ASSESSMENT OF THE RELATIONSHIP BETWEEN WATER SURFACE TEMPERATURE AND DISSOLVED OXYGEN TO IDENTIFY AQUATIC VEGETATION DISTRIBUTION - A STUDY IN BATTICALOA LAGOON, SRI LANKA

P. J. E. Delina[1], N. D. K. Dayawansa[2] and Ranjith Premalal De Silva[2]
[1]Postgraduate Institute of Agriculture, University of Peradeniya, Sri Lanka
[2]Faculty of Agriculture, University of Peradeniya, Sri Lanka
Email: evandel_foa@yahoo.com, ndkdayawansa@yahoo.com

KEYWORDS
Algae, Aquatic weeds, Chlorophyll index, Regression model, TIR band

ABSTRACT
Most of the natural water bodies in Sri Lanka are infested with aquatic weeds and algae possibly due to high nutrient levels in water. Batticaloa Lagoon is the second largest lagoon in the country which is frequently affected by algae and aquatic weeds mainly *Eichhornia crassipes.* This problematic situation is an indicator of lagoon pollution. The present study aims to develop a regression model that can satisfactorily detect and map the spatial distribution of Aquatic weeds (*Eichhornia crassipes*) and Algae in Batticaloa Lagoon, using both surface temperatures derived with Thermal Infrared (TIR) band of Landsat 8 satellite data and field measurements of Dissolved oxygen (DO). The TIR band 10 was chosen for the study and it was converted to Lagoon surface water temperature (°C) (SWT) image. Field measurements of Lagoon SWT (°C) and DO (mg/l) were obtained in 30 locations in one month interval for the period from April to June, 2017 where the distribution of aquatic vegetation is at peak. The values were graphed in a scatter plot and a linear inverse relationship was observed between Lagoon SWT and DO. The near real time Lagoon SWT map was converted to DO map using the equation $y = -2.0888x + 75.332$. With more field sample collection to improve the accuracy, the combined surface water temperature - DO map can be used as a model in the lagoon to identify the locations which are affected by aquatic weeds and algae and can be used as an indicator of lagoon pollution.

1. INTRODUCTION

Estuaries and lagoons are highly dynamic ecosystems that are very vulnerable both to natural and anthropogenic disturbances. One of the main anthropogenic threats facing lagoons and estuaries is point and non-point source pollution which leads to eutrophication (Gamito *et al.*, 2005). The relative low flushing rates of coastal lagoons are favorable habitats for primary producers (phytoplankton and aquatic plants). Nutrients are transported to lagoons from surface water and groundwater flows and through exchange with the ocean. However, primary production that exceeds the demand of consumers can lead to eutrophication. Eutrophication is characterized by excessive phytoplankton and macro algal blooms and subsequent hypoxia, reduced light penetration, stress and dying off of marine organisms, loss of sea grass beds, changes in food web interactions and community structure, and loss of biodiversity (Jugas, 2010). Overloaded nutrients and inappropriate water quality can also accelerate the growth of aquatic plants which are harmful to other organisms (Smith, 1990). The excessive growth of water plants is also a source for many common water quality problems throughout the world (Chapman *et al.*, 1974; Shireman *et al.*, 1982). These problems include loss of water storage due to transpiration, effects on fisheries, provision of habitats for vectors of diseases, interference with navigation, slow decomposition leading to decrease in water clarity and increased siltation (Sastroutomo, 1985). In some aquatic ecosystems, alien species have grown to such an unprecedented level that they have even resulted in the drying up of water bodies (e.g. *Eichhornia* spp, *Salvinia* spp and *Pistia* spp). Decomposition of the aquatic plants can lead to foul odors and oxygen depletion, which can in turn, lead to fish deaths (Carpenter *et al.*, 1998; Smith, 1998).

Dissolved oxygen (DO) and Surface Water Temperature (SWT) are the crucial water quality parameters that influence the living conditions of all aquatic organisms that require oxygen. They also influence and control the growth and spreading of aquatic plants and algae in the water bodies. The desirable level of DO in water bodies can be affected by anthropogenic activities and natural occurrences (Gholizadeh *et al.*, 2016). Water temperature, the amount of oxygen taken out of the system by respiring and decaying organisms, and the amount of oxygen put back into the system by photosynthesizing plants, stream flow, and aeration are the factors that control the amount of dissolved oxygen in water bodies. Among these factors, SWT is one of the important parameters that affect dissolved oxygen concentrations in water; as oxygen solubility decreases with increasing water temperature which is highly fluctuated due to seasonal variations. Low DO (usually called hypoxic) levels usually indicate pollution or some type of changes caused by human. Water with high quantity of aquatic plants has higher levels of dissolved oxygen, since submerged plants produce oxygen through photosynthesis. Also, as mentioned above, too many plants will ultimately reduce the DO levels, because of either night-time oxygen use by plants or the decay process that consumes oxygen (Chang *et al.*, 2015).

If populations of algae and aquatic plants grow too fast in relation to the rest of the system, they may create water quality problems in the lagoon ecosystem, such as algal blooms. The Chlorophyll – a (Chl-a) can be used as a pollution indicator for the lagoon water quality where, the absorption peak and the reflection peaks are near 440nm and 550nm, respectively. Chl-a also shows a relationship between water quality parameters and algal production. Therefore, it can be used to estimate of the amount of aquatic plants growing in water bodies (Li *et al.*, 2007).

Remote sensing techniques can be used to study spatial and temporal view of surface water quality parameters more effectively and efficiently to monitor the water bodies and quantify water quality issues. Thermal infrared remote sensing (TIR) technique is a useful approach to monitor change of water temperature (Khalil *et al.,* 2016). TIR Bands of Landsat-5 Thematic Mapper (TM), Landsat-7 Enhanced Thematic Mapper (ETM) and Landsat 8/OLI has wide range of electromagnetic wavelength band, including visible, infrared and thermal bands. TIR data can aid identifying severe environmental phenomenon in water bodies.

2. BACKGROUND OF THE STUDY

Recent studies and reports have revealed that both natural and artificial water bodies in Sri Lanka have become infested with aquatic weeds. The areas inhabited by these plants appear to be increasing in the recent years and this issue has received very little attention of the government, farmers and public due to lack of aquatic management knowledge, expertise and programmes (Sobadini, 2006). Batticaloa District of Sri Lanka covers an area of approximately 2600 square kilometers with 168 square kilometers consisting of the lagoon and inland fresh water, and tanks (Selvadurai, 1997). Batticaloa district has about 13,682 hectares of lagoons and associated with estuarine basins and 365 hectares of other water bodies (Jugas, 2010). The Batticaloa lagoon is a main live wire of the District. The lagoon has a great impact on the life and environment of the District. It receives almost the entire drainage from the rivers and streams, and discharges the excess to the sea at the outfalls at Palameenmadu and Kallar (CEA/NORAD, 1993).

Pollution, sedimentation, eutrophication, degradation of the ecosystem and excessive growth of aquatic weeds can be considered as the main threats to aquatic ecosystems. At the global scale, invasive species have been identified as one of the main reasons of biodiversity loss and substantial economic damage (Gunawardena *et al.,* 2014). Batticaloa Lagoon is subjected to significant pollution as a result of anticipated unplanned development works since 2009 (Kularatne, 2014). The mangrove cover has declined in 20-year period due to infrastructure development, construction of aquaculture ponds and security reasons (Jayasingham, 2000). The estuary has become a dumping ground for domestic and municipal wastes as well as untreated effluents from industries such as rice mills, dying and shrimp farming. Frequent algal blooms due to eutrophication and subsequent death of aquatic fauna have been reported. During the 2004 tsunami, the estuary was inundated with debris and silt. In some places, the flow and exchange of water within the estuary is impeded by causeways with culverts of insufficient capacity. Spread of invasive alien species such as *Parthenium hysterophorus, Eichhornia crassipes* and *Salvinia molesta* is also becoming a problematic issue in the lagoon area (IUCN, 2006). Seasonal variations in the plants structure and density are also a concern especially during the dry and rainy seasons. Seasonal fluctuation of plant distribution, water quality and anthropogenic activities threat are some of the main issues that impact the ecological diversity of Batticaloa lagoon. Phytoplanktons and Macro Algae (Harris and Vinobaba, 2013) are found to be good indicators of water pollution. Thus, it is evident that places where the above mentioned aquatic plants are prominent are polluted.

3. OBJECTIVES

The present study aims to develop a regression model that can satisfactorily detect and map the spatial distribution of aquatic weeds (*Eichhornia crassipes*) and algae in Batticaloa Lagoon, using both surface temperatures derived from Thermal Infrared (TIR) band of satellite data and field measurements of Dissolved oxygen (DO).

4. MATERIAL AND METHODS

4.1. Study area

Batticaloa lagoon is located in the Eastern Province of Sri Lanka between 7°24’-7°46’ N and 81°35’-81°49’ E. The lagoon is about 56.8 km long along meridian axis and it varies widely 0.5 km to 4 km. More than 90% of the lagoon is located in the Batticaloa District while the southern end is located within the Ampara District. The Batticaloa estuary is the second largest brackish water system in Sri Lanka and is connected to the Indian Ocean at two points; one at Palameenmadu and the other at Kallar (Figure 1).

The lagoon is shallow with irregular bottom topography. Three distinct longitudinal zones could be recognized in this lagoon, the upper saline zone, the middle transitional zone with salinity fluctuations and the lower zone which is predominately with fresh water. The seawater intrusion ranges from approximately 1 to 2.5 km from the mouth depending upon flow conditions of sea water. At present, the lagoon covers an area of approximately 135.5 square kilometers. The climate of the study area comprises a wet season during North-East monsoonal period (November to February) characterized by high mean precipitation (1250 ± 230 mm), and prolong dry season during the South-West monsoonal period (March to October) marked by low mean precipitation (300 ± 23 mm) (IUCN, 2006).

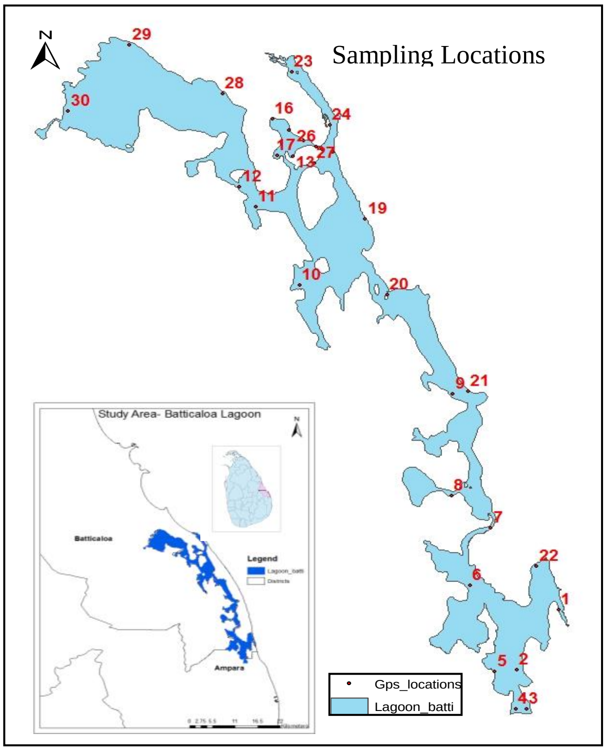

Figure 1: Map of Study Area- Batticaloa Lagoon and Sampling Locations

Table 1: Sampling points of field measurements

Sampling Points	Locations	Sampling Points	Locations
1	Periyakallar	16	Urani
2	Thuraineelavanai	17	Thiruperunthurai
3	Kittanki	18	Kallady
4	Sorikalmunai	19	Kathankudy
5	Annamalai	20	Manmunai
6	Mandoor	21	Kurukalmadam
7	Paddiruppu	22	Onthachimadam
8	Palugamam	23	Mugathuvaram
9	Ampalanthurai	24	Uppodai
10	Kothiyapulai	25	Arasadi
11	Kannankuda	26	Batticaloa gate
12	Vavunatheevu	27	Fort park
13	Lakeroad	28	Chathrukondan
14	Newbridge	29	Eravur
15	Lagoonpark	30	Pankudaveli

4.2. Sample collection

Thirty sampling sites covering the entire study area (Table 1) were selected to measure DO and Lagoon SWT in one month interval for the period from April to June, 2017 in Batticaloa Lagoon (Figure 1). Global positioning system was used to detect the coordinates of each site location in the field. Samplings were done in the morning hours between 9.00 am to 11.00 am. Portable DO meter (Hanna portable HI 8043 Dissolved Oxygen Meter) was used to measure DO and SWT directly in the field.

4.3. Image acquisition and processing

Landsat-8 OLI_TIRS (Band 10) images dated 28 April, 14 May 2017 and 16 June 2017 (Path: 140/ Row: 55) were used for the analysis. The image acquisition dates were selected to be as near real time date to water sampling collections. At the same time, Landsat 8/OLI multispectral bands from the above dates were also used for the image analysis. The layers (band 2- 7) were layer stacked and atmospheric correction was carried out as preprocessing steps. The study area was subset from the raw image using Erdas Imagine 2014 for further analysis.

4.4. Development of aquatic vegetation map

The subset MS image of the Landsat 8 was used to develop the Chlorophyll Index for the aquatic vegetation system using simple band ratio of (NIR (Band5)/Red (Band3)).

4.5. Development of Lagoon WST images

Landsat-8 OLIS (Band 10) for the months April to June were converted to Lagoon Surface Water Temperature Maps using the following equations (Landsat 8, Users Handbook, 2016).

1. OLI and TIRS at Sensor Spectral Radiance

   $L\lambda = ML*Qcal + AL$-------------------------- (1)

   Where:

   $L\lambda$ = Spectral radiance (W/ (m2 * sr * µm))

   ML = Radiance multiplicative scaling factor for the band (RADIANCE_MULT_BAND_n from the metadata)

   AL = Radiance additive scaling factor for the band (RADIANCE_ADD_BAND_n from the metadata).

   Qcal = L1 pixel value in DN

2. <u>Conversion of Spectral Radiance to Temperature in Kelvin</u>

$$\mathbf{T_k = K_2/\ln[K_1/ L\lambda +1]}\text{---------------------------(2)}$$

Where:

T_k = TOA Brightness Temperature, in Kelvin.

$L\lambda$ = Spectral radiance (Watts/(m2 * sr * µm))

K1 = Thermal conversion constant for the band (K1_CONSTANT_BAND_n from the metadata)

K2 = Thermal conversion constant for the band (K2_CONSTANT_BAND_n from the metadata)

3. <u>Conversion of Kelvin to Celsius</u>

$$\mathbf{T_c = T_k - 273}\text{----------------------------------(3)}$$

4.6. Development of regression model of SWT-DO for TIR image

The Statistical Package for Social Sciences version 16.0 (SPSS) was used for the correlation and regression analysis to develop a relational equation for the Lagoon SWT and DO. The average values of the measured values of Lagoon SWT (°C) and DO (mg/l) for 30 samples in the study area were graphed in a scatter plot and linear equation was obtained using trend line to see the relationship between Lagoon SWT (°C) and DO (mg/l). The Lagoon SWT map (°C) was converted to DO map using the liner equation using model maker in Erdas Imagine 2014.

The Figure 2 shows the schematic diagram of the methodology followed in the study.

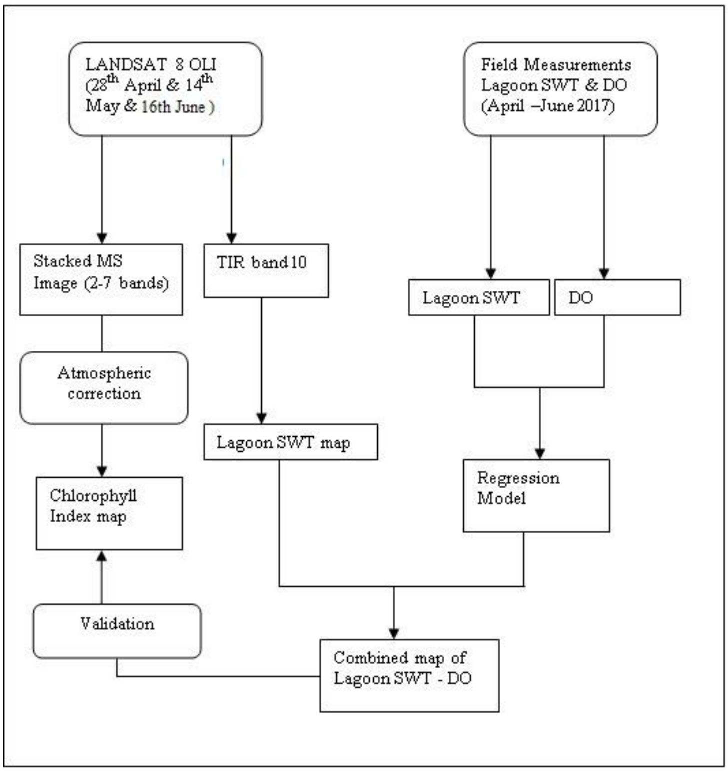

Figure 2: Remote sensing based framework to develop combine Lagoon SWT and DO map

5. RESULTS AND DISCUSSION

5.1. Statistical analysis of field measurements

The present study elaborates the relationship between the Lagoon SWT and Dissolved Oxygen to develop a regression model and use the model with the Lagoon Surface Temperature map derived using TIR band 10 (Landsat 8/OLI) to detect the presence of aquatic vegetation in the Batticaloa Lagoon.

Dissolved oxygen can be used as index of lagoon's productivity (Harris and Vinobaba, 2012). Batticaloa Lagoon shows a wide range of dissolved oxygen variation from 2.08 mg/l to 15.28 mg/l at New Bridge (Location 14) and Manmunai (Location 20), respectively. Studies shows that DO level should be > 7mg/l to maintain the ecosystem viable and pollution free. The mean value of DO was 8.07 mg/l in April to June 2017 in Batticaloa Lagoon. According to Santini *et al.* (2010), this range supports fish and vegetation health. Khalil *et al.* (2016) observed different levels of DO at different time intervals due to sea water extrusion and warm condition of the lagoon. Studies also indicate that high presence of algae and aquatic plants reduces the amount of DO due to excessive consumption of oxygen in nights (Chang *et al.*, 2015). The Lagoon SWT varies from 30.7°C to 35.0°C among the sampling stations. Where the minimum SWT recorded at Manmunai and maximum was recorded at New Bridge, vice versa to the DO points. The correlation matrices between the measured Lagoon SWT and DO showed negative correlation (-0.70) for the months April to June 2017. A regression model was developed between Lagoon SWT and DO obtaining linear equation of y = -2.0888x + 75.332 (R= 0.49) (Figure 3).

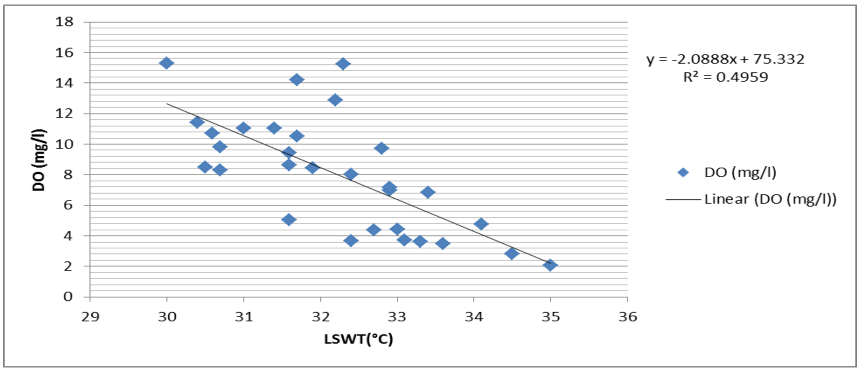

Figure 3: Regression Model of Lagoon SWT and DO

5.2. Spatial distribution maps

Surface water temperature in lagoons is an important regional indicator of water quality that is influenced by both ground- and surface-water inputs, and indirectly by land use in the surrounding watershed. TIR measurements can be used for monitoring spatial patterns of water temperature in streams and rivers for practical applications in water resources management. The Figure 4 illustrates the Lagoon SWT maps produced from TIR band 10 Landsat 8/OLI.

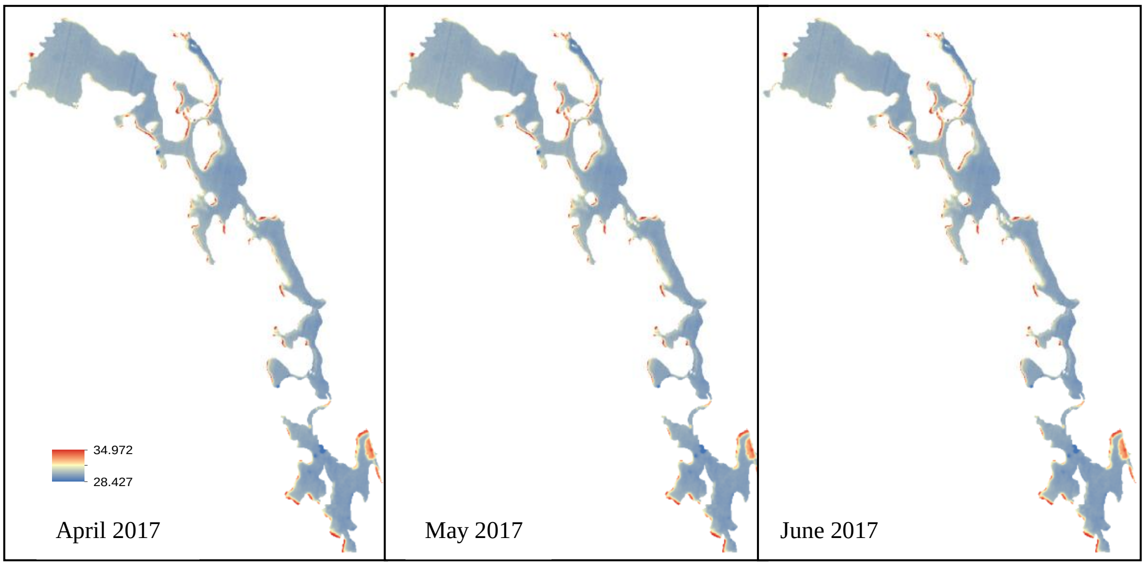

Figure 4: Lagoon Surface Water Temperature Map

Water temperature is a good indicator to estimate primary production and phytoplankton growth rates (Gholizadeh *et al.*, 2016). According to the Lagoon SWT map the temperature varies from 28 to 35 °C. The temperature shows high at the locations of 5, 6, 13, 14, 15, 16, 17, & 27 namely Annamalai, Mandoor, Lake road, New Bridge, Lagoon park, Urani, Thiruperunthurai and Fort park. These are the places identified with highly infested with Aquatic vegetation. However, the temperature decreases from the shore to the central part of the lagoon where the water circulation and depth of lagoon increases.

Preliminary studies showed that the application of remote sensing combined with traditional in situ temperature measurements can provide reliable information on temperature zones at a relatively low cost. Many studies have shown the applicability of remote sensing to temperature estimation for rivers and streams (Gholizadeh *et al.*, 2016). The developed regression model for Lagoon WST and DO was applied on TIR band 10 (Landsat 8/OLI) images in order to establish a spatial distribution map for Dissolved oxygen. Figure 5 illustrates the produced maps for the DO for April, May and June 2017.

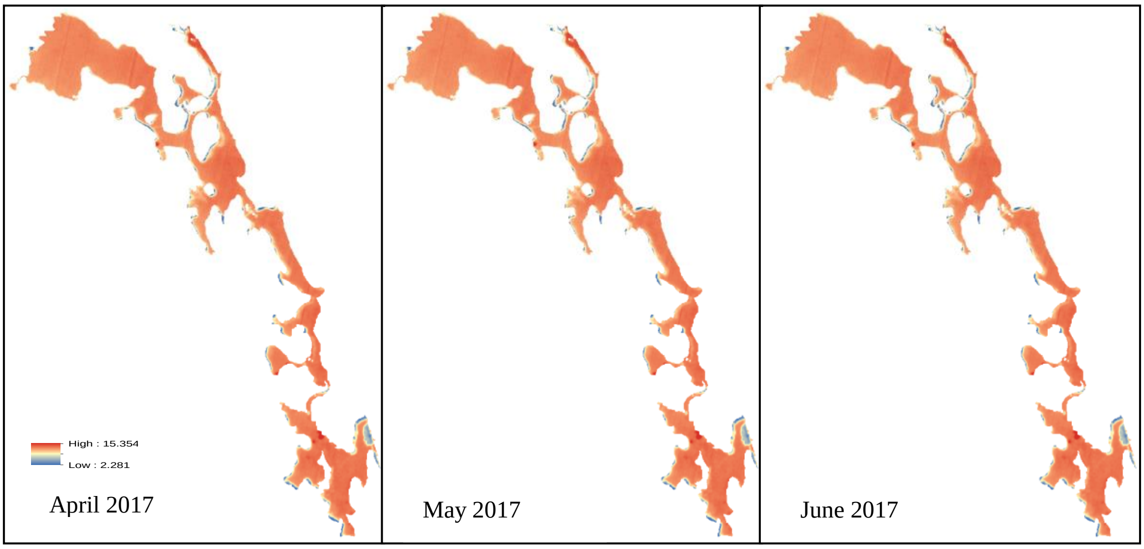

Figure 5: Combined Map of Lagoon SWT and DO

The spatial distribution of estimated DO generally shows a decrease along the shore line and increase towards the central part of the lagoon body. The lowers values of DO observed in the locations of 5, 6, 13, 14, 15, 16, 17, & 27 namely Annamalai, Mandoor, Lake road, New Bridge, Lagoon park, Urani, Thiruperunthurai and Fort park, where the temperatures are high. Similar results were obtained from the study of Harris *et al.*, (2013), where the mean spatial variation of dissolved oxygen varies between 3.00-5.00 mg/l in the same sites and also evidenced with the higher temperatures in dry season (mean temperature 33.34 ± 0.23°C).

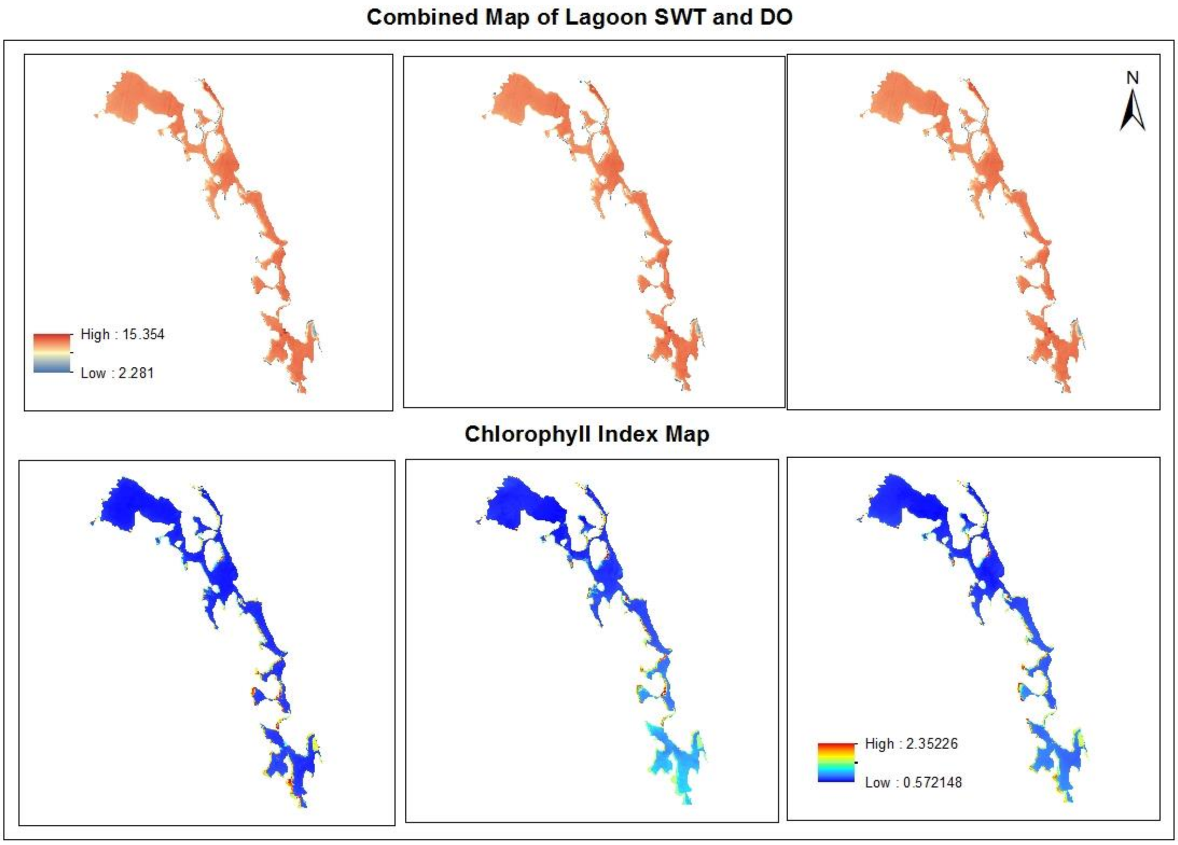

Figure 6: Combined Maps of Lagoon SWT - DO & Chlorophyll Index

Studies showed that estimated Chl-a index can be presented with band ratio of Band 5/Band 3(Lim and Choi, 2015) in Landsat 8. Models based on these type of different band combinations are used to compared to estimate the chlorophyll-a (Chl-a) concentration. Thus, the band ratio of Band 5 (NIR)/ Band 3(Red) was used in the study to prepare the Chlorophyll index for the lagoon aquatic vegetation to compare with the Lagoon SWT-DO model map (Figure 6).

The algal species available in the Batticaloa lagoon belong to five different groups with a total of 44 species (Harris and Vinoba , 2012) and the abundant aquatic plant is *Eichhornia crassipes* which has a high spatial and temporal distribution. The results revealed from the Chlorophyll index map shows that the higher index values are presence in the locations (Annamalai, Mandoor, Lake road, New Bridge, Lagoon park, Urani, Thiruperunthurai and Fort park) where the dissolved oxygen falls in between 3-5 mg/l. these conditions create a favourable environment for eutrophication leading to algal blooming. When considering the land use of these locations, Annamalai and Mandoor are surrounded by paddy lands and the *Yala* cultivation season begins in April. There are high possibilities of discharge of Nitrogen and Phosphorous into the lagoon system. The rest of the locations fall under the urban part of the district which are contaminated by the non-agricultural effluents and the water circulation is disturbed by the unplanned constructions. This is also supported by the study of Harris and Vinoba (2012) where the similar locations were noticed with dense algal blooms due to increase in SWT, lagoon shallowness and effluents from shrimp and paddy lands lay along lagoon shore. The values obtained from Chl –index map shows that the aquatic vegetation presence in Batticaloa Lagoon negatively correlated with dissolved oxygen and surface water temperature.

6. CONCLUSIONS

The study was aimed to use the field measurements of Dissolved Oxygen and Lagoon Surface Water Temperature to combine with Landsat-8/OLI TIR band 10 to derive Combined Lagoon SWT – DO map to detect the distribution of aquatic vegetation in Batticaloa Lagoon. A linear inverse relationship was obtained between field measurements of Lagoon SWT and DO ($R^2 = 0.4959$) in the study. The Regression model developed between field measurements of Lagoon SWT and DO used to create combined Lagoon SWT – DO map using TIR band 10 in Landsat 8. Thus, this study proved that the DO can be used as an indicator to detect the distribution of aquatic vegetation in the lagoon and can be used to predict the eutrophication condition in Batticaloa Lagoon.

7. ACKNOWLEDGEMENT

This study was supported by the Postgraduate Institute of Agriculture, Unviversity of Peradeniya, Sri Lanka under Research Facilitation Fund. We thank the Director and the committee, Postgraduate Institute of Agriculture, Unviversity of Peradeniya, Sri Lanka for providing financial support to carry out this research.

8. REFERENCES

- Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley, and V. H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications, 8, pp. 559–568. In: Monitoring Lake Simcoe Water Quality using Landsat TM Images, edited by Guan, X., 2009. Retrieved August 10, 2017 from https://uwspace.uwaterloo.ca/bitstream/handle/10012/4491/Xian%20Guan.pdf

- CEA/NORAD 1993. An Environmental Profile of the Batticaloa District: A Report written by MS Environetal Engineering Consultants for a study, Central Environmental Authority, Sri Lanka with NORAD collaboration. p.33. Retrieved June 20, 2017 from http://cea.nsf.ac.lk/bitstream/handle/1/4902/04486.pdf?sequence=1&isAllowed=y

- Chang, N.,Sanaz, I. and Benjamin,V., 2015. Remote Sensing for Monitoring Surface Water Quality Status and Ecosystem State in Relation to the Nutrient Cycle: A 40-Year Perspective. Critical Reviews in Environmental Science and Technology, 45, pp.101–166. Retrieved April 20, 2017, from https://www.researchgate.net/publication/267341064 (DOI: 10.1080/10643389.2013.829981)

- Chapman, V. J., Brown, J.M.A., Hill, C.F and Carr, J.L., 1974. Biology of Excessive Weed Growth in the Hydro-electric Lakes of the Waitako River, New Zealand. Hydrobiologia. 44, pp. 349-367.

- Gamito, S., Gilabert, J., Diego, C.M and Pérez-Ruzafa., A. 2005. Effects of Changing Environmental Conditions on Lagoon Ecology. In: Coastal Lagoons Ecosystem Processes and Modeling for Sustainable Use and Development, edited by Gönenç, I . E., Wolflin, J. P. and I. E. Gönenç. CRC Press 2004.

- Gholizadeh, M. H., Assefa M. M. Reddi, L., 2016. Review: A Comprehensive Review on Water Quality Parameters Estimation Using Remote Sensing Techniques. Sensors, pp. 2-43. Retrieved June 13, 2017, from www.mdpi.com/journal/sensors (DOI: 10.3390/s16081298).

- Gunawardena, A.R., Fernando, T.T., Nissanka, S.P and Dayawansa, N.D.K., 2014. Assessment of Spatial Distribution and Estimation of Biomass of Prosopis juliflora (Sw.) DC. in Puttlam to Mannar Region of Sri Lanka using Remote Sensing and GIS. Tropical Agricultural Research. 25(2), pp. 228–239. Retrieved April 18, 2017 from http://www.pgia.ac.lk/files/Annual_congress/journel/v25/Journal-No%202/Papers/8.%20Gunawardena%20-%2080%20OK%20Final%20-%20OK.pdf

- Harris JM, Vinobaba P., 2012 Impact of Water Quality on Species Composition and Seasonal Fluctuation of Planktons of Batticaloa lagoon, Sri Lanka. J Ecosyst Ecogr 2, p.117. (DOI:10.4172/2157-7625.1000117)

- Harris, J.M and Vinobaba, P., 2013. Assessment the Present Status of Batticaloa Lagoon, Sri Lanka by means of Water Quality, Fish Diversity. Indices and Pollution Indicating Planktons. J Biodivers Endanger Species 1:105. Retrieved May 10, 2017 from http://www.esciencecentral.org/journals/assessment-the-present-status-of batticaloa-lagoon-sri-lanka-by-means-of-water-quality-fish-diversity-indices-and-pollution-indicating-planktons-2332-2543.1000105.pdf

- Harris, J. M., Vinobaba, P., Kularatne, R. K. A., Kankanamge, C. E., 2016. Spatial and temporal distribution of cyanobacteria in Batticaloa Lagoon. Journal of Environmental Sciences. 47, pp. 211-218. Retrieved August 14, 2017 from www.sciencedirect .com (http://dx.doi.org/10.1016/j.jes.2016.01.020).

- IUCN Sri Lanka and the Central Environmental Authority., 2006. National Wetland Directory of Sri Lanka, Colombo, Sri Lanka.

- Jayasingham T., 2000. Batticaloa Lagoon: An Idle, In: Samad M, Wijesekera NTS and Birch A (Eds.) Status and Future Direction of Water Research in Sri Lanka, Proceedings of the National Conference, held at BMICH, Colombo, Sri Lanka, 4 -6th November 1998.

- JUGAS Ltd, 2010. A Participatory Assessment of the Dynamics, Seasonal variation and Current Status of Fishery in Batticaloa Lagoon. Final Draft Report. P. 126, Annexure 8, September 2010.

- Khalil, M. T., Saad, A. H. A., Ahmed, M. H. M.,Kafrawy S. B. E. and Emam, W. W.M., 2016. Integrated Field Study, Remote Sensing and GIS Approach for Assessing and Monitoring Some Chemical Water Quality Parameters in Bardawil Lagoon, Egypt. International Journal of Innovative Research in Science, Engineering and Technology. 5(8), pp. 14656- 14669. Retrieved July 25, 2017 from https://www.ijirset.com/upload/2016/august/77_Integrated.pdf (DOI:10.15680/IJIRSET.2016.0508077 14656)

- Kularatne, R.K., 2014. Phytoremediation of Pb by Avicennia marina (Forsk.) Vierh and spatial variation of Pb in the Batticaloa Lagoon, Sri Lanka during driest periods: a field study. Int J Phytoremediation. 16(5), pp. 509-23. Retrieved April 18, 2017 from http://www.ncbi.nlm.nih.gov/pubmed/24912232

- LANDSAT 8, 2016. Data Users Handbook (Version 2.0). Retrieved May 30, 2017 from https://landsat.usgs.gov/documents/Landsat8DataUsersHandbook.pdf

- Li, Y., W. Lu, and H. Wang, 2007. Inversing chlorophyll-a concentration by multi-temporal models using TM images, Proceedings of the 27th International Congress on High-Speed Photography and Photonics, 17-22 September, Xian, China. In: Critical Reviews in Environmental Science and Technology, 45, pp.101–166. Retrieved April 20, 2017, from https://www.researchgate.net/publication/267341064 (DOI: 10.1080/10643389.2013.829981)

- Lim, J.; Choi, M. Assessment of water quality based on Landsat 8 operational land imager associated with human activities in Korea. Environ. Monit. Assess. 2015, pp.187, 1–17.

- Santini, F., Alberotanza, L., Cavalli, R.M., Pignatti, S., 2010. A two-step optimization procedure for assessing water constituent concentrations by hyperspectral remote sensing techniques: An application to the highly turbid Venice lagoon waters. Remote Sens. Environ. 114, pp. 887–898.

- Sastroutomo, S. S., 1985. The Role of Aquatic Vegetation in the Environment. Workshop on Ecology and Management of Aquatic Weeds, Jakarta, Indonesia. p. 26-29.

- Selvadurai, N 1997. Analytical studies of Batticaloa and Valaichenai Lagoon. A Technical report.

- Shireman, J. V., Haller, N., Canfield, D.E. Jr and Vandiver, V.T., 1982. The Impact of Aquatic Resources of the United States: An Overview. U.S. EPA-600/4-81-007.

- Smith, V. H. 1990. Introduction to Applied Phycology, SPB Academic Publishing. In: Monitoring Lake Simcoe Water Quality using Landsat TM Images, edited by Guan, X., 2009. Retrieved August 10, 2017 from https://uwspace.uwaterloo.ca/bitstream/handle/10012/4491/Xian%20Guan.pdf

- Smith, V. H. 1998. Limitations and Frontiers in Ecosystem Ecology. New York: Springer-Verlag. In Monitoring Lake Simcoe Water Quality using Landsat TM Images, edited by Guan, X., 2009. Retrieved August 10, 2017 from https://uwspace.uwaterloo.ca/bitstream/handle/10012/4491/Xian%20Guan.pdf

- Sobadini, K., 2006. Aquatic weeds in Sri Lanka, edited by, Darshani, S., Biodiversity, Water Resources. Retrieved May 10, 2017 from http://environmentlanka.com/blog/2006/aquatic-weeds-in-sri-lanka/