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Detection and Mapping of Spatial Distribution of Floating Algae in Batticaloa Lagoon, Sri Lanka Using Remote Sensing & GIS

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Abstract - This study intended to detect and map the spatial distribution of floating algae (FAg) in Batticaloa Lagoon in Sri Lanka using sub-pixel classification of satellite imagery and to assess the impact of land use/ land cover (LULC) and water quality in the lagoon surrounding on its spatial distribution. Cloud free three Sentinel-2A satellite images were acquired for the dry period of May to September 2017. Since an alga is mixed with water in most of the locations, mixed pixels were present in the images. Hence, sub-pixel classification was used to detect the FAg. Near real time field measurements of selected water quality parameters were conducted in 30 locations in monthly interval for the period of March 2017 to February 2018 to develop a water quality index (WQI) and to identify its relationship with the presence of FAg. A buffer zone of 3 km was created around the lagoon to obtain LULC distribution to study their influence on FAg. Spatial coverage of FAg showed significant correlations ($p<0.05$, $p<0.01$) with water quality of the lagoon in dry season. The developed WQI showed a strong inverse relationship with the coverage of FAg ($r^2 = 0.78$) in dry season. Further, the locations with high (> 70%) and moderate (50-70%) level of algal infestation showed poor (< 50%) WQI, where the area was prone to urban and agricultural runoff discharges. However, the sampling locations confined to natural habitats were free from FAg and showed better (> 50%) WQI. The study shows that the sub-pixel classification has the potential to detect and map the level of spreading of FAg which can be linked to overall water quality of the lagoon represented by WQI and the LULC in the lagoon surrounding.

Keywords - Floating Algae, Land Use/Land Cover, Spatial Coverage, Sub-Pixel Classification, Water Quality Index.

I. INTRODUCTION

Coastal lagoons and Estuaries are described as the ecosystems with high levels of biotic production [1]. Algae are one of the important biotic components of the coastal lagoons and estuaries which act as a producer of oxygen within the environment via photosynthesis [2], provide the primary food source for most of the invertebrate animals, provide habitat for small animals as a means of increasing productivity of fish and play important roles in the ecology of coral reefs by acting as the major reef formers by depositing Calcium Carbonate [3]. Even, Algae can supply useful information about the productivity and health of aquatic ecosystems. For instance, some forms of algae are indicative of low nutrient conditions while others indicate high nutrient levels and blooming conditions [2], [3].

However, studies [4], [5] show that it is hard to find situations where the algae maintain an ecosystem balance and fulfill the requirements of humans because, estuaries and lagoons are very susceptible for the disturbances caused by natural and anthropogenic processes which lead to nutrient enrichment. Estuaries tend to be naturally eutrophic because of discharge of nutrients through surface runoff. Eutrophication plays an important role in promoting the excessive growth of algae [3] under elevated level of Nitrogen and Phosphorous which leads to algal blooms. Majority of the coastal ecosystems in Sri Lanka are facing various anthropogenic threats mostly from point and non-point sources. Large quantities of nitrogen and phosphorous are added through non-point source pollution with agricultural runoff which leads to eutrophication [6], [7] and infestation with floating algae.

The Batticaloa lagoon located in Eastern Sri Lanka is the main live wire having a great impact on the life of people and the environment. The lagoon has been subjected to significant pollution as a result of accelerated development works in the post - Tsunami (2004) and post-conflict (2009) periods. Batticaloa Lagoon can be categorized as a barrier-built estuary under geomorphological conditions [6] indicating high rate of siltation and eutrophic in nature. The northern part of the lagoon is frequently affected by algae dominated by *Microcystis aeruginosa* during dry season [8], while the southern part of the lagoon is dominated by floating aquatic plants. This is mainly due to salinity variation where the northern lagoon shows brackish and southern lagoon shows fresh water condition. However, the presence of FAg becomes extinct with the onset of monsoonal rain in October/November due to salinity reduction in the lagoon water. Studies show that the FAg is highly responsible for the eutrophic condition of the lagoon which results unpleasant odour, degradation of water quality and absence of advantageous algae [8], [9].

Remote sensing approach can provide reliable information about the spatial distribution of algae under good spatial and temporal coverages [10], [11]. The launch of Sentinel-2A Multispectral Imager (S2A- MSI) in 2015 opened up a great potential in lake remote sensing [11]. The imagery with 10 m, 20 m and 60 m spatial resolution gives an opportunity to study even small water bodies. However, detecting the distribution of FAg in the surface of the lagoon using satellite imagery is a difficult task. It can be observed that naturally FAg is mixed with lagoon water and other aquatic vegetation creating mixed pixels in satellite images. Several studies [4], [12], [13] have shown that sub-pixel classification can be used as an effective tool to avoid the mixed pixel problem in mapping of wetlands and coastal areas. Sub-pixel classification is an advance image processing method designed to detect materials that are smaller than an image pixel, covering an area as small as 20% of a pixel [14] using multispectral imagery.

The objective of the study was to map the spatial distribution pattern of FAg in the lagoon with Sentinel 2A satellite images using sub-pixel classification approach. It was also intended to develop a water quality index (WQI) and assess the impact of water quality and Land Use/ Land Cover (LULC) in the reservation area buffer in lagoon on distribution of FAg in the dry season.

II. MATERIALS AND METHODS

2.1. 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 km in length and is 0.5- 4.0 km in width and covers an area of 168 km^2 (Figure 1).

Three distinct zones can be identified in this lagoon as the upper saline zone, the middle transitional zone with salinity fluctuations and the lower predominantly fresh water zone [15]. The lagoon area receives around 60% of the rainfall from the North-East monsoonal (NEM) period (October to February) characterized by high mean precipitation (1250 ± 230 mm). A distinct dry season prevails over the lagoon area for five months during the South- West monsoonal (SWM) period (March to September) where only 12% of the annual rainfall (300 ± 23 mm) occurs during this period. The mean atmospheric temperature ranges between 27.5 to 33.6 °C during wet and dry seasons, respectively [16].

2.2. Acquisition of satellite images

Cloud free S2A (MSI) images with 10, 20 and 60 m resolution in UTM projection over Batticaloa Lagoon were acquired for 2017 and 2018 representing dry season (May, July and September 2017) of the study area from the USGS website (http://earthexplorer.usgs.gov/). The multispectral images were used along with vector layer of Batticaloa Lagoon boundary extracted from 1:50000 scale topographic maps of the Survey Department of Sri Lanka to subset the study area.

2.3. Detection of floating algae

The S2A images of 10 m spatial resolution for dry period of 2017/2018 were used for sub-pixel classification to detect the distribution of Fag. Sub-pixel Classifier in ERDAS Imagine 2014 was used as the tool. According to [17], the procedure contained five major steps including Preprocessing, Environmental Correction, Signature Derivation, Signature Refinement and Material of Interest (MOI) Classification. FAg was considered as the MOI in the sub-pixel classification. The classes were defined and ordered from low to high reflection which indicated the level of pixel algal coverage.

2.4. Land Use/Land Cover mapping

The S2A images were used to generate LULC maps for the period of 2017/2018 according to 1:50000 scale topographic maps of Survey Department, Sri Lanka (2016). A buffer zone of 3 km was created around the lagoon to obtain the LULC distribution around the lagoon area to study the influence on the fluctuation of FAg. The images were classified using unsupervised classification technique into 36 classes with the aid of field observations and high resolution Google Earth Images, LULC classes were identified and similar classes were merged to obtain 10 LULC classes which are dominant in the area. Accuracy assessment for the maps was also carried out. The software used ArcGIS 10.5.1, ERDAS IMAGINE 2014 and Google Earth Pro.

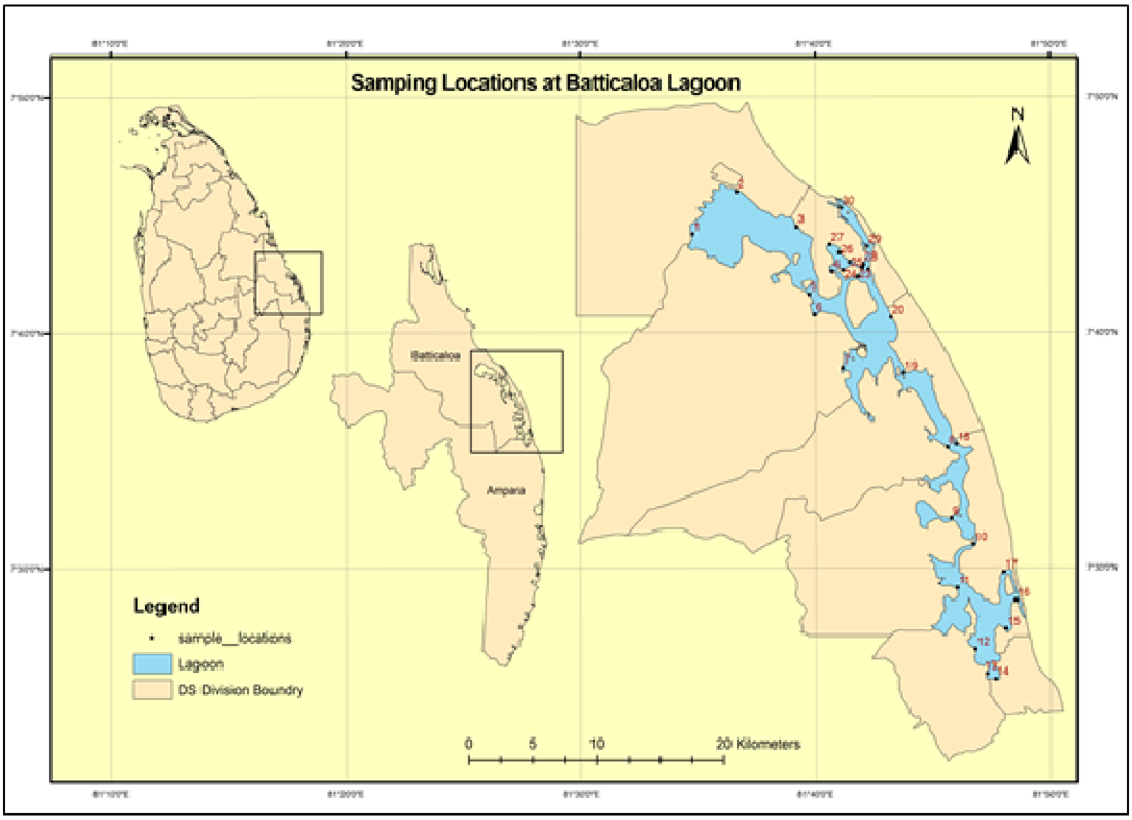

Figure 1. Map of the study area & Sampling locations in Batticaloa Lagoon

2.5. Water sampling, analysis and formulation of Water Quality Index

A total of thirty (30) water sampling locations (Table 1) were identified along the coast of the Batticaloa Lagoon (10-15 m from the shore). The surface water samples between the depths of 15-30 cm were collected once a month for a period of one year from March 2017 to February 2018 covering dry and wet seasons of the year. *In-situ* field measurements were taken for Water Surface Temperature (WST), Dissolved Oxygen (DO), Electrical Conductivity (EC), Total Dissolved Solids (TDS and pH, while other physical and chemical parameters such as Salinity, Turbidity Hardness, Alkalinity, Nitrate, Nitrite and Phosphate were analyzed at National Water Supply & Drainage Board (NWSDB), Batticaloa. In addition, water level was measured at the sampling locations.

Table 1. Description of the sampling locations with GPS coordinates

ID	Locations	Latitude	Longitude	Land use/Land cover features
1	Pankudaveli	N 7° 44' 10.2"	E 81° 34' 47.2"	Mangroves systems and natural vegetation
2	Eravur	N 7° 45' 58.9"	E 81° 36' 38.5"	Close to rice mill outlets and paddy lands

3	Chathrukondan	N 7° 44' 28.6"	E 81° 39' 13.1"	Surrounded by a mangroves wetland
4	Thiruperunthurai	N 7° 42' 34.7"	E 81° 40' 44.5"	Urbanized area. Disturbed by unplanned infrastructures. Highly infested with floating algae
5	Vavunatheevu	N 7° 41' 36.8"	E 81° 39' 43.6"	Close to newly built bridge, Natural vegetation
6	Kannankuda	N 7° 40' 44.7"	E 81° 39' 58.3"	Mangroves system and paddy lands
7	Kothiyapulai	N 7° 38' 29.1"	E 81° 41' 9.5"	Mangroves system and paddy lands
8	Ampalanthurai	N 7° 35' 6.9"	E 81° 45' 36.1"	One of the well-known wet land in the Eastern Province
9	Palugamam	N 7° 32' 5.8"	E 81° 45' 46.3"	Paddy lands. High abundance of floating aquatic plants and cattail grass
10	Paddiruppu	N 7° 31' 0.2"	E 81° 46' 42.8"	Close to newly built bridge and paddy lands.
11	Mandoor	N 7° 29' 8.2"	E 81° 46' 1.7"	Paddy lands. High abundance of floating aquatic plants.
12	Annamalai	N 7° 26' 32.3"	E 81° 46' 48.6"	Paddy lands. High abundance of floating aquatic plants.
13	Sorikalmunai	N 7° 25' 30.1"	E 81° 47' 17.4"	Paddy lands. High abundance of floating aquatic plants
14	Kittanki	N 7° 25' 16.2"	E 81° 47' 39.8"	Disturbed by unplanned infrastructures. Highly infested with floating algae. Paddy lands. High abundance of floating aquatic plants
15	Thuraineelavanai	N 7° 27' 23.7"	E 81° 48' 6.7"	Wetland. Surrounded by paddy lands and close to rice mills.
16	Periyakallar	N 7° 28' 36.6"	E 81° 48' 32.1"	Close to Bar mouth. Surrounded by natural vegetation
17	Onthachimadam	N 7° 29' 48.7"	E 81° 48' 1.1"	Close to Kallar causeway.
18	Kurukalmadam	N 7° 35' 14.8"	E 81° 45' 59.9"	Close to paddy lands. Ferry service point
19	Manmunai	N 7° 38' 16.3"	E 81° 43' 46.2"	Close to Manmunai bridge
20	Kathankudy	N 7° 40' 37.5"	E 81° 43' 13.2"	Urban location. Highly disturbed by unplanned urbanization and close to Kathankudy UC Dumpsite
21	Kallady	N 7° 42' 40.4"	E 81° 42' 16.5"	Urban location. Highly disturbed by infrastructure. Close to Kallady Bridge
22	Batticaloa Gate	N 7° 42' 44.4"	E 81° 42' 0.4"	Urban location. Highly disturbed by infrastructure
23	Fort Park	N 7° 42' 21.5"	E 81° 41' 49.3"	Urban location. Highly disturbed by infrastructure
24	Lake Road	N 7° 42' 38.0"	E 81° 41' 11.1"	Urban location. Highly disturbed by infrastructure
25	New Bridge	N 7° 42' 58.9"	E 81° 41' 27.7"	Urban location. Highly disturbed by infrastructure and unplanned New Bridge causeway
26	Lagoon park	N 7° 43' 21.3"	E 81° 41' 2.1"	Urban location. Highly disturbed by infrastructure and landfilled area
27	Urani	N 7° 43' 42.7"	E 81° 40' 38.0"	Urban location. Highly disturbed by infrastructure. Close to Municipal

				dumping site
28	Arasadi	N 7° 42' 53.4"	E 81°42'3.5"	Urban location. Highly disturbed by infrastructures
29	Uppodai	N 7° 43' 38.3"	E 81° 42' 13.9"	Urban location. Highly disturbed by infrastructure
30	Mugathuvaram	N 7° 45' 16.8"	E 81° 41' 5.9"	Close to Palameenmadu Bar mouth and surrounded by natural vegetation and mangroves.

Principle Component Analysis (PCA [18] was used to develop a WQI index for the Batticaloa Lagoon. PCA was carried out using SPSS-16.0. The following steps were used to develop the WQI; Selection of variables, Run correlations, Perform PCA and Factor Analysis, Create factor scores, Compute initial index and Compute WQI. WQI was calculated according to the following formula adopted from [19].

$$WQI = \sum_{n=1}^{n} (\lambda_n / \sum \lambda) \times PC_n \qquad \text{....................Equation 1}$$

Where
n: The number of effective components
λn, are the Eigen values of the effective components of water quality parameters
Σ λ is sum of the Eigen values
PCn are the n critical principal component factor scores

A Standardized WQI was developed for easy interpretation of the level of water quality (as a %) where, the values range from 0 to 100%, using the following formula adopted from [20].

$$WQI\ (\%) = \frac{(\text{Initial score of Sampling Location} - \text{Min initial score})}{(\text{Max Initial score} - \text{Min Initial score})} \times 100 \qquad \text{.....Equation 2}$$

2.6. Assessment of the relationship between WQI and coverage of FAg

Correlation analysis was carried out to test the relationship between WQI and the coverage of FAg in dry season. A linear regression model was developed using relationship between the coverage of FAg and WQI.

III. RESULTS AND DISCUSSION

3.1. Spatial and temporal distribution of Floating Algae in Batticaloa Lagoon

The classified images (Figure 2) of FAg for the period of 2017/2018 revealed that FAg is highly noticeable in dry season of the year in the northern part of the lagoon. According to image classification, the total algal extent is around 3.4 km^2 in the early dry period (May 2017), 4.1 km^2 in the mid dry period (July 2017) and 5.2 km^2 in the later part of dry period (September 2017). The resulting classification (Figure 2) at sub-pixel level indicates that the level of distribution of FAg highly varies between sampling locations. Further, it depicts that the floating algae is concentrated more in the locations close to urban part of the lagoon shore.

Table 2 presents the percentage coverage of FAg in individual pixels in Batticaloa Lagoon during dry period. The coverage of FAg increased throughout dry period from April to September in most of the sampling locations.

The lagoon shows 20-40 % of algal coverage per pixel in the early part of dry season (Figure 2 and Table 2) and increased persistently throughout dry period and reached to 60-90 % in the later part.

Table 2. Percentage of FAg in Batticaloa lagoon according to sub-pixel classification

Location ID	Sampling Locations	Pixel Algal Percentage (%)		
		Early dry period	Mid dry period	Late dry period
1	Pankudaveli	Free from FAg	Free from FAg	Free from FAg
2	Eravur	Free from FAg	Free from FAg	20-30
3	Chathrukondan	Free from FAg	Free from FAg	Free from FAg
4	Thiruperunthurai	40-50	50-60	80-90
5	Vavunatheevu	Free from FAg	20-30	20-30
6	Kannankuda	Free from FAg	30-40	50-60
20	Kathankudy	20-30	60-70	60-70
21	Kallady	Free from FAg	Free from FAg	Free from FAg
22	Batticaloa gate	30-40	50-60	60-70
23	Fort park	30-40	70-80	80-90
24	Lake road	40-50	70-80	80-90
25	New bridge	40-50	80-90	80-90
26	Lagoon park	40-50	80-90	80-90
27	Urani	40-50	80-90	80-90
28	Arasadi	Free from FAg	20-30	20-30
29	Uppodai	Free from FAg	Free from FAg	Free from FAg
30	Mugathuvaram	Free from FAg	Free from FAg	Free from FAg

The sampling locations such as 4, 24, 25, 26, 27 and 20 show high algal infestation throughout dry period varies between 40-90 % which are surrounded by urban built ups and unplanned structures across the lagoon. Further, studies show [7], [9] that the Batticaloa Municipal city limit is situated around Batticaloa lagoon and most of the urban development taken place which includes settlements, commercial buildings, pavements/parks, roads and bridges across the lagoon, prawn farms and landfills is confined to the lagoon shore. The influences of these anthropogenic activities show subsequent impacts on algal communities in shallow aquatic system. Meanwhile, locations such as 1, 3, 21, 29 and 30 were identified as the locations free from FAg whereas, 5, 6 and 28 were free from FAg in the early dry period and only have low coverage (20-30 %) of FAg in the mid and late dry period. These areas are surrounded by mangroves and other natural vegetation. The accuracy of the maps was assessed using ground truth data. The overall accuracy of classification of images was 80.0% for May, 82.5% for July, 83.0 % for September and the Kappa Coefficients were 0.89, 0.89 and 0.88 respectively.

3.2. Impact of LULC on distribution of FAg in Batticaloa Lagoon

Figure 3 presents the link between LULC in the buffer zone and the distributional pattern of FAg in the lagoon.

Figure 3 illustrates that the western bank of the lagoon is occupied by paddy lands which drain agricultural pollutants into the lagoon whereas the eastern bank of the lagoon is highly populated with settlements and urban infrastructure. Further, Figure 3 shows that dense coverage of FAg (> 70%) is found at the locations surrounded by settlements which are confined to Manmunai North, Eravur Town and Kathankudy DSDs. The unplanned bridges and causeways across the lagoon obstruct free flow of lagoon water which enhances siltation and eutrophication during dry season increasing the abundance of FAg in the locations of 4, 23, 24 and 25. Lagoon filling is another type of urban expansion in the buffer zone [7], [9] which is contributed to sedimentation of the lagoon shore. Settlements and commercial buildings hamper free flow of lagoon water in certain locations such as 22, 26 and 27 which maintains a high level (40-80 %) of algal coverage throughout dry season. The indiscriminate dumping of municipal solid waste also favours the eutrophication condition at 4 and 20 resulted in high level (60-80 %) of floating algal coverage. This is also evident from the study by [21] which indicates that these places have high turbidity which enhances the growth of algae in dry season especially with cyanobacteria sp.

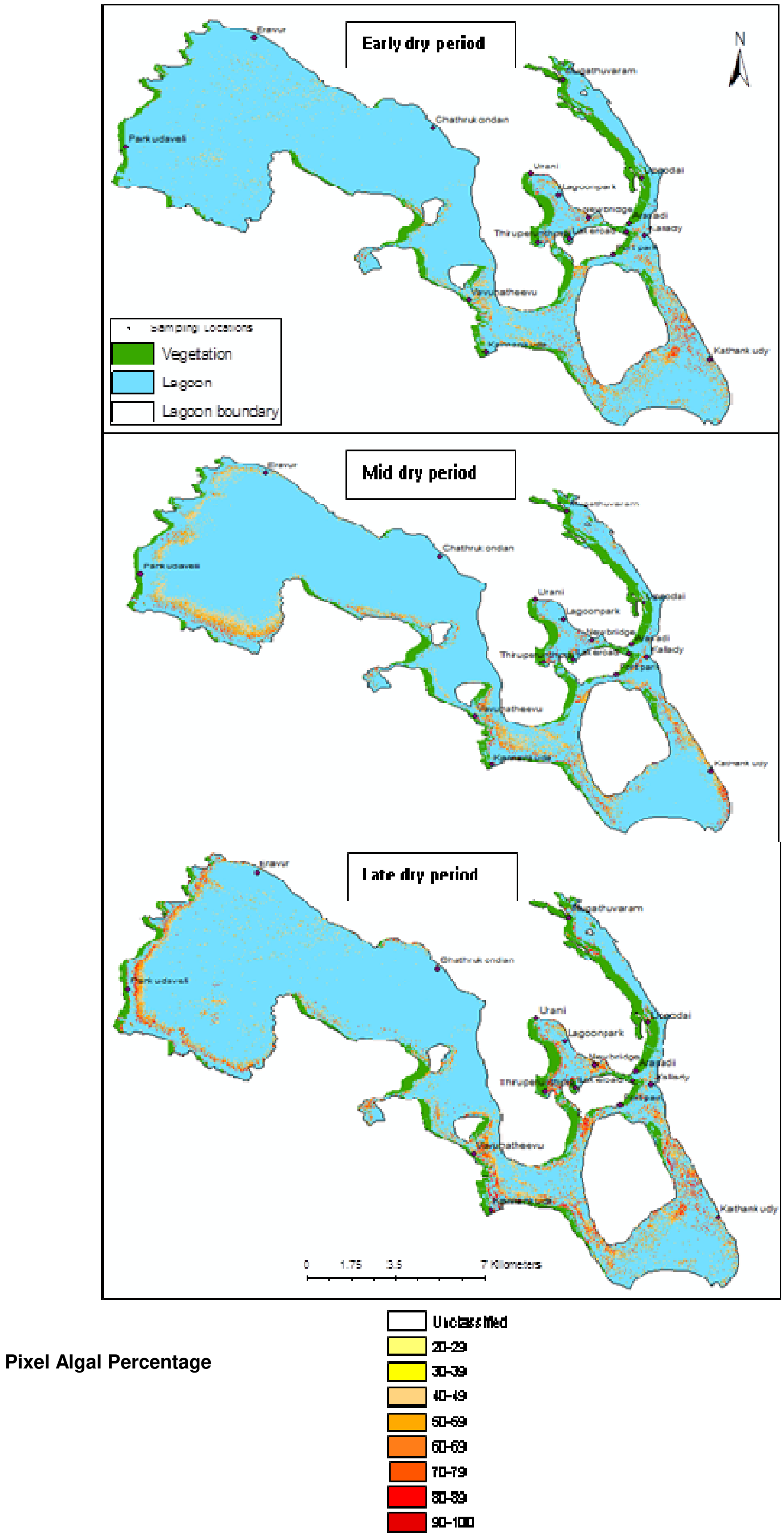

Figure 2. Distribution of FAg in Dry Season (2017/2018)

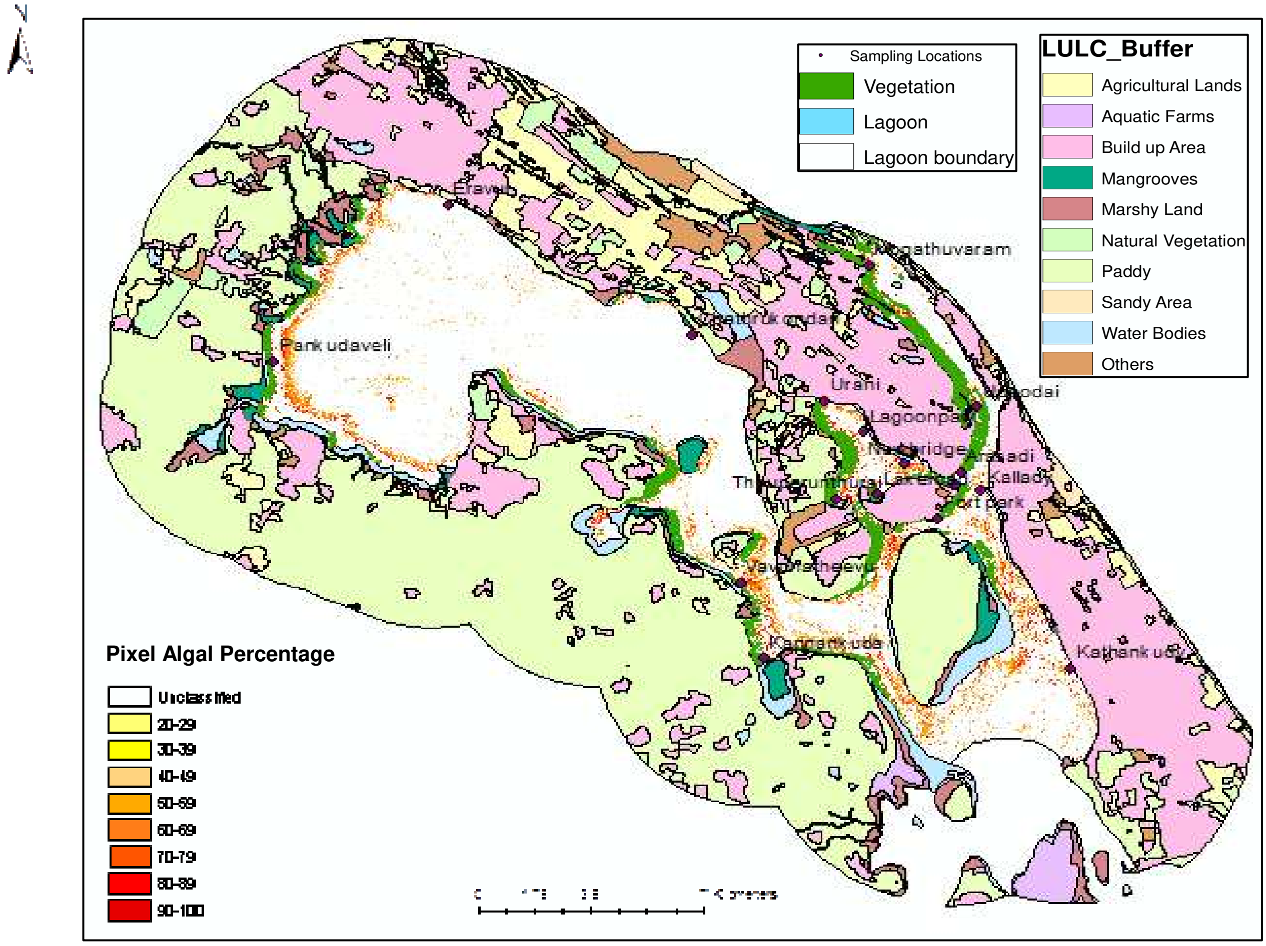

Figure 3. Distribution of the FAg along with LULC of the buffer zone of Batticaloa Lagoon during dry period (2017/2018)

A moderate level of FAg coverage (50-70%) at early dry period were identified in the locations confined to Eravur Pattu and Manmunai West DS divisions, which are surrounded by paddy and agricultural lands. Accumulation of nutrients transported through runoff coming from paddy and agricultural land uses and increased salinity level favour the growth of FAg in these locations. Locations surrounded by natural vegetation (1, 3, 29 and 30) are free of algae throughout the dry period. The studies by [8], [22], [23] indicate that the natural vegetation play a protective role in safeguarding stream health by retarding eutrophication and presence of harmful algae in the water bodies.

4.3. Impact of water quality on distribution of FAg

Water pollution leads to heavy infestations of algae in the coastal waters [24]. The spatial distribution of FAg in Batticaloa Lagoon shows significant ($p< 0.05$, $p<0.01$) positive and negative correlations with more than one physicochemical parameters of the lagoon water in dry season. The algal coverage showed high positive correlation ($p< 0.05$) with Salinity ($r = 0.53$), EC ($r = 0.58$), pH ($r = 0.54$), Hardness ($r = 0.63$), TDS ($r = 0.64$) and Turbidity ($r = 0.51$). A weak positive correlation ($p<0.05$) was observed between algal coverage and WST ($r = 0.33$) and Alkalinity ($r = 0.32$) while the algal coverage was negatively correlated with DO ($r = -0.76$) and Water level ($r = - 0.71$) ($p<0.01$) in the dry season.

The northern lagoon shows alkaline condition with variation of pH (8.0-8.7), Alkalinity (62.3-100.1 mg/l) and Hardness (1754.3 -4710.0 mg/l) under the influence of high WST which was around 30.0 °C in the dry season. The sampling locations 4, 20, 25, 22, 25, 26 and 27 (Table 3) with high algal coverage (60-90 %) fall into the salinity zone of the lagoon. The variation of salinity (6-21 ppt) and conductivity (14-34 ms/cm) along with low DO level (< 7 mg/l) in dry season favour the growth and distribution of brackish water algae. A study conducted by [21] reported that high salinity level with EC and low DO level favour the growth of *Microcystis* sp. A strong positive correlation of algal coverage with TDS and Turbidity indicate that the presence of floating algae in the northern lagoon at the locations of 4, 20, 25, 22, 25, 26 and 27 is attributed to accumulation of nutrients and turbidity during dry season. The classified images of FAg (Figures 2 & 3) show that the distributions of algal communities are primarily located along the shore of the lagoon. The reduction in the water level of these locations increases the WST and reduces DO level and enhances the prevalence of FAg in dry season.

Nitrates and phosphates are closely related to the phytoplankton distribution [25]. The algal coverage in the lagoon is strongly correlated with Nitrates ($r = 0.51$, $p<0.05$) and Phosphates ($r = 0.84$, $p<0.01$). Sampling locations such as 4, 20, 25, 22, 25, 26 and 27 were observed with high nitrate (> 5 mg/l) and phosphate levels (> 0.1 mg/l) during the mid-part of dry season compared to other locations in the northern lagoon. Accumulation of nitrates and phosphates facilitates eutrophication in the lagoon during dry season. However, sampling sites such as 1, 3, 29 and 30 showed lower values of nitrate and phosphate levels in both seasons. Study by [22] indicates that the natural vegetation improves water quality due to lower human intrusion and higher biological nutrient retention capacity.

According to the developed WQI, most of the sampling locations in northern part of the lagoon have WQI below average (50 %) in both seasons. Thiruperunthurai (4) shows the minimum value of WQI (<10%) in both seasons. The sampling locations with low WQI (below 50%) are prone to urban and agricultural runoff discharges and highly abundant with floating algae. The adjacent land uses of these locations are highly exposed to anthropogenic activities such as rapid urbanization and intensive agricultural activities. Nutrient loading is higher in these locations compared to others. The sampling locations with WQI above average (50%) are the places with less human interference and consist of natural habitats. However, certain locations such as 5, 6, 7 and 8have the WQI close to 50% which should be able to improve with better land management practices.

The algal coverage in the lagoon shows highly significant correlation ($p<0.01$) with WQI ($r = 0.83$) in the dry season. Strong inverse linear relationship ($r^2 = 0.78$) was obtained from the regression analysis between algal coverage and WQI. The inverse relationship of algal coverage and WQI of the lagoon reveals that the distribution of FAg is seemed to be high where the quality of the water is degraded. The sampling locations with high algal infestation (> 60 %) showed WQI below average (50 %) in dry season. Thiruperunthurai (4) and New Bridge (25) showed the minimum value of WQI (<10%) where the algal coverage ranged between 80-90% throughout dry period (Table 2). The sampling locations with low WQI (below 50%) are prone to urban and agricultural runoff discharges and the adjacent land uses of these locations are highly exposed to anthropogenic activities such as rapid urbanization and intensive agricultural activities. Hence, the study identifies that there is a strong relationship between water quality and presence of floating algae during the dry period in Batticaloa lagoon.

IV. CONCLUSIONS

Sub-pixel classification provided a great potential in detecting spatial and temporal distribution of FAg in Batticaloa Lagoon. The classified images of FAg in the lagoon for the period of 2017/2018 resulted that the total algal extent is around 3.4 - 5.2 km^2 in the early to latter part of dry period in the region. According to the study, high level of FAg is an indication of poor water quality. Sampling locations with high algal infestation (> 70%) in the northern part of the lagoon showed WQI below 50% in dry season and these locations are surrounded by settlements. Sampling locations of Thiruperunthurai and New Bridge showed the minimum value of WQI (<10%) where the algal coverage detected between 80-90% throughout the dry period. The sampling locations surrounded by natural vegetation were free from FAg and showed WQI above 50%. The findings show that there is a strong link between the distribution of FAg and LULC of lagoon buffer zone and the water quality of lagoon water. Based on the results drawn from the study it is identified the S2A images and sub-pixel classification have the potential to detect the level of risk in the spreading pattern of FAg along with WQI and LULC dynamics in the lagoon. The developed combined FAg-LULC map and FAg-WQI regression model can be used to identify the locations which are affected by FAg in order to take proper control measures.

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