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Analysis of Correlation and Mapping of Chlorophyll-a Concentrations and Sea Surface Temperatures in Coastal Areas Based on Terra MODIS Satellite Image Data

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Abstract

Ecosystems in aquatic environments are distinct from ecosystems on land. Changes that occur in ecosystems in aquatic environments affect the lives of biota in these waters, including the fish used as a food source in fishing communities in coastal areas. This study aims to determine the role of remote sensing in mapping and analyzing the relationship between the parameters of sea surface temperature and chlorophyll-a concentrations on the coast. The correlation of sea surface temperature with chlorophyll-a concentrations is modeled via linear regression. An analysis of variance test is performed to establish the suitability of the temperature data for the data on chlorophyll-a concentrations and to map the concentration distribution with the SeaDAS program. Results revealed a linear Chlor (mg/m^3) = 63,695 − 2,014T (°C) with an R^2 coefficient value of 0.325. This work concludes that Terra MODIS satellite imagery can be used to predict the distribution of chlorophyll-a concentrations on the coast, although its results require further comparison with those of other sensors.

Abstrak

Analisis Korelasi dan Pemetaan Konsentrasi Klorofil-a dan Suhu Permukaan Laut di Wilayah Pesisir Berdasarkan Data Citra Satelit Terra MODIS. Ekosistem di lingkungan perairan berbeda dengan ekosistem di darat. Perubahan ekosistem yang terjadi pada lingkungan perairan mempengaruhi kehidupan biota di perairan tersebut, termasuk ikan yang dijadikan sebagai sumber makanan pada masyarakat nelayan di wilayah pesisir. Penelitian ini bertujuan untuk mengetahui peran penginderaan jauh dalam pemetaan dan menganalisis hubungan antara parameter suhu permukaan laut dengan konsentrasi klorofil-a di pantai. Korelasi suhu permukaan laut dengan konsentrasi klorofil-a dimodelkan melalui regresi linier. Uji analisis varians dilakukan untuk mengetahui kesesuaian data suhu dengan data konsentrasi klorofil-a dan memetakan sebaran konsentrasi dengan program SeaDAS. Hasil penelitian menunjukkan Klor linier (mg / m3) = 63.695 - 2.014T (° C) dengan nilai koefisien R^2 0,325. Pekerjaan ini menyimpulkan bahwa citra satelit Terra MODIS dapat digunakan untuk memprediksi distribusi konsentrasi klorofil-a di pantai, meskipun hasilnya memerlukan perbandingan lebih lanjut dengan hasil dari sensor lain**.**

Keywords: correlation analysis, chlorophyll-a, sea surface temperature, satellite image data, Terra MODIS

1. Introduction

Coastal ecosystems play an important role in the lives of people living in coastal areas, most of whom are fishermen who depend largely on the biota in the coastal waters. Changes in ecosystems are bound to affect life in water bodies on the coast and the high seas. Most fishermen who live on the coast are familiar with the areas that are rich in fish that are fit for consumption. This phenomenon will continue as long as the ecosystem is not disturbed.

Climate change has been known to affect ecosystems in water bodies, especially shallow sea waters in coastal areas. The magnitude of this change will affect the lives of living things in coastal waters, including fish populations whose size could consequently decline. One approach to determine the size of fish populations in shallow marine waters is to detect the concentrations of chlorophyll-a, which is spread in water bodies. Chlorophyll-a compounds are found in phytoplankton, which serve as the main food source of fish in high and shallow seas, especially in coastal areas. Detecting

chlorophyll-a concentrations in large areas requires technology that can monitor and map the chlorophyll-a content of the environment offshore.

Remote sensing has been widely used and developed toward the mapping of chlorophyll-a concentrations in high seas [1]. Extensive studies have explored chlorophyll-a content with the use of satellite imagery from various satellite image sensors with distinct characteristics. Several researchers use the widely popular Medium Resolution Imaging Spectrometer (MERIS) [2]–[4] while others use SeaWiFS [5],[6]. For medium-resolution imagery, scholars use MODIS sensors [6]–[8] and Landsat [9]–[11]. In the current study, medium-resolution satellite images from the MODIS sensor on board the Terra satellite platform are used. This study aims to map the concentrations of chlorophyll-a scattered on the coast of Sidoarjo Regency and Pasuruan Regency and to establish the correlation between climate change in the form of rising sea surface temperature (SST) and chlorophyll-a concentrations, samples of which were obtained at coordinates 112.9º to 113.26º for longitude and –7.4º to –7.6º for latitude.

2. Materials and Methods

Retrieval of Satellite Images. The satellite images used in this study were obtained from https://oceancolor.gsfc.nasa.gov/, from which Terra MODIS images for specific time periods can be downloaded for free. The selected satellite images showing ocean color (OC) and SST were downloaded in June 2018. One downloaded image was named T2018179031500.L2_LAC_OC.nc, where T refers to the Terra satellite carrying MODIS sensors. From this file, the chlorophyll-a concentration values can be extracted using an algorithm developed by the team from the United States Geological Survey (USGS). The other image was T2018179031500.L2_LAC_SST.nc, which was used to extract the values of SST on the basis of the algorithm developed by the NASA/USGS team.

The downloaded images were processed with the SeaDAS software, and the results are shown in Figures 1 and 2.

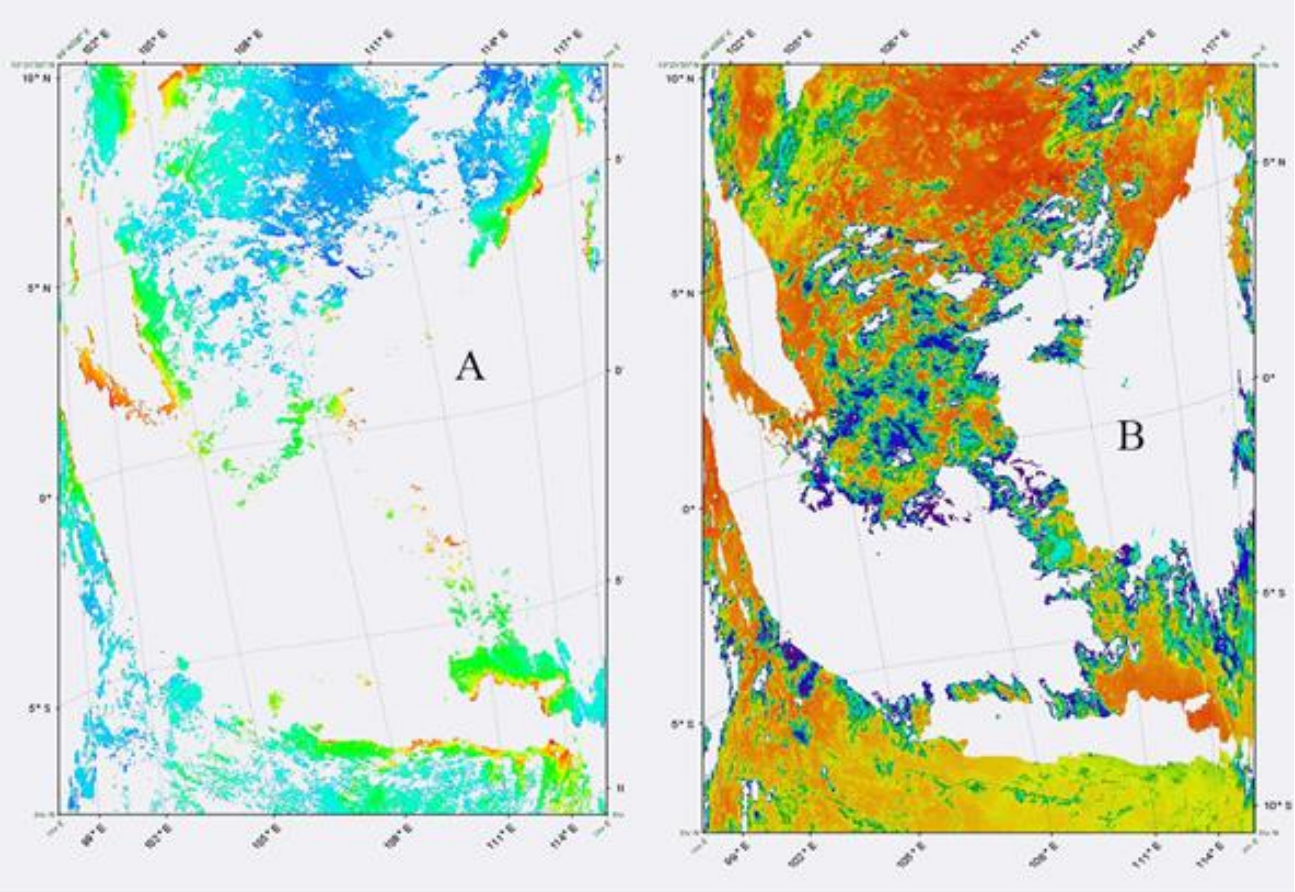

Figure 1. Terra MODIS Satellite Imagery in June 2018 Showing (A) Ocean Color Denoting Chlorophyll-a (B) Sea Surface Temperature

Table 1. Longitudes and Latitudes of Data Sample Points

No	Longitude	Latitude	No	Longitude	Latitude
1	112.92121	−7.4502	26	112.98800	−7.4232
2	112.90788	−7.4636	27	113.00144	−7.4365
3	112.90794	−7.4770	28	112.98812	−7.4499
4	112.93482	−7.5036	29	112.96141	−7.4634
5	112.96166	−7.5168	30	112.94809	−7.4768
6	112.98842	−7.5167	31	112.88066	−7.3569
7	113.00186	−7.5300	32	112.88078	−7,3836
8	113.01531	−7.5433	33	112.88084	−7,3970
9	113.04208	−7.5432	34	112.89427	−7,4103
10	113.02882	−7.5699	35	112.90771	−7,4236
11	113.06904	−7.5831	36	112.93436	−7,3967
12	113.08230	−7.5563	37	112.93424	−7,3700
13	113.09555	−7.5296	38	112.93418	−7,3566
14	113.08210	−7.5163	39	112.92075	−7,3434
15	113.08198	−7.4896	40	112.90731	−7,3301
16	113.06854	−7.4763	41	113.12284	−7,6363
17	113.08185	−7.4628	42	113.13609	−7,6095
18	113.06841	−7.4496	43	113.16287	−7,6094
19	113.05496	−7.4363	44	113.18971	−7,6226
20	113.04152	−7.4230	45	113.18984	−7,6493
21	113.04146	−7.4096	46	113.16320	−7,6761
22	113.02802	−7.3963	47	113.14975	−7,6628
23	113.00126	−7.3964	48	113.21675	−7,6759
24	112.97450	−7.3966	49	113.23000	−7,6491
25	112.96117	−7.4100	50	113.25677	−7,6489

Coordinates of Sample Points. The coordinates of 50 data sample points on the Terra MODIS images were identified using the SeaDAS software. The latitude and longitude measurements are shown in Table 1. These coordinates were used to extract the chlorophyll-a concentration values and the corresponding SST values.

The placement of the 50 sample points on the Terra MODIS satellite images carried out on the SeaDAS software is illustrated in Figure 2.

Data Validation Process. The validation process was carried out as follows. The data obtained from the 50 data sample point were not used entirely for the correlation analysis and variance analysis (analysis of variance [ANOVA]). Of the 50 data points, only 40 were used for the correlation analysis; the remaining 10 were used for the validation of the linear regression models obtained from the calculation results of the SeaDAS program.

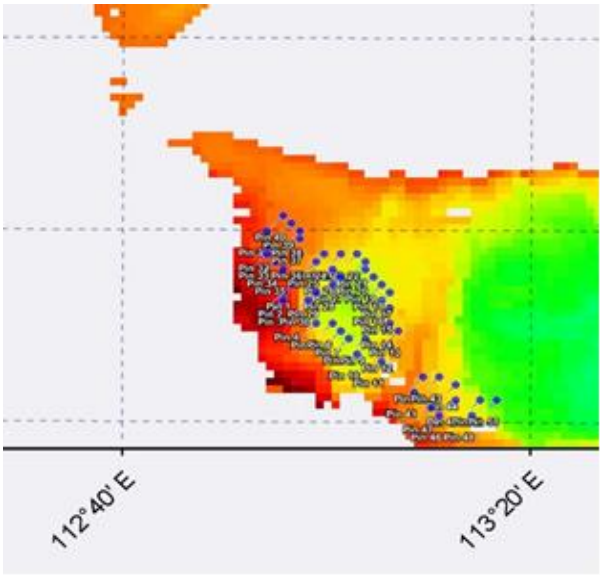

Figure 2. Coordinate Placement of Sample Data Points on Terra MODIS Satellite Imagery

3. Results and Discussion

On the basis of the OC file in Figure 1A and the SST file in Figure 1B, several advanced processes are carried out on the original files occupying large areas from the 100°E–117°E longitude and 10°S–10°N latitude. One process involves cutting the satellite imagery or "cropping" in accordance with the research area on the coast of the Sidoarjo and Pasuruan districts. With the SeaDAS program, the satellite images are cut at 110.472°E–115.454°E longitude and 6.074°S–8.17°S latitude. The results are shown in Figure 3.

The next process involves the projection or "reprojection" arrangement of the previously cut satellite images to achieve accurate projection (Figure 3). The latitude and longitude measurements are still diagonally arranged. Following the reprojection, the latitude and longitude measurements become perpendicular. The results of the reprojection are shown in Figure 4.

The SST file is subjected to the same cutting process previously described, and the results are shown in Figure 5, where the cutting results cover the research area.

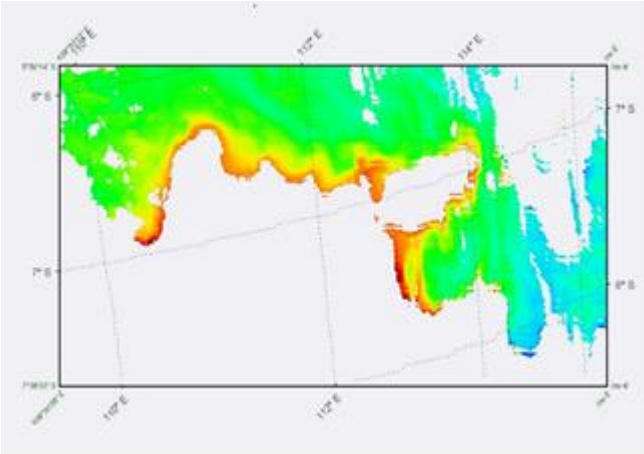

Figure 3. Cutting Results of Terra MODIS Satellite Imagery in The Study Area

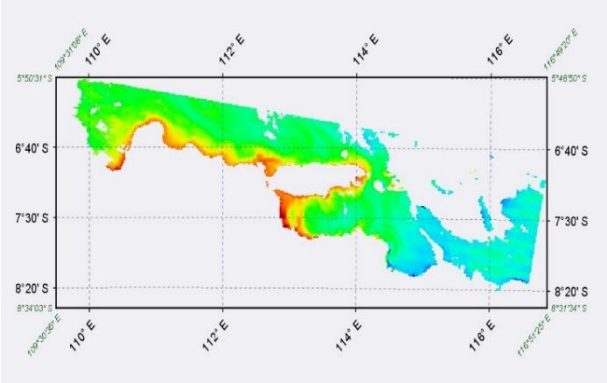

Figure 4. Satellite Image of Research Area After Reprojection

The results of the reprojection of the SST file are shown in Figure 6, which shows that the coordinate lines are perpendicular to one another.

The satellite imagery undergoes projection similar to that in Figure 4 for chlorophyll-a and Figure 6 for SST to obtain the chlorophyll-a concentrations and SST values. On the basis of the specified coordinates of the data sample points in Table 1, the chlorophyll-a and SST concentration values are obtained, and the results are provided in Table 2.

Linear Regression Calculation. The data in Table 2 were subjected to linear regression analysis, with chlorine concentration as the dependent variable (y-axis) and the SST as the independent variable (x-axis). From the linear regression model y = ax + b, where a is the coefficient of the variable x and b is the intercept, the calculation yields x = −2,014 and b = 63,695. Hence, the linear regression model can be rewritten as follows:

$$\text{Chl (mg/m}^3\text{)} = 63{,}695 - 2{,}014.T\ (°C) \quad (1)$$

where T is the SST in Celsius and Chl is the concentration of chlorophyll-a in mg/m^3.

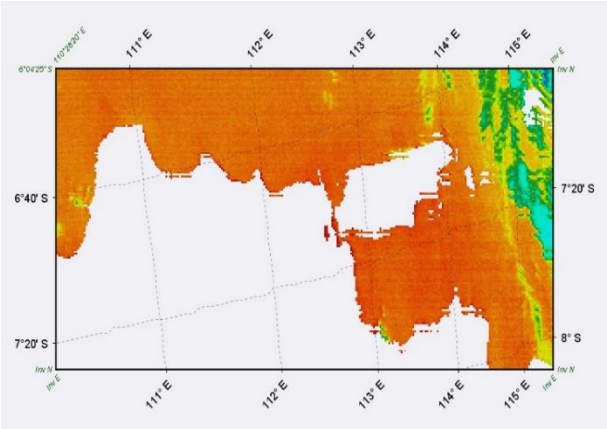

Figure 5. SST-related Cutting Results of Terra MODIS Satellite Imagery of The Research Area

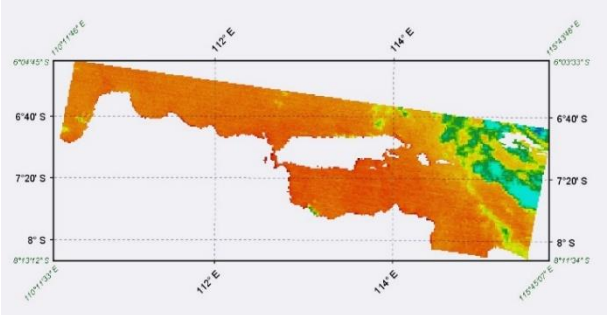

Figure 6. SST-related Reprojection Results of Terra MODIS Satellite Imagery

Extraction of Chlorophyll-a Concentration and SST.

Table 2. Extraction Results of Chlorophyll-a Concentration and Sea Surface Temperature

No	chlor_a (mg/m^3)	sst (°C)	No	chlor_a (mg/m^3)	sst (°C)
1	7,40856	30,465	26	1,36504	30,695
2	1,19316	30,115	27	1,10917	30,615
3	1,36096	30,850	28	1,32586	30,570
4	7,52312	29,660	29	1,55548	30,725
5	3,75279	29,610	30	8,11384	28,240
6	1,44082	30,725	31	4,62601	29,750
7	1,21629	30,025	32	6,56125	29,910
8	1,40376	30,025	33	8,47176	28,340
9	1,05103	30,715	34	5,63219	29,215
10	1,31002	30,680	35	5,91959	30,450
11	1,54508	30,575	36	4,84452	30,775
12	1,77467	30,285	37	3,50046	30,635
13	1,50256	30,475	38	3,32946	31,015
14	1,16467	30,920	39	3,44814	30,415
15	1,17943	30,115	40	3,79353	30,730
16	0,95468	30,655	41	3,35039	29,875
17	1,05879	29,745	42	3,38799	30,060
18	0,88536	30,655	43	2,06982	29,880
19	0,80173	30,250	44	1,62916	30,045
20	0,77044	30,765	45	1,90404	30,110
21	1,12439	30,535	46	3,08356	29,740
22	1,21180	30,680	47	2,60763	29,790
23	1,56794	30,525	48	1,68546	29,970
24	2,28471	29,080	49	1,28762	29,790
25	2,46415	29,310	50	1,06598	30,865

Table 3. Analysis of Variance of Sea Surface Temperature with Chlorophyll-a Concentration From Terra MODIS Satellite Imagery

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	69,226	69,226	19,18	9,012E-05
Residual	38	137,149	3,6091		
Total	39	206,375			

The regression model has a coefficient R value of 0.579 and R2 value of 0.3354 with a standard error of 1.899. The R2 value of 0.3354 is not good enough to describe the linearity of the existing data. With an error rate of 5%, the SST data return a value of only 33.5%, which indicates conformity with the chlorophyll-a concentration. The ANOVA results are shown in Table 3.

In Table 3, the value of the F distribution is 19.18, which denotes the ratio of the Mean Square (MS) regression to the residual MS. The MS regression value is obtained from the regression SS divided by the degree of free (df) regression. The residual MS obtained from the residual SS is divided by the df residue. The significant value F is obtained at 9.018E-05, which is quite small relative to the desired percentage error rate of 5% or 0.05. Hence, the data show good linear significance statistically. This phenomenon is depicted in a residual graph shown in Figure 8.

Validation Test for Chlorophyll-a Data. The data on chlorophyll-a concentration are validated with the model algorithm obtained in the linear regression calculation, that is, Equation (1).

The SST values for the 41 sample data points up to the 50th point are used as the input data. The input data are then used to determine the chlorophyll-a concentration values. The results are shown in Table 4.

As shown in Table 5, the t-test value is 4.42, which is greater than the critical t. With a 5% error rate, this result indicates a difference between the chlorophyll-a from the satellite images and the chlorophyll-a from the linear algorithm validation.

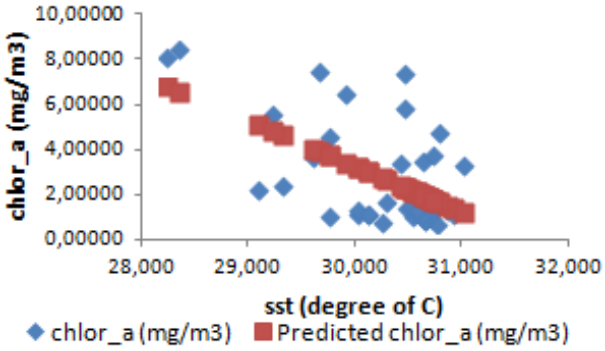

Figure 7. Linear Regression of SST to Chlorophyll-a Concentration

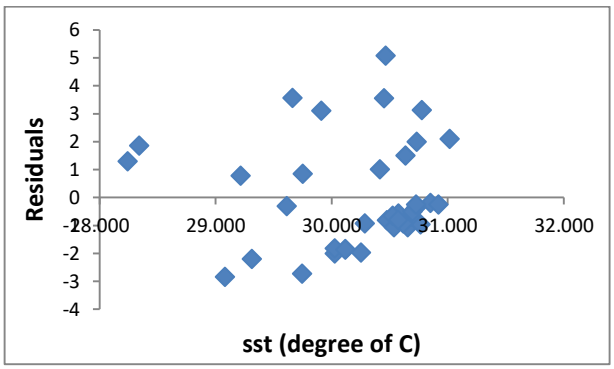

Figure 8. Residual Graph for Distribution of SST Values

Table 4. Validation Data for Sea Surface Temperature Against Chlorophyll-a Concentration

No	SST (°C)	chlor_a (mg/m^3)	Chlor-a from linear algorithm
41	29,875	3,35039	3,527
42	30,060	3,38799	3,154
43	30,045	2,06982	3,184
44	29,880	1,62916	3,517
45	30,110	1,90404	3,053
46	29,740	3,08356	3,799
47	29,790	2,60763	3,698
48	29,970	1,68546	3,335
49	29,790	1,28762	3,698
50	29,865	1,06598	3,547

Table 5. T-test for Comparison of Chlorophyll-a from Images with Chlorophyll-a from Validation

	chlor_a (mg/m^3)	*Chlor-a from linear algorithm*
Mean	2,207	3,451
Variance	0,722	0,066
Observations	10	10
Pearson Correlation	−0,0089	
Hypothesized mean difference	0	
df	9	
t Stat	−4,42	
P(T<=t) one-tail	0,0008	
t Critical one-tail	1,83	
P(T<=t) two-tail	0,0017	
t Critical two-tail	2,26	

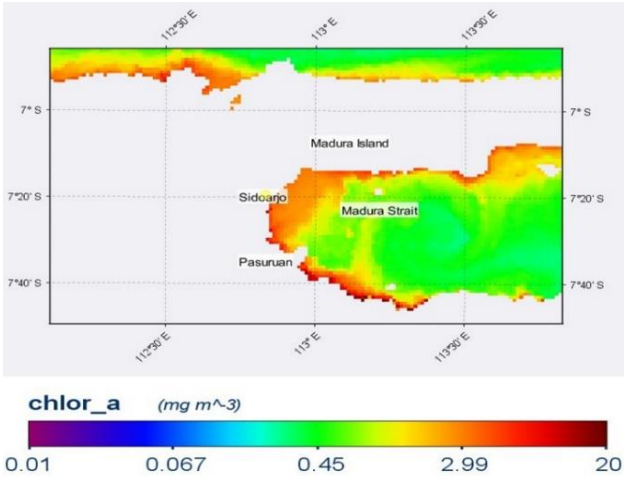

Figure 9. Thematic Map of Chlorophyll-a Concentration Distribution in Sidoarjo and Pasuruan Districts

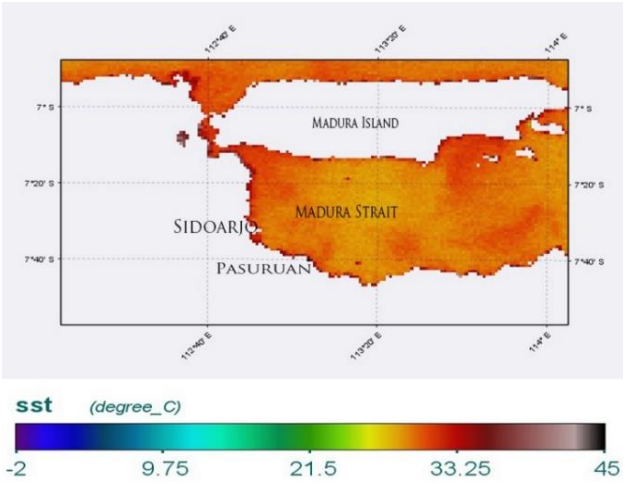

Figure 10. Thematic Map of SST Distribution in Sidoarjo and Pasuruan Districts

4. Conclusion

Thematic maps depicting the distribution of chlorophyll-a and SST can be compiled from the Terra MODIS satellite images. Good results can be obtained from these satellite images when they contain minimal clouds, which could block the penetration of electromagnetic waves reflected in sensors for remote sensing.

The statistical t-test with a 5% error level shows the absence of any similarity between the chlorophyll-a concentrations from the satellite imagery and from the validation of the sample data with linear regression calculations.

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