters. Chlorophyll-a concentration, salinity, and TSS are identified using remote sensing data such as Landsat-8 OLI multi temporal images according to dry and wet month parameters in the 2014-2015. The results of the processed image are then validated between in-situ measurements in the field and remote sensing imagery at the same time. This research utilizes descriptive analysis, and statistics with spatial approach. The results of the research show that temporally, chlorophyll-a levels have a tendency to be higher in wet months compared to dry months, while chlorophyll-a is higher in areas near the coastline compared to open sea areas. The distribution of chlorophyll-a concentration is affected by salinity and TSS distribution, where salinity has the negative relationship and TSS has the positive relationship with chlorophyll-a distribution.

Keywords: Landsat 8, chlorophyll-a, Cirebon

1. Introduction

Phytoplankton is a microscopic plant that lives floating in the water, be it in estuary waters, coast, or sea. Phytoplankton is also an autotrophic organism that produces food through photosynthesis process. Therefore, phytoplankton has an important role as a producer in marine ecosystems cycle [1, 2]. Chlorophyll-a is a colour pigment most common in phytoplankton species, so that the existence of phytoplankton can be identified by looking at the concentration of chlorophyll-a in water bodies. Therefore, concentration levels of chlorophyll-a are able to indicate the abundance of phytoplankton and primary productivity in a waters area [3].

The abundance of phytoplankton and chlorophyll-a can experience change according to seasons. This is caused by the variability of nutrients between wet season and dry season. In the wet season of Cirebon, tends to have high rainfall which causes an abundance of river nutrients compared to dry season which has low rainfall. The abundance of nutrient supply will cause the tendency of high concentration of chlorophyll-a in water bodies to rely on oceanographic conditions in the region [4].

Oceanographic conditions can affect the distribution of phytoplankton and chlorophyll-a spatially, like salinity and Total Suspended Solid (TSS). Salinity as a physical parameter in seawater that states the level of dissolved salt in water can cause osmotic pressure between the body of the organism and seawater, so that the higher the level of salt will lessen the existence of phytoplankton [5]. TSS as a representation of the level of turbidity can affect the productivity of seawaters as an effect of the disrupted light penetration inside seawater, where the light is needed by phytoplankton to photosynthesize [6]. Chlorophyll-a, salinity, and TSS can be detected using remote sensing technology.

Remote sensing is a technology which can monitor the sea appearance through satellites, where from the satellite creates images consist of several spectral band sensors. One of the images which has said properties are Landsat 8 OLI Imagery [7]. Ocean colour sensors on Landsat-8 OLI can be processed using certain algorithms and software therefore this method can identify spatial information related to the distribution of chlorophyll-a concentrations [8]. This statement is also supported by Snyder et al. [9] in his research to map potential of oyster cultivation based on chlorophyll-a concentration, sea surface temperature, and sea surface turbidity using Landsat-8 OLI Imagery.

This research explains the spatial and temporal distribution of Chlorophyll-a. The results of this research are expected to be used by the stakeholders whose activities concern the field of marine and fisheries as a source of information in predicting fertile seawaters. This research can also be used as an indicator to map pelagic fish catching potential areas in Cirebon seawater according to concentration of chlorophyll-a distribution conditions in seawater.

2. Methodology

The study area of this research, is done in parts of seawater that exist in the coast of a part of a district that is in the city and regency administrative border of Cirebon next to Java Sea. The districts mentioned in this research, are Mundu, Astanajapura, and Pangenan district in Cirebon regency along with Kejaksan district, and Lemahwungkuk in Cirebon city. The research area is in the coordinate location of 108°34'00"-108°39'30" E and 6°41'30"-6°47'00" S.

The variables used in this study are the distribution of chlorophyll-a concentration, salinity, and TSS. These three variables are obtained from several data which are rainfall data and reflectance data on Landsat 8 OLI images. Materials needed to gather data are Landsat 8 OLI images and in-situ samples from the three variables. The rainfall data used to determine wet months and dry months, are rainfall >200 mm/month are categorised as wet month and rainfall <100 mm/month are categorised as dry month [10]. Landsat 8 OLI images are used as a representation of the distribution of chlorophyll-a variables, salinity, and TSS. In-situ data samples are used to validate images that have been processed.

The processing of Landsat 8 OLI imagery (Figure 1) are done using ENVI 5.1 and ArcGIS 10.1 software. ENVI 5.1 is used to process radiometric correction and calibration, cropping, and algorithm input. Radiometric calibration is used to convert image pixels into reflectance value. The radiometric corrections that are done are sun angle corrections to fix error reflectance values caused by sun positioning [11]. Cropping is done to minimize the image coverage according to the study area. Algorithm inputs are done to convert reflectance values of images into chlorophyll-a, salinity, and TSS values using a certain equation. The data processing uses ENVI 5.1 software to produce three raster data, which are raster with the three variable values. After the three data of raster are produced, ArcGIS 10.1 is used to process said data for image validation and classification. A detailed explanation regarding validation is provided in the next paragraph. Classification is done to divide three variable values into four or five classes to simplify the spatial analysis of the three variables. Data processing using ArcGIS 10.1 software will produce the chlorophyll-a distribution map, salinity map, and TSS map.
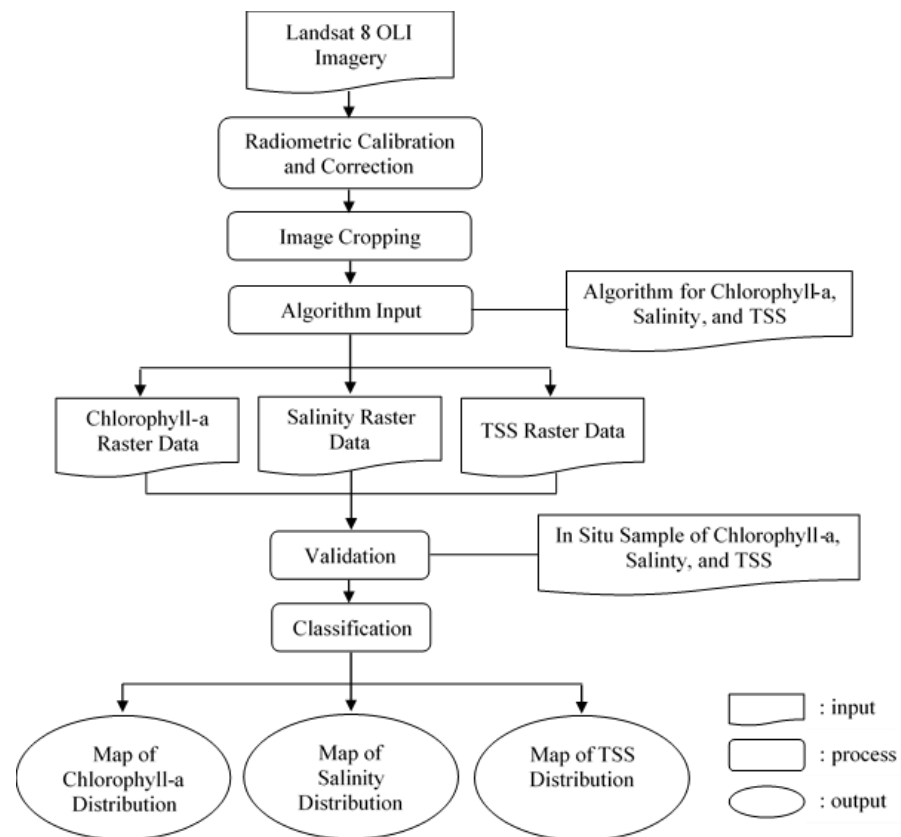
Figure 1. Landsat 8 OLI Data Processing Workflow

Landsat 8 OLI imagery data that have been corrected and calibrated are then converted into chlorophyll-a concentration values, salinity, and TSS. There are three algorithms which are used to identify the concentration of chlorophyll-a, salinity, and TSS. Chlorophyll-a concentration using algorithm of Wibowo et al. [12], salinity using the algorithm of Supriatna et al. [13], and TSS using the algorithm of Budhiman [14], where these three researches have done the mapping of variables related to Indonesian seawaters. These three algorithms can be seen in equations 3.1, 3.2, and 3.3.

The imagery that has been processed into the three variables, can then be validated by counting the Root Mean Square Error (RMSE) between specified sample data from image processing with in-situ measurements which obtained by field survey. Acquiring sample points are based on distance from coastline each 600 meters until it reaches the distance approximated about 6 km as many as 20 points (Figure 2). RMSE uses the equation 3.4 below.

$$Log\ Chl = (2,41*B4/B3)+0,187 \dots\dots\dots (3.1)$$

$$Sln = 29,983+165,047(B2)-260,227(B3)+2,609(B4) \dots\dots\dots (3.2)$$

$$TSS = 7,9038*exp(23,942*B4) \dots\dots\dots (3.3)$$

$$RMSE = \sqrt{\frac{\Sigma(z_i-z_j)^2}{n}} \dots\dots\dots (3.4)$$

Notes: Chl   = Chlorophyll-a Concentration (mg/m^3)   RMSE   = Root Mean Square Error
            Sln   = Salinity (ppt)   Zi   = imagery data
            TSS   = Total Suspended Solid (mg/L)   Zj   = in-situ data
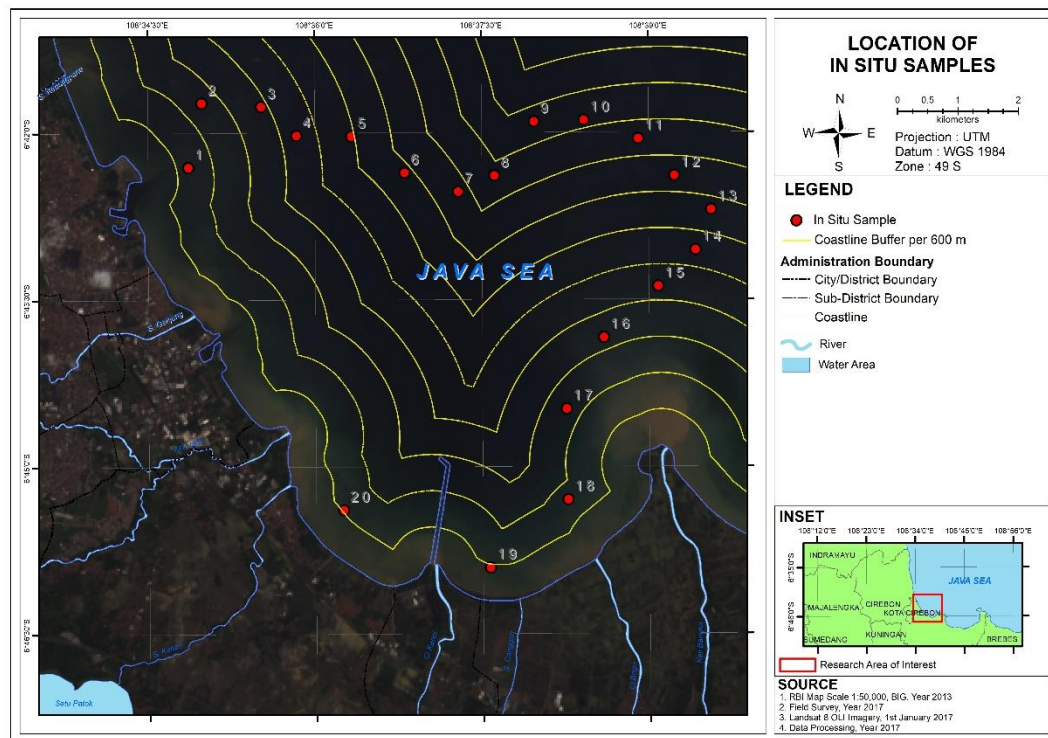   B(n)   = Landsat 8 OLI canal reflectance value   n   = samples count
                         on n order band

Figure 2. In-situ Samples Location

Data analysis used in this research are spatial analysis and descriptive statistics. Spatial analysis is done by overlaying the three map variables. Statistical analysis is done with testing the relationship between the sample values of the three variables during wet season and dry season with regression method. Temporally, chlorophyll-a concentrations are discussed according to wet month and dry month on the year 2014-2015. In regard to spatial distribution, the concentration of chlorophyll-a is discussed with salinity variables and TSS to discover its relationship.

3. Result and Discussion

3.1. Rainfall Condition of Cirebon

Cirebon regency and city which is in the coastal area including inside the tropical climate and has a monsoon rainfall pattern caused by wind movement. Rainfall season usually occurs on the months October till May, while dry season falls on the months of June-September. Badan Meterorologi Klimatologi dan Geofisika (BMKG) data (Table 1) shows that the count of monthly rainfall in the year 2014-2015 has a range of 0-710,4 mm/month.

Table 1. Rainfall Data in Cirebon Region

Month	Rainfall in 2014 (mm/month)	Rainfall in 2015 (mm/month)
January	710.4	276
February	319.7	383.1
March	243.4	107.9
April	216	48
May	85	139.6
June	169.5	10
July	62	0
August	0	0
September	0	0
October	37	0
November	66.7	30.6
December	459.4	119.5

Notes:
　Wet Month
　Dry Month

According to Oldeman classification [10], there are 5 wet months and 6 dry months in the year 2014, while in the year 2015 there are 2 wet months and 7 dry months. This research uses four Landsat 8 OLI imagery data, among others acquisition of date 9 January 2014, 6 September 2014, 28 January 2015, and 9 September 2015. The selection of this data is based on the conditions of the image that is avoided from the amount of cloud cover and as a representation of the wet months and dry months on each year.

3.2. Data Validation

The data which is measured to validate Landsat 8 OLI processed data are the in-situ value of chlorophyll-a concentrations, salinity, and TSS which are obtained from the field survey on the date 7 April 2017 and pixel values from Landsat 8 OLI imagery data processing of Landsat 8 OLI acquisition of date 1 January 2017.

Table 2. Comparison of In-situ and Imagery Processed Data

Sample	Coordinates		Chlorophyll-a (mg/m3)		Salinity (ppt)		TSS (mg/L)	
	Lat	Long	in situ	image	in situ	image	in situ	image
1	-6.7052	108.5811	0.77	0.59	26	24	40.50	39.39
2	-6.6956	108.5831	0.77	0.57	29	27	28.50	32.19
3	-6.6961	108.5921	0.49	0.55	27	27	26.25	30.43
4	-6.7004	108.5974	0.66	0.55	28	28	22.25	26.53
5	-6.7006	108.6056	0.70	0.56	26	29	31.75	26.31
6	-6.7060	108.6135	0.41	0.54	28	29	26.25	24.03
7	-6.7089	108.6215	0.35	0.53	29	29	25.75	23.83
8	-6.7065	108.6270	0.46	0.53	28	29	31.50	24.07
9	-6.6984	108.6329	0.55	0.53	28	29	27.75	24.38
10	-6.6982	108.6404	0.33	0.53	25	28	23.75	25.94
11	-6.7010	108.6486	0.37	0.56	26	28	27.25	28.94
12	-6.7065	108.6540	0.36	0.50	25	28	31.50	24.92
13	-6.7116	108.6594	0.50	0.50	25	27	32.50	27.31
14	-6.7176	108.6571	0.64	0.54	24	27	33.00	29.83
15	-6.7231	108.6515	0.59	0.51	23	26	28.50	31.03
16	-6.7307	108.6433	0.69	0.55	23	25	41.75	37.59
17	-6.7414	108.6377	0.69	0.47	26	27	25.50	25.87
18	-6.7550	108.6379	0.43	0.48	20	22	37.50	38.29
19	-6.7651	108.6262	0.95	0.61	21	19	68.75	61.20
20	-6.7565	108.6042	0.93	0.60	19	20	65.50	58.21
RMSE			0.168		2		4.35	

The results of validation calculation by comparing in-situ values with image processing results show that RMSE values (Table 2) as large as 0,168 for chlorophyll-a, two for salinity, and 4,35 for TSS. According to the RMSE values on each variable this shows that there exists a positive correlation between in-situ data with remote sensing image, so that the algorithms which are used on the image can be used to represent the actual condition of chlorophyll-a concentration, salinity, and TSS distribution in the study area.

3.3. Chlorophyll-a Distribution

Values of chlorophyll-a concentration in the study area, are according to Landsat-8 OLI imagery processing, that has a range value of 0.35-1.1 mg/m^3. Averages of chlorophyll-a concentration on 9 January 2014 (Wet 1) are 0.60 mg/m^3, on 6 September 2014 (Dry 1) with the value of 0.54 mg/m^3, on 28 January 2015 (Wet 2) with the value of 0.61 mg/m^3, and on 9 September 2015 (Dry 2) with the value of 0.55 mg/m^3. This shows that the average values of chlorophyll-a concentrations tend to grow higher in wet month compared to dry month.

Distribution of chlorophyll-a in the study area varies temporally as well as spatially. Temporally, the area of chlorophyll-a classification in wet months has a higher score compared to dry months (Figure 3). This is shown by the wet months which are dominated by the chlorophyll-a values of 0.5-0.65 mg/m^3 with the area of 60.20% on the date 9 January 2014 and the area 81.52% on the date 28 January 2015, while the dry month is dominated by chlorophyll-a 0.35-0.5 mg/m^3 with an area of 61.76% on the date 6 September 2014 and the area of 59.94% on 9 September 2015. Chlorophyll-a with the highest classification of 0.85-1.1 mg/m^3 is only available in wet months such as 9 January 2014 with the area of 6.22% and 28 January 2015 with an area of 0.82%, while on dry months there are almost none. Temporal variations are caused by rainfall which affects the runoff from river flow as a main nutrient supplier for the phytoplankton. Wet months which have higher rainfall compared to dry months cause the high amount of freshwater poured out into the sea which have salt water, so that the concentration of chlorophyll-a becomes higher. According to the results of this temporal analysis, it can be shown that phytoplankton in this study area has a higher abundance on wet months than dry months.
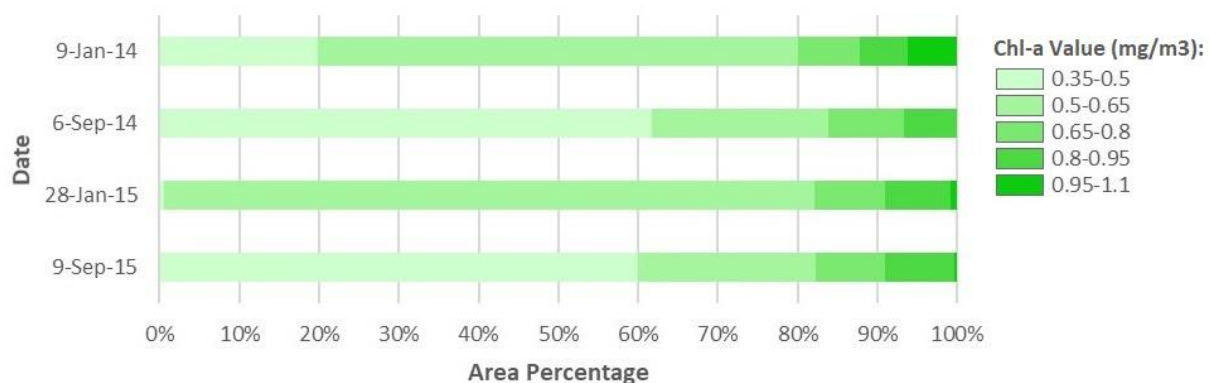

Figure 3. Graph for Area Percentage of Chlorophyll-a Classification

The distribution of chlorophyll-a concentration on study area is spatially tend to have significant differences based on distance from coastline. Chlorophyll-a has higher value on the area near of coastline and estuary zone, while it has getting lower towards the open sea area. This statement is based on sample data of number 1, 2, 18, 19, and 20 which are the nearest samples with the coastline and estuary zone. These five samples have highest average chlorophyll-a concentration level with pixel value of each 0.589, 0.592, 0.599, 0.752, and 0.829 mg/m^3. These values are higher than other samples pixel value which are located on further marine water area. This dominancy of chlorophyll-a concentration spatial pattern caused by mainland influence which has more nutrient supply brought by runoff of river flow.

The nutrient mentioned can be formed by many causes, be it caused by agricultural activities, domestic waste, industry waste, and many other activities. This chlorophyll-a concentration pattern means that phytoplankton abundance has higher amount if it near of coastline of estuary zone, be compared to far on the marine waters area.

On the map of chlorophyll-a concentration distribution (Figure 4) it can also be seen that the distribution has similar patterns between wet months and dry months on the year 2014 as well as 2015, however there is a significant difference on the level of concentration. Chlorophyll-a levels on the dry months have a tendency to be lower compared to the wet months. This difference in chlorophyll-a levels can be seen on the outer regions of the coastline which are dominated by the concentration 0.35-0.5 mg/m3, however on the wet months this region tends to change into higher levels of concentration 0.5-0.65 mg/m^3.
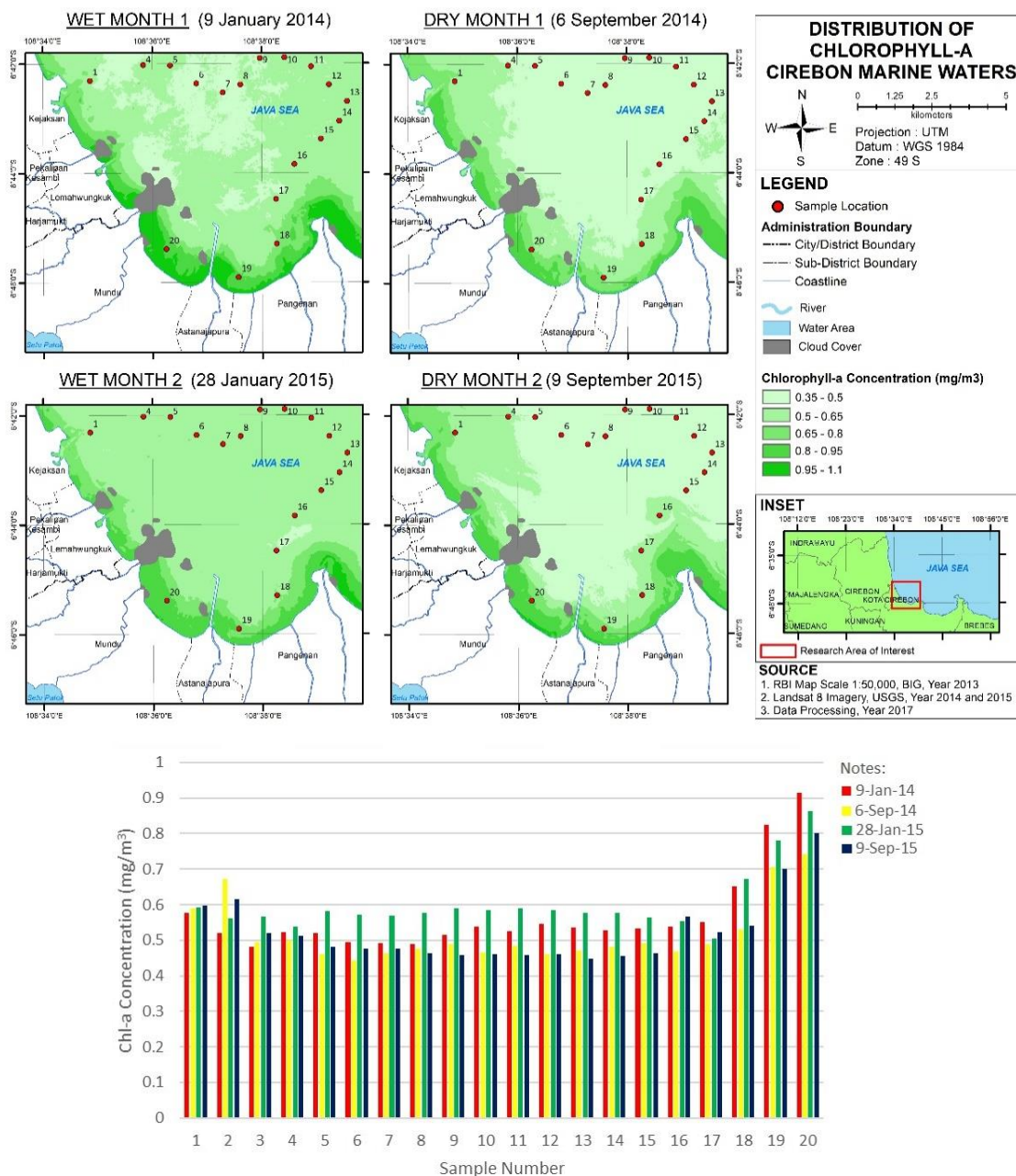

Figure 4. Map of Chlorophyll-a Distribution and Its Value on each Samples

3.4. Relationship of Chlorophyll-a with Salinity and TSS

The result of linear regression test between chlorophyll-a concentration and salinity (Figure 5a and 5b) shows that salinity variable affects the distribution of chlorophyll-a concentration whether on wet or dry month in study area. The regression result on both wet and dry month shows significance value of 0.000, which is less than significance level of 5% or 0.05. It is means that H_0 rejected so that salinity significantly affects chlorophyll-a on wet and dry month. Salinity on wet month has strong relationship as indicated by R value of 0.852 and R^2 value of 72.6%. These values are higher when it compared with dry month condition which has R value of 0.798 and R^2 value of 63.8%. The regression model on wet month shows the equation of Y=1,148-0.022X, which means that in each addition on salinity with value of 1 ppt can reduce the level of chlorophyll-a concentration in amount of 0.022 mg/m³. This equation model has a little bit different when it compared on dry month condition which has equation of Y=1,236-0,027X, which means that in each 1 ppt value of salinity will reduces 0.027 mg/m³ of chlorophyll-a concentration. Both on these wet and dry month equation shows that salinity has a negative or reversed linear relationship with chlorophyll-a on both season.

The other linear regression is also test the relationship between chlorophyll-a concentration and TSS (Figure 5c and 5d) which shows that TSS affects the distribution of chlorophyll-a concentration on both wet and dry month in study area. It has same value of significance value from salinity test, which shows value of 0.000. This means there is significant influence of TSS variable into chlorophyll-a distribution. This result supported by R value of 0.902 on wet month and 0.948 on dry month, and also R^2 value of 81.3% on wet month and 90% on dry month. These values show that TSS has higher influence on dry month than on wet month. The regression model shows the equation of Y=0,341+0,005X on wet month and Y=0,293+0,004X on dry month. It means that in each addition of 1 mg/L of TSS can increase the amount of chlorophyll-a concentration with value of 0.005 on wet month and 0.004 on dry month. These equations also show that TSS has positive or direct linear relationship with chlorophyll-a on both season.
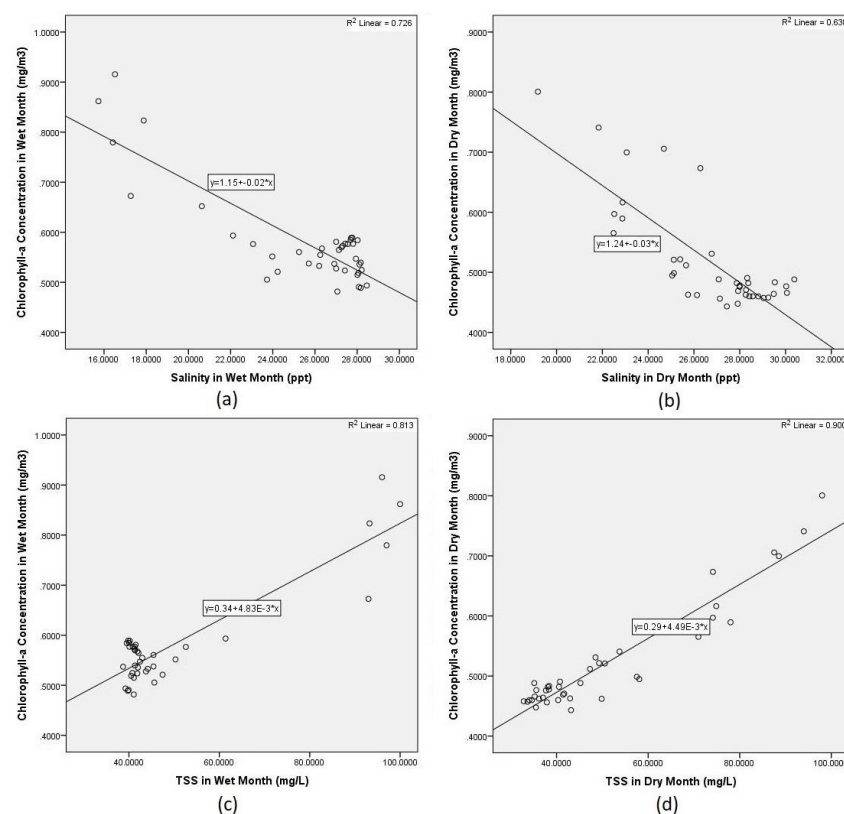

Figure 5. Regression Model for Chlorophyll-a with Salinity and TSS Relationship in Each Season
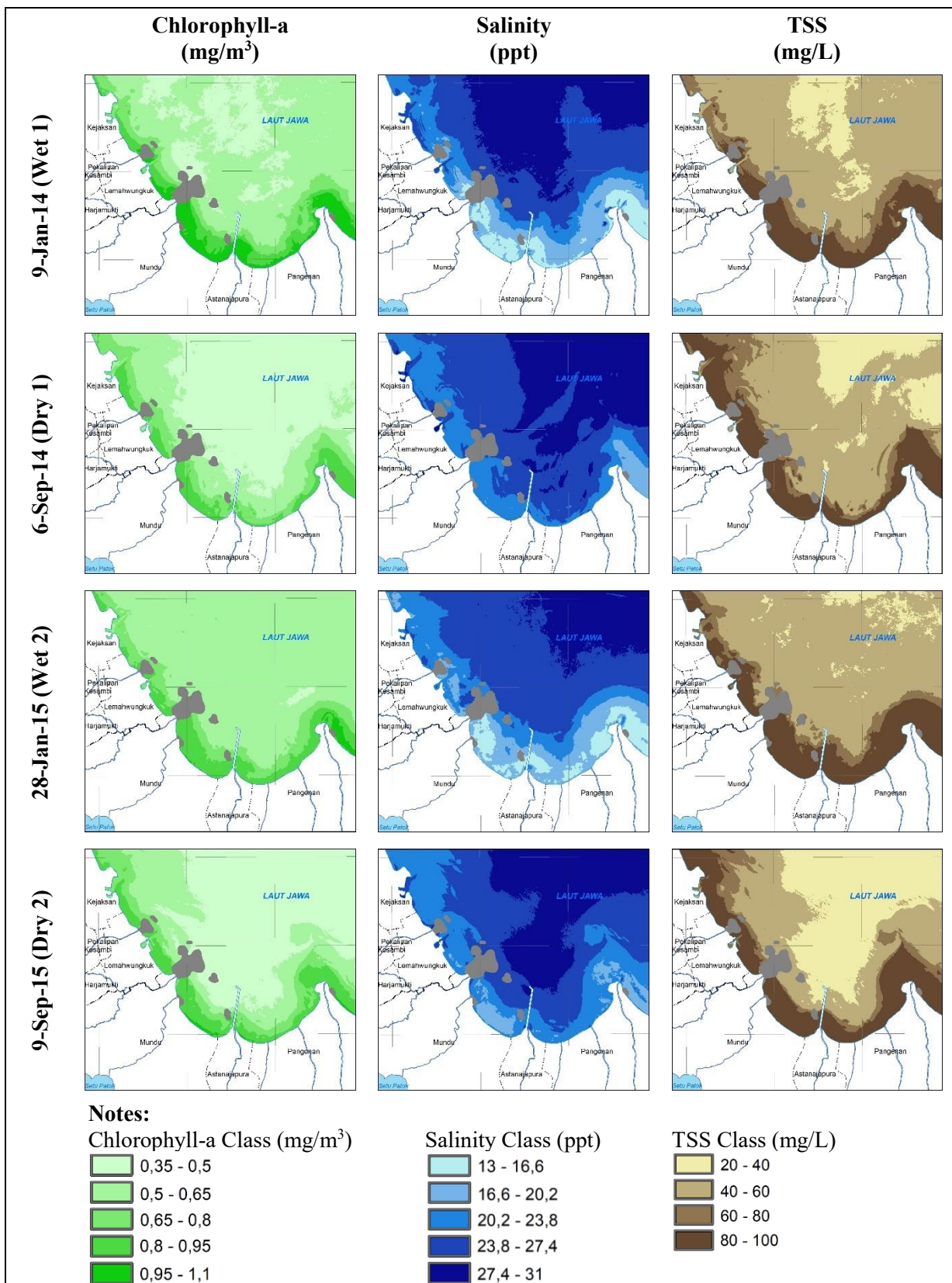
Figure 6. Spatial Comparison of Chlorophyll-a, Salinity, and TSS Distribution

Spatial appearance of chlorophyll-a concentration and salinity on each month (Figure 6) which obtained by Landsat 8 OLI processed data has a similar statement with the linear regression test result. Temporally, the salinity on wet month tend to has lower level compared to salinity on dry month. This temporal pattern shows that marine waters is more saltiness on dry month than on wet month. It is because wet month has higher rainfall than on dry month so river runoff is also in high intensity. This high intensity of runoff leads high supply of freshwater from mainland into river outlet and marine waters. Spatially, salinity distribution tends to associated and grouped based on its direction from coastline. The closer of coastline makes salinity has lower level in a value of 16 ppt, meanwhile it is get higher on the further to marine water in a value of 31 ppt in study area. This spatial and temporal pattern of salinity distribution has a reverse relationship with the distribution of chlorophyll-a concentration. Temporally, the amount of chlorophyll-a concentration is in high level, meanwhile salinity is in low level. Spatially, both chlorophyll-a concentration and salinity tend to associated or grouped based on its direction from coastline. Chlorophyll-a concentration has high level in the area near with coastal zone, meanwhile salinity has low level in the same zone. Conversely, chlorophyll-a until the direction of approximately 6 km from coastline has low level, meanwhile salinity has high level in the same location.

Spatial appearance of chlorophyll-a concentration and TSS (Figure 6) are also connected to the linear regression test result. Temporally, TSS on wet month tend to has higher level compared to TSS on dry month. This temporal pattern shows that marine waters is more turbid on wet month than on dry month in study area. It is because the high rainfall intensity on wet month period makes the runoff by river get increased. The increasing of runoff on wet month period will cause high amount of suspended solid materials flows from mainland to river outlet then to marine waters at the end. Spatially, TSS distribution in study area tend to associated and grouped based on its distance location from coastline and estuary zone. The closer of coastline makes TSS has high level in a value of 100 mg/L, meanwhile it is get lower on the further to marine water in a value of 100 mg/L in study area. This spatial and temporal pattern of salinity distribution has a direct linear relationship with the distribution of chlorophyll-a concentration. Temporally, the amount of chlorophyll-a concentration is in high level, followed by TSS in high level. Spatially, both chlorophyll-a concentration and TSS tend to associated or grouped based on its direction from coastline. Chlorophyll-a concentration has high level in the area near with coastal zone, followed by TSS with low level in the same zone. Conversely, chlorophyll-a until the direction of approximately 6 km from coastline has low level, meanwhile salinity has high level in the same location.

4. Conclusions

This research is done on the year of 2014-2015 based on wet month and dry month in study area of Cirebon marine waters. Wet month in the study area occur on January to April 2014 and December 2014-February 2015 in count of 7 months, meanwhile dry month occur on May-November 2014 and April-November 2015 in count of 13 months. The selection of one of wet and dry season on each year used as the research temporal termination to processing Landsat 8 OLI imagery data. Imagery data processed result combined with in-situ measurement samples shows that Landsat 8 OLI imagery can be used to represent the distribution chlorophyll-a concentration by Wibowo et al. [12] algorithm, salinity by Supriatna et al. [13] algorithm, and TSS by Budhiman [14[algorithm. Temporally, the distribution of chlorophyll-a concentration shows higher value on wet month than on dry month. Spatially, the distribution of chlorophyll-a concentration has a tendency to grouped based on its direction from coastline, which it has higher level on the areas near with coastline. Salinity and TSS significantly affect the distribution of chlorophyll-a concentration on both wet and dry month in study area. Salinity has reverse relationship pattern with chlorophyll-a, meanwhile TSS has direct relationship. Low level of salinity and high level of TSS can increase the amount of chlorophyll-a concentration.

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