Inter-Comparison And Selection Of Best Suited Algorithm For Chlorophyll-A Estimation Using Landsat 8 Oli Satellite Data – Chennai Coast, Tamilnadu - India

RM.Narayanan, K.J.Sharmila, K.Radhika, B.Krishnakumari, S.Laxmipriya

Abstract: The increase in population and fast dwindling land resources lead to tapping and exploitation of oceanic resources include marine habitats. Ludicrous abuse of oceanic resources may imbalance the ecology. The centralization of Chlorophyll-a (standard phytoplankton pigment) is as often taken as a record of biomass in an assumed area. Marine based photosynthetic life forms comprise of single celled phytoplankton, which includes less than 1 percent of the worldwide biomass anyway it speaks to 40 % of universal carbon obsession. According to previous studies, carbon dioxide released by anthropogenic activity adds 7 gigatons per year of which 2 (Gt per yr.) is thought to be sequestered in the oceanic environment. In the stable state, phytoplankton fixes 35 to 50 Gt of C per yr. Hence, the study is streamlined to retrieve Chl-a values using satellite imageries of Landsat 8OLI data in order to find Chl-a variations along three different regions. In view of three vital situations (SEE, NASH and MAPE), it is inferred that all the five algorithms alongside the estuary, nearshore and offshore regimes are resulted with undue estimate of phytoplankton (Chl-a) qualities. However, among most of the five distinct algorithms, Tasson algorithms has a superior matchup as far as field measured Chlorophyll-a than other algorithms consequently Tasson algorithm is taken into consideration as a reasonable algorithm for inferring the Chl-a making use of satellite information that is then trailed by Hamilton algorithm.

Keywords: Chlorophyll a, Remote Sensing algorithms, Marine water, Standard error estimate (SEE), Nash–Sutcliffe coefficient (NASHE), and mean absolute percentage error (MAPE).

I. INTRODUCTION

Coastal zones frame more fruitful and beneficial parts in spite of exceedingly perplexing and variable natural conditions contrasted with deep seas. The physical, chemical and biological measurements of the surface ocean are essential for understanding the structure and a process that affects the climate and the environment (Narayanan et al., 2016).Satellite data are used for various ecological applications including water quality perceptions and evaluation. Diverse practices had been advanced at some point of the previous few many years for reckoning environmental variables including Chl-*a*. Remote sensing and GIS is utilized to screen the environment progressively and appropriate administration measures can be inferred (Dharanirajan et al., 2010). In this research, various algorithms created were tried to recover Chl-a qualities utilizing satellite imageries of Landsat 8 OLI information. (Karter Singh et al., 2014) tested variety of regression models with different band combinations. Among these tested regression models, the highest R^2 = 0.88 was observed for $[R_{rs}^{-1}(660) - Rrs^{-1}(482)] \times Rrs^{-1}(825)$, which represents the fine co-linearity between modeled and laboratory-measured Chl-*a*.

$$C_{chl\,a} = A + B\left[\left(\frac{1}{R_{rs}(\lambda 1)} - \frac{1}{R_{rs}(\lambda 2)}\right) \times \left(\frac{1}{R_{rs}(\lambda 3)}\right)\right]$$

Where C_{chla} is Chl-*a* concentration in µg L^{-1} and λ1, λ2, and λ3 are the Landsat ETM+ band central wavelengths (660, 482, and 825, respectively). A (5.4003) and B (0.0937) are derived coefficients.

(Hamilton et al., 1993) assessed the Chlorophyll *a* from the AVIRIS information for the surface waters of Lake Tahoe utilizing the CZCS algorithm for low pigment concentration.

$$log_{10}[chl\ a] = 0.053 + 1.71\ log_{10}\left({L_w(550)}/{L_w(443)} \right)$$

Where Lw (550) and Lw (443) are the estimations of upwelled radiance from the surface in 20 nm (fwhm) groups focused at 550 nm and 443 nm. (Chauhan et al., 2001) attempted the (O' Reilly et al.,1998) empirical computations i.e. OC2 which is tackled SeaWiFS ocean color data on IRS P4 around oceanic systems of India, which gets the distinctive sigmoidal correlation between Rrs 490/Rrs 555 band proportion and chlorophyll concentration C,

$$C = 10^{0.319 - 2.336\,R + 0.879\,R^2 - 0.135\,R^3} - 0.071$$

Where R = $Log_{10}[R_{rs}(490)/R_{rs}(555)]$

Where Rrs is remote sensing reflectance and the set of rules discovered to have affordable suit with predicted chlorophyll versions of Indian oceanic regimes.

The set of rules stated in his research paper for the Chl-*a* tiers from 0.01 mg/m^3 ≤C≤50 mg/m^3 is given above. Chl-*a* estimation in the lake was tried to apply the LCI algorithm to Landsat-8 data by (Sakuno and Kunii, 2015). In his research they have obtained a significant correlation (R =

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0.66 and RMSE 4.3) between LCI and $\log_{10} Chl\ a$ was observed and the relationship employed to acquire lake chlorophyll a is given below.

$$\log_{10} Chl\ a = -26.91\ LCI + 1.273$$

(Tassan 1987) has recalled the data provided by CZCS bands 1 to 3 are used in the chlorophyll retrieval algorithms

$$Log\ (C) = A + B\ log(R\ (443)\ /R\ (550))$$

$$Log\ (C) = A' + B'\ log(R\ (520)\ /R\ (550))$$

Where R (λ) = Flux radiant energy reflected from unit area.

During the sea truth campaign, (Tassan and strum, 1986) developed some numerical expressions for chlorophyll a estimation and is given below.

$$Log\ (C) = (0.19 \pm 0.04) + (-2.19 \pm 0.13)\ log\ (R\ (443/R\ (550)),\ C \leq 1.5 mg/m^3$$

$$Log\ (C) = (-0.012 \pm 0.04) + (-5.4 \pm 0.34)\ log\ (R\ (520/R\ (550)),\ C \geq 1.5 mg/m^3$$

The OC_3 algorithm uses a maximum band ratio of $R_{rs}443$, Rrs488, and Rrs551

$$C_a = 10^{(0.283 - 2.753\ R + 1.457\ R^2 + 0.659\ R^3 - 1.403\ R^4)}$$

Where R = Log10 (Rrs_443>Rrs_488) /Rrs_551

The best applicable algorithms, by using factor sampling information and synchronized satellite data beneath five different algorithms adopted in this study. Further all the algorithms has been tested and validated by comparing the estimated Chl-a concentrations values of respective insitu measurements and from the published literatures to identify the most relevant algorithms for the Chennai coast.

Study area: The chosen study area Chennai region is one of biggest populated city of India and represented in fig.1. The study focused on three important transects and the marine water sample was collected at 21 stations covering three different locations and categories i.e. Ennore (E – Station 1: Industrial), Coovam (C - Station 2: Municipal and Agricultural) and Kovalam (K- station 3: Fresh and Tourism) stretching ~ 70 Km from south to north.

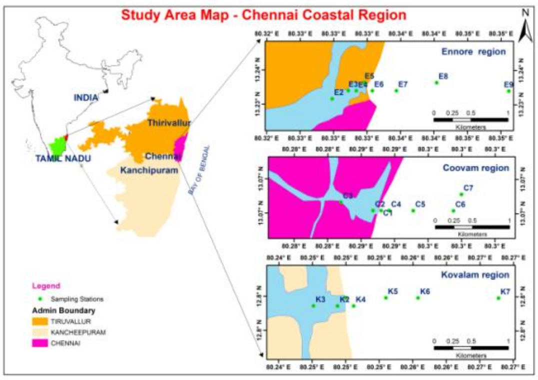


Fig.1. Measured and Extracted Chlorophyll *a* values from different algorithms using Satellite data

II. METHODS

1. Insitu data collection:

Water samples garnered at twenty-one stations from three different locations i.e. Ennore (E – Station 1), Coovam (C - Station 2) and Kovalam (K- station 3) at surface from the coastal, estuarine, and offshore waters of Chennai region, Tamil Nadu. The sampling network was designed in such a way that the samples should fulfill the projected conditions of the area. Sampling was carried in 2-4 smaller motor boats. At each station (or by boat) water sample was taken from the sea surface until the photic depth at appropriate intervals for the years between 2013 and 2015. For every sampling, a fresh set of one-liter pre-cleaned acid washed polyethylene bottles and niskin sampler were used and two-three liters of samples are collected. The collected samples were well kept under dry ice, in an icebox, and stockpiled in the cold room at 4°C and Chlorophyll a parameter is immediately analyzed. The chlorophyll determination was done by concentrating the sample by filtering through a membrane filter (Whatman, Glass fiber filter GF/F of 47 mm, 0.7 µm pore size) (ESS Technique, 1981), (ICMAM, 2012). The pigments are obtained through algal pattern solution kept in 90% acetone for 24 hrs. The Chl *a* fixation is spectrophotometrically discovered by computing the absorbance of the accumulate at 750 664 647 and 630 nm and then applied to a standard equation.

2. Image Analysis and Statistical Computations

Concurrently, Landsat OLI satellite data was collected for Post Monsoon period (16th Feb) from path 142 and row 51 during year 2015subsequent to the date of field sampling. The obtained satellite image is converted from DN to Lλ spectral radiance by means of the radiance scaling aspect bestowed in the metadata. Transformation of Spectral Radiance to TOA Reflectance (ρλ) at the sensor is acquired by changing over the brilliance ($L_{Pixel,\ Band}$) recorded at the sensor to reflectance (ρλ) utilizing standard circumstances. Further, the satellite information of Landsat OLI is subjected to climatic redress utilizing the FLAASH module introduced with the ENVI 5.1 software. Dark object removal was tried in this study using image-processing capabilities of ENVI 5.1 software. The scattering is isolated by subtracting this dark value from each pixel in the band to get remote detecting reflectance. The retrieved remote sensing reflectance is used in five different algorithms to quantify the remote sensing Chl *a* concentration that is further subjected to statistical analysis for appropriate algorithm identification.The three essential variables/parameters for acquiring reasonable algorithm among estuary, close shore and profound seas for the examination of Chlorophyll-*a*are assessed via estimates of standard error, Nash–Sutcliffe efficiency and absolute mean percentage error.

The condition behind the estimation of three important factors are 1) The lowest standard error estimated algorithm have results that are more accurate, 2) From the estimation of Nash–Sutcliffe efficiency we can arrive to the following conclusions. a) If (E = 1) the modeled discharge has an ideal match to the observed information. b) IF (E = 0) the model forecasts are as exact as the mean of the observed information. c) If (E < 0) the observed mean is a superior indicator than the model.3) the lowest mean absolute percentage error estimated among the algorithms is indicated with the better model.The standard error of estimate (SEE), Nash–Sutcliffe coefficient (E), and mean absolute percentage error (MAPE) were needed for the error computation to assess the precision of various calculations are given beneath:

$$SEE = \sigma/\sqrt{N}$$

$$\text{Where } \sigma = \sqrt{\frac{1}{N-1}\sum_{1}^{n}(x_i - \mu)^2}$$

$$x_i = Chl_{\,a\,meas}$$

$$\mu = Chl_{\,a\,mean}$$

$$E = 1 - \left[\frac{\sum_{i=1}^{n}(Chl_{\,a\,meas,\ i} - Chl_{\,a\,mod,i})^2}{\sum_{i=1}^{n}(Chl_{\,a\,meas,\ i} - \overline{Chl}_{\,a\,meas,i})^2}\right]$$

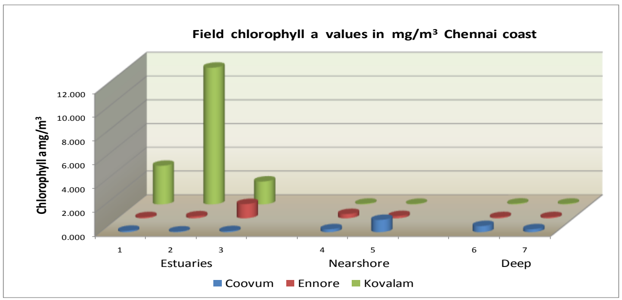
$$M = n^{-1}\sum_{i=1}^{n}\left|\frac{Chl_{\,a\,meas,\ i} - Chl_{\,a\,mod,i}}{Chl_{\,a\,meas,\ i}}\right| \times 100$$

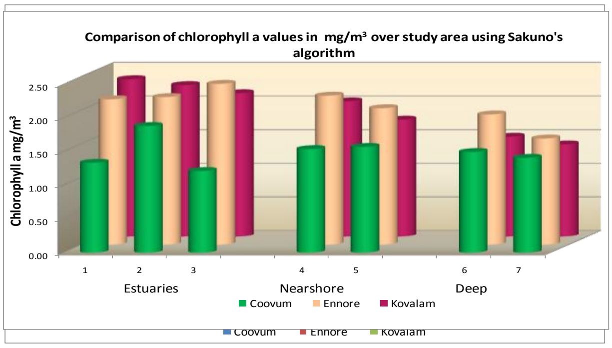
Where n is the number of samples, Chl-*a* meas, i and Chl-*a* mod, i are the measured and modeled Chl-*a* level of the respectivei$_{th}$ sample.

III. RESULTS AND DISCUSSIONS

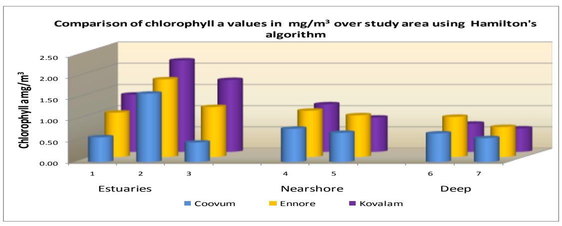
1. Phytoplankton (Chlorophyll)

The results accomplished from the investigation of field and sensor data are shown in Fig.2 and 3.The Chl-*a* values are estimated from the sensed data using five different algorithms are depicted in Table 1. The graphic insights for every one of the calculations alongside field estimations are exhibited in Table 2. From the characteristic values of Chl-*a*it is established that, the field observed mean Chl-*a*(0.98 mg/m^3) is nearly equal to the mean Chl-*a* value generated from





B. Estuary: From the evaluations of three critical parameters appeared in Table III and Table IV. It is observed from the estuarine region, the standard error of estimate for Tasson algorithm has the most minimal error (0.029) trailed by Yuji Sakuno (0.148) and then by Hamilton (0.195) when



Hamilton's algorithms (1.08mg/m^3).The obtained results are comparable with those of previous literatures cited for Bay of Bengal region as represented in Table V

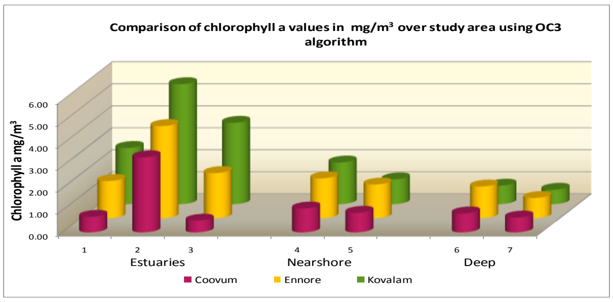
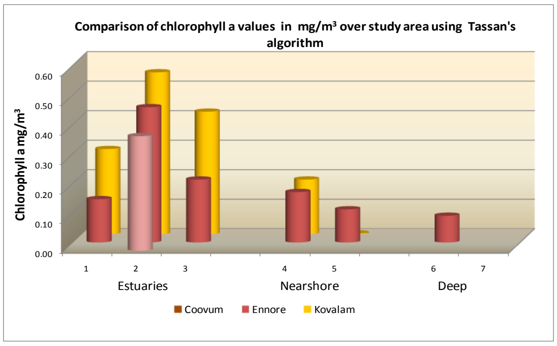


Fig2. Measured and Extracted Chlorophyll *a* values from different algorithms using Satellite data



contrasted with different algorithms. The Nash–Sutcliffe efficiency observed for all the five algorithms in the estuarine areas results in negative valves i.e. E < 0 indicated that field determined mean is an effective predictor than the modeled (satellite derived).According to Nash–Sutcliffe efficiency results, the efficiency that is closer to 1 can be considered as accurate model. In this case, though the model shows negative values the Tasson algorithm showed closer to one, which is then followed by Hamilton algorithm. The mean absolute percentage error assessed for the estuarine locale mirrors that the Tasson algorithm is better and having the MAPE of (246.82), trailed by Yuji sakuno algorithm (422.57)

C. Near shore:

The standard error estimate of near shore region results with the lowest error (0.045) for Tasson algorithms followed by Hamilton algorithm with the SEE of (0.073). The Nash–Sutcliffe efficiency observed for all the five algorithms in the near shore regions too results in negative values i.e. E < 0 indicated that field determined mean is an effective predictor than the modeled (satellite output). According to Nash–Sutcliffe efficiency results, the efficiency, which is closer to 1, can be believed as precise model. In our case though the model shows negative valves the Tasson algorithm showed closer to 1 which is then followed by Hamilton algorithm. The mean absolute percentage error estimated for the near shore region reflects that the Tasson algorithm is better and having the MAPE of (105.83) then followed by

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Hamilton algorithm (800.74).

Table I. Field and extracted Chlorophyll *a* from different stations

S.No	Sampling station	Longitude	Latitude	Field Chlorophyll-a	OC3	Yuji sakuno	Chauhan	Hamilton	Tasson
1	C1	80.290	13.067	0.112	0.705	1.336	1.567	0.583	-0.178
2	C2	80.289	13.067	0.051	3.414	1.883	3.903	1.613	0.388
3	C3	80.285	13.068	0.083	0.532	1.214	1.293	0.460	-0.310
4	C4	80.291	13.067	0.242	1.083	1.540	1.846	0.786	-0.012
5	C5	80.294	13.067	1.031	0.888	1.572	1.765	0.688	-0.086
6	C6	80.299	13.067	0.513	0.862	1.497	1.585	0.674	-0.097
7	C7	80.300	13.069	0.243	0.673	1.410	1.420	0.563	-0.197
8	E2	80.329	13.234	0.092	1.694	2.160	2.304	1.045	0.147
9	E3	80.331	13.235	0.131	5.876	2.397	5.855	2.255	0.574
10	E4	80.332	13.235	0.160	4.192	2.193	4.553	1.830	0.458
11	E5	80.333	13.236	1.195	2.053	2.390	2.739	1.178	0.213
12	E6	80.334	13.235	0.355	1.816	2.214	2.406	1.092	0.171
13	E7	80.337	13.235	0.185	1.534	2.028	2.136	0.982	0.112
14	E8	80.342	13.236	0.097	1.442	1.935	2.139	0.945	0.091
15	E9	80.351	13.235	0.097	0.922	1.578	1.662	0.706	-0.071
16	K1	80.250	12.804	3.251	2.558	2.339	3.481	1.350	0.289
17	K2	80.249	12.803	11.513	5.456	2.251	5.142	2.154	0.549
18	K3	80.246	12.803	1.925	3.700	2.130	6.558	1.695	0.415
19	K4	80.251	12.803	0.055	1.894	2.010	2.642	1.121	0.186
20	K5	80.255	12.804	0.039	1.127	1.737	1.968	0.807	0.003
21	K6	80.259	12.804	0.063	0.841	1.483	1.437	0.663	-0.107
22	K7	80.269	12.804	0.055	0.656	1.368	1.230	0.552	-0.208

Table 2 Descriptive statistics for various algorithms

Parameter	Mean	Standard Error	Median	Standard Deviation	Sample Variance	Kurtosis	Skewness	Range	Min	Max
Field Chlorophyll-a	0.98	0.53	0.15	2.48	6.14	17.30	4.03	11.47	0.04	11.51
OC3	2.00	0.33	1.49	1.57	2.46	0.99	1.37	5.34	0.53	5.88
Yuji sakuno	1.85	0.08	1.91	0.38	0.15	-1.48	-0.08	1.18	1.21	2.40
Chauhan	2.71	0.33	2.14	1.55	2.39	0.79	1.33	5.33	1.23	6.56
Hamilton	1.08	0.11	0.96	0.53	0.28	0.01	0.98	1.80	0.46	2.26
Tasson	0.11	0.05	0.10	0.26	0.07	-0.90	0.33	0.88	-0.31	0.57

Table III (a). Standard Error estimated for Estuarine region

Standard Error of Estimates along Estuaries	
Estimation methods	Standard Error of Estimate
Field Measurements	0.379
OC 3	0.577
Chauhan	0.609
Yuji Sakuno	0.148
Hamilton	0.195
Tasson	0.029

Table III (b). Standard Error estimated for Near shore region

Standard Error of Estimates along Near shore Waters	
Estimation methods	Standard Error of Estimate
Field Measurements	0.151
OC_3	0.170
Chauhan	0.139
Yuji Sakuno	0.112
Hamilton	0.073
Tasson	0.045

Table III(c). Standard Error estimated for Deep ocean region

Standard Error of Estimates in Deep Oceans	
Estimation methods	Standard Error of Estimate
Field Measurements	0.073
OC_3	0.117
Chauhan	0.040
Yuji Sakuno	0.083
Hamilton	0.058
Tasson	0.044

Table IV(a). Nash- Sutcliffe efficiency and MAPE estimated for Estuarine region

Nash–Sutcliffe efficiency and MAPE along estuaries		
Estimation methods	Nash–Sutcliffe efficiency	MAPE
OC_3	-5.59	1825.61
Chauhan	-8.61	2236.63
Yuji Sakuno	-1.13	422.57
Hamilton	-0.42	853.20
Tasson	-0.23	246.82

Table IV(b). Nash- Sutcliffe efficiency and MAPE estimated for Near shore region

Nash–Sutcliffe efficiency and MAPE along Near shore		
Estimation methods	Nash–Sutcliffe efficiency	MAPE
OC_3	-12.58	1272.85
Chauhan	-30.66	2002.93
Yuji Sakuno	-21.84	880.09
Hamilton	-3.88	800.74
Tasson	-1.011	105.73

Table IV(c). Nash- Sutcliffe efficiency and MAPE estimated for Deep ocean region

Nash–Sutcliffe efficiency and MAPE along deep ocean		
Estimation methods	Nash–Sutcliffe efficiency	MAPE
OC_3	-22.83	574.88
Chauhan	-72.69	1106.55
Yuji Sakuno	-1.507	704.81
Hamilton	-10.56	451.47
Tasson	-3.38	218.96

Table V.Chlorophyll *a* (mg/m^3) ranges in published literature for marine waters

S.No	Name	Location	Year	Chl-*a* value (mg/m^3)
1	Raghu Prasad and Ramachandran Nair (1963)	Gulf of Mannar	1960	2 to 12
2	Kannan (1996)	Gulf of Mannar	1996	0.18 and 0.59
3	Sathe and Namitha jadhav (2001)	12° 35'N - 21° 38'N & 64°59'E - 74°08'E Bay of Bengal	2001	0.02 to 0.99
4	Madhu et al (2002)	Chennai coastal waters (SW monsoon)	2002	0.16 to 0.38
5	Madhu et al (2002)	Chennai coastal waters (post super cyclone)	2002	0.29 to 0.97
6	Madhu et al (2002)	Chennai offshore waters (SW monsoon)	2002	0.18 to 0.23
7	Madhu et al (2002)	Chennai coastal waters (post super cyclone)	2002	0.3 to 0.49
8	Dey and Singh (2003)	Southern Bay of Bengal	2003	< 3
9	Dey and Singh (2003)	Krishna and Godavari delta in the Bay of Bengal	2003	3.5-4
10	Dey and Singh (2003)	Palk straight	2003	> 2
11	Dey and Singh (2003)	Gulf of Mannar	2003	< 1.5
12	Dey and Singh (2003)	Bay of Bengal ~ 12 km away from the coast	2003	< 0.5
13	Prasanna Kumar et al (2006)	9°N and 12°N of Bay of Bengal	2006	~0.30
14	Patra et al (2007)	Northern Bay of Bengal	2006	~0.2-0.5
15	Sharmila and Narayanan (2016)	Chennai coastal waters	2017	0.178 to 2.043

D.Deep Ocean/Offshore:

The standard error estimate of deep oceanic region (offshore) e) results with the lowest error (0.040) for Chauhan algorithm developed by (Chauhan et al., 2001) followed by Tasson algorithm with the SEE of (0.044). The Tasson algorithm has extremely trivial variations in the blunder differentiated with Chauhan algorithms. Similar to Estuarine and near shore regions, the Nash–Sutcliffe efficiency observed for all the five algorithms in the estuarine areas resulted in negative

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values i.e. E < 0 indicated that field determined mean is an effective predictor than the modeled (satellite derived). According to Nash–Sutcliffe efficiency results, the efficiency which is closer to 1 can be considered as accurate model. In our case, though the model shows negative values the Yuji Sakuno algorithm showed closer to 1, which is then followed by Tasson algorithm. The mean absolute percentage error assessed for the profound maritime regime mirrors that the Tasson algorithm is better and having the MAPE of (218.96), trailed by Hamilton (451.47).

IV CONCLUSION

In view of three vital conditions (SEE, NASH and MAPE), it is inferred that all the five algorithms along the estuary, nearshore and offshore regimes are resulted with undue approximation of Chlorophyll-a qualities. However, among the five distinct algorithms Tasson algorithms has a superior matchup as far as field measured Chl-a than other algorithms consequently Tasson algorithm is considered as a reasonable algorithm for inferring the Chlorophyll-a utilizing satellite information which is then pursued by Hamilton algorithm, but Yuji Sakuno's algorithm is considered as second best choice of algorithm in case of Chennai estuarine region.

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