ASSESSMENT OF ALGAL BLOOMS IN KURUNEGALA LAKE USING INDICES DERIVED WITH OPTICAL REMOTE SENSING DATA

S.C.D. Siyambalapitiya[1] and N.D.K. Dayawansa[2]
[1]Postgraduate Institute of Agriculture
University of Peradeniya
Email: deshani_siyambalapitiya@yahoo.com .au
[2]Department of Agricultural Engineering
Faculty of Agriculture
University of Peradeniya
Email: ndkdayawansa@yahoo.com

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ABSTRACT: Kurunegala lake is located in the heart of Kurunegala city and serves as the supplementary water source for city water supply. In 2002, 2003 and 2009, algal blooming conditions have occurred in the lake. When surface waters become enriched with nutrients such as Phosphorous, the phytoplankton community often dominates by algae species. In 2002, dominant species was *Cylindrospomosis rasiborskii*, 2003 dominant species were *Microcystis aeruginosa* and *Anabaena sp* and in 2009 the dominant species was *Botrycoccus brunnaii* and the lake was identified as hyper-eutrophic. After this situation, rehabilitation of the lake has started in 2003 and has taken about 3 years for the completion. Routine water quality analysis will help to identify algae bloom conditions with the use of traditional methods which are time consuming and costly. Optical remote sensing can be used to develop different indices based on reflectance from the water surface to establish relationships with the concentrations of algae. Objective of this study was to develop indices/ band ratios using optical remotely sensed data to assess the algal bloom conditions in Kurunegala lake. Therefore, two periods were identified with respect to rehabilitation of the tank to develop these indices/ band ratios. Six Landsat satellite images were selected to represent the two periods (Landsat ETM+: 24-Aug-2002, 28-Nov-2002, 31-Jan-2003, 16-Feb-2003 (before rehabilitation), Landsat 8: 21-Jan-2014, 22-Feb-2014, 10-Mar-2014, 11-Apr-2014 (after rehabilitation). Six band ratios/ indices were developed. These index/ band ratio values were statistically assessed to identify possible differences between pre and post rehabilitation. Land use/ land cover change around the lake was also assessed to identify the impact on water quality. According to the results, there is a statistically significant different observed in the index/ band ratio values before and after rehabilitation. When considering land use change inside the 500 m buffer from the tank from 2001 to 2014, area of settlements has increased by 30% and vegetation cover has decreased by 21.5%. High concentrations of Nitrates and Phosphates were observed in the lake before rehabilitation. To identify the best index/band ratio to be used in the future, this study needs some modifications such as photosynthetic pigment validation using ground truth and laboratory data. These indices/ band rations coupled with ground truth data can be successfully used to identify the changes occur in the lake.

1. INTRODUCTION

Eutrophication of inland water bodies which nourishes algal blooms is a severe social, environmental and economic problem (Duan *et al*., 2009). Algae bloom condition has been recognized as a result of importing nutrients such as inorganic nitrogen and phosphorous into freshwater bodies. Routine water quality analyses will help to identify algal blooms with the use of traditional methods. However, these traditional methods are very time consuming and not cost effective especially for large water bodies. Studies have confirmed that remote sensing coupled with Geographic Information System (GIS) could offer integrated solutions to map quality of surface waters (Dewidar and Khedr, 2005; Hereher *et al*., 2010). Eutrophication in water bodies is associated with growth of phytoplankton biomass which is easily detected by satellite sensors (Dewidar and Khedr, 2001; Vincent *et al*., 2004). Landsat imagery with fine spectral resolution increases the accuracy of quantifying Secchi disk depth, chlorophyll-a (Farag and Gamel, 2012).

Objective of this study was to develop satellite based indices/ band ratios to identify the presence of algal blooms in Kurunegala lake and to assess the land use changes in the immediate catchment to identify possible threats to the lake. It was also attempted to assess the water quality variation of the lake before and after rehabilitation.

1.1 Study Area

Kurunegala lake is situated in Daduru Oya river basin and at present it has an area of 37 ha and a maximum depth of 2.5 m. Figure 1 shows the location of Kurunegala lake in Kurunegala District.

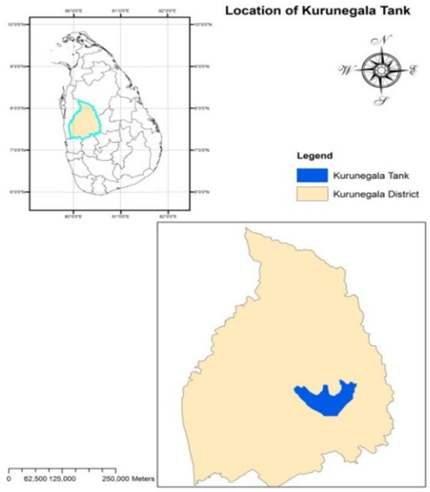


Figure 1: Location of Kurunegala Lake in Kurunegala District

Jayasinghe (2011) stated that this tank has no perennial inflow and the water spills over the outflow sluice only during rainy season. The lake does not get flushed regularly and water retention time is very high and stagnant. The drainage basin is relatively small and the lake receives rainwater and storm water from its micro catchment. Kurunegala lake is the main supplementary water source for Kurunegala Town. According to Jayasinghe (2011) nearly 2500 m3 of water per day is extracted from the lake for water supply. Kurunegala lake is very important for groundwater recharge to the surrounding area and for its aesthetic appearance. According to Jayasinghe, (2011) there have been three algal bloom conditions occurred in the lake in 2002, 2003 and 2009 respectively. In 2002 and 2003, the water source has been identified as unsuitable for drinking and extraction of water has been banned temporarily (Jayasinghe, 2011). Subsequently, rehabilitation of tank has started in 2003 and has taken about 3 years to complete. Again algal blooms have appeared in 2009 showing poor lake management practices.

2. MATERIALS AND METHODS

Both spatial and non-spatial data was used in the study. As the spatial data Landsat ETM^{+} images and Landsat 8 OLI images was used. Secondary data on water quality were obtained from the regional laboratory of the National water Supply & Drainage Board, Kurunegala. ERDAS Imagine 2014 and ArcGIS 10.2 software were used in remote sensing and GIS analysis and statistical analysis was carried out using Minitab 15.

2.1 Developing Indices/ Band Rations Using Landsat Satellite Data

Satellite images were selected based on the algal bloom conditions occurred in the lake as shown in Figure 2.

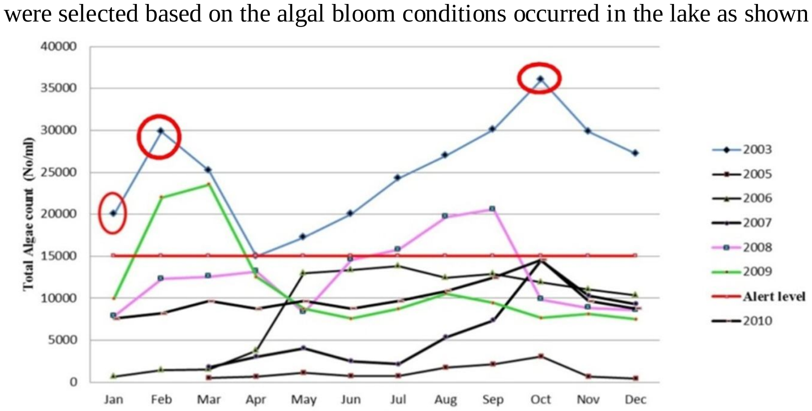


Figure 2: Monthly Variation of Algal Count during 2003-2010

Algal blooms have appeared in the lake in 2002, 2003 and 2009. Year 2003 was selected as the base year since it shows the highest algal count (Figure 2). In 2003, high levels of algal count are reported in October and February. Satellite images were available only for January and February, 2003 and additional two images were obtained from 2002 August and November since Jayasinghe (2011) reported that in 2002 also there were algal blooms appeared in the lake. Table 1 presents the dates and sensors of satellite images. Since lake rehabilitation has been started in 2003, two periods to represent before and after rehabilitation were considered for the study. Accordingly, 2002-2003 period was considered as the pre rehabilitation period and after 2007 was considered as the post rehabilitation period. Satellite images of 2014 were used to represent post rehabilitation period and normal conditions of the lake.

Table 1: Dates of Satellite Images and their Sensors

Landsat ETM$^+$	Landsat 8 OLI
24-Aug-2002	21-Jan-2014
28-Nov-2002	22-Feb-2014
31-Jan-2003	10-Mar-2014
16-Feb-2003	11-Apr-2014

2.2 Processing of Landsat Images and Development of Indices/ Band Ratios

Since the developed indices were normalized, no radiometric corrections were carried out for the multi temporal data. Kurunegala lake was extracted from the images for further analysis. In developing indexes and band ratios, it was assumed that reflectance of green, and NIR bands will increase with increasing algal count due to presence of chlorophyll. Therefore, reflectance before rehabilitation should be higher than after rehabilitation hence index/ ratio values should vary accordingly. The statistical significance of the index values before and after rehabilitation was tested at 95% confidence interval. After calculating the indices, all the images were classified and mapped.
For the detection of land use change, Landsat ETM$^+$ image of January 31, 2001 and Landsat 8 OLI image of 10 March, 2014 were used. After creating a 500 m buffer around the lake, image subsets were created and classified to identify land use/ land cover. Subsequently, land use/ land cover changes were assessed. Nitrogen and Phosphorus contents in the lake before and after tank rehabilitation were assessed based on secondary data.

3. RESULTS AND DISCUSSION

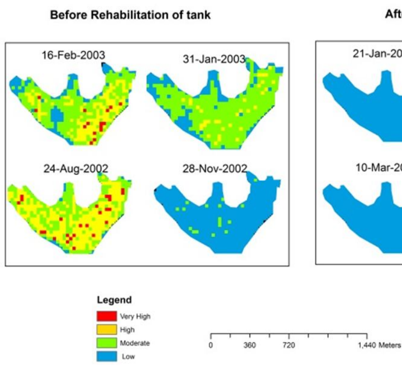
3.1 Development of Indexes/ Band Ratios

Six Band Ratios and normalized indices were developed as shown in Table 2.

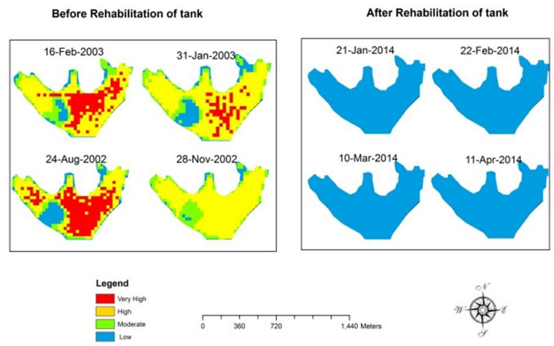
Table 2: Developed Band Ratios and Indices (Bands are denoted as TM.)

Equation	Landsat ETM$^+$	Landsat 8
Equation 1(Eq1)	$(TM_2-TM_3)/(TM_2+TM_3)$	$(TM_3-TM_4)/(TM_3+TM_4)$
Equation 2(Eq2)	TM_2/TM_3	TM_3/TM_4
Equation 3(Eq3)	TM_2/TM_4	TM_3/TM_5
Equation 4(Eq4)	$(TM_3-TM_4)/(TM_3+TM_4)$	$(TM_4-TM_5)/(TM_4+TM_5)$
Equation 5(Eq5)	TM_3/TM_4	TM_4/TM_5
Equation 6(Eq6)	$(TM_1-TM_3)/(TM_1+TM_3)$	$(TM_2-TM_4)/(TM_2+TM_4)$

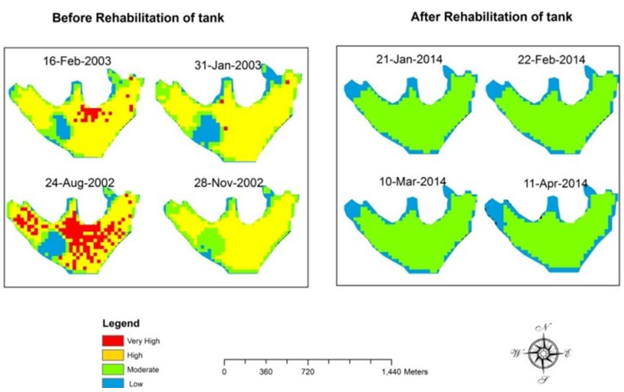
Condition of the lake surface according to the index/ band ratio value variations are shown in Figure 3 (a, b, c, d, e and f). Accordingly, it is evident that pre and post rehabilitation periods show a considerable difference in terms of index and band ratio values. This implies that the developed indices and band ratios can be used to assess the eutrophic conditions of the lake.



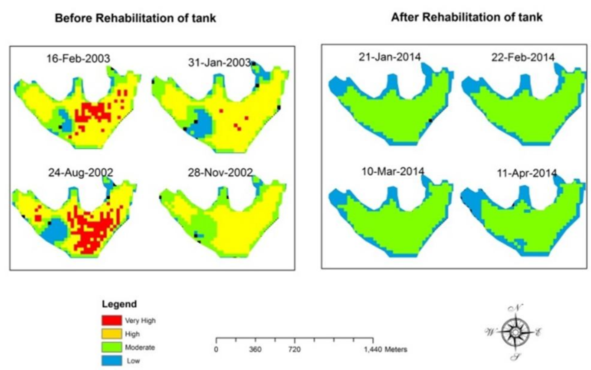
a: Condition of the Lake Surface - Eq1



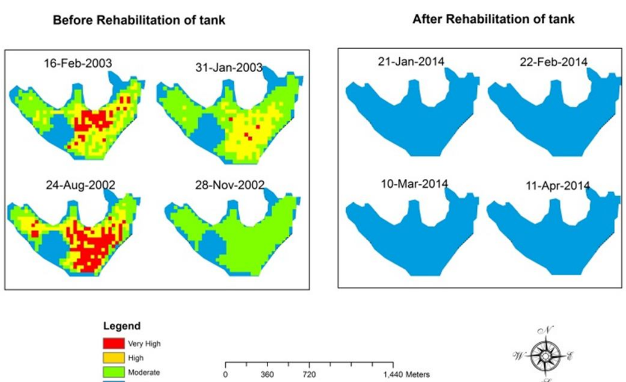
b: Condition of the Lake Surface - Eq2



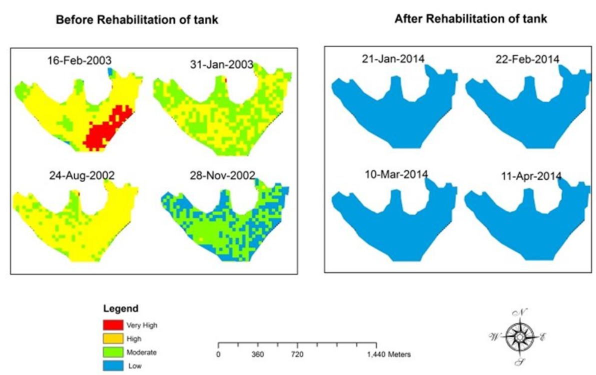
c: Condition of the Lake Surface - Eq3



d: Condition of the Lake Surface - Eq4



e: Condition of the Lake Surface - Eq5



f: Condition of the Lake Surface - Eq6

Figure 3: Surface Conditions of the Lake Represented by Indices and Band Ratios

Results of the Paired-T test revealed that the average value of each index and band ratio was higher in before rehabilitation of the lake than after rehabilitation. Therefore, it indicates that the index/ band ratio values represent the conditions created by the presence or absence of algal blooms in the lake.

3.2 Land Use/ Land Cover Change During 2001 to 2014

There were five land use changes identified from the study area. They are water (Tank), settlements, rocks (Ethugala, wewgala & Andagala), paddy, bare lands and vegetation cover (Figure 4). Land use changes are presented in Figure 5.

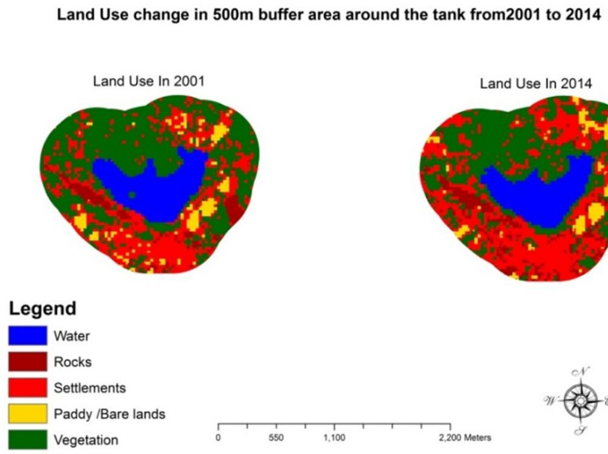


Figure 4: Land Use/ Land Cover in 500 M Buffer Area around Kurunegala Lake in 2001 And 2014

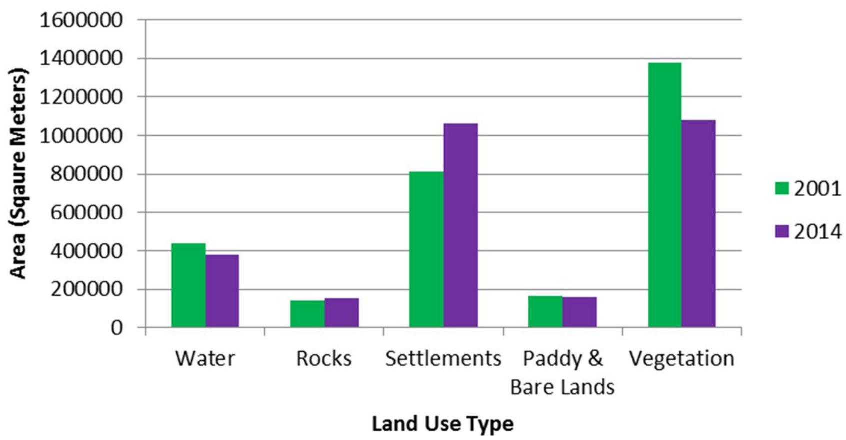


Figure 5: Land Use/ Land Cover Change During 2001 to 2014 within 500 M Buffer of Kurunegala Lake

It is evident that vegetation cover around the lake has decreased during the period while settlement extent has increased. Since these changes have occurred in the adjacent catchment areas of the lake, it can create harmful impacts on the water quality. According to Jayasinghe (2011) illegal settlements have come up around the lake and they do not have proper sanitary facilities and their wastewater drains into the lake. Storm water draining has also increased due to the increasing number of settlements and there is a possibility of high organic pollutant loads coming into the lake from these settlements.

3.3 Water Quality Trends in Kurunegala Tank

Figure 6,7 &8 presents the Nitrogen and Phosphorus levels in the lake at different times.

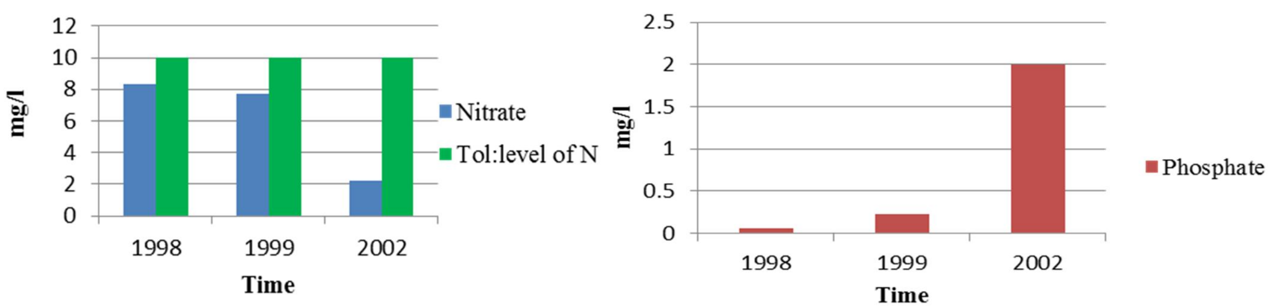
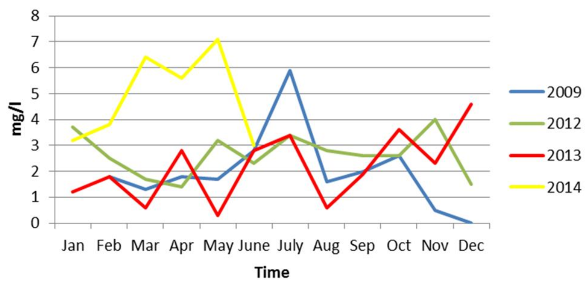


Figure 6: Water Quality Variations of Kurunegala Lake Before Rehabilitation



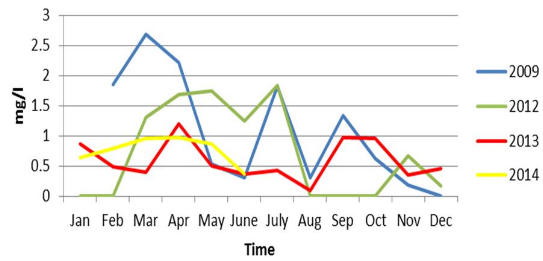


Figure 7: Nitrate Concentration after Rehabilitation

Figure 8: Phosphate Concentration after rehabilitation

According to Figure 6 Total Nitrogen concentrations has gradually decreased towards 2002 and total Phosphorus levels has increased. Phosphate is a main nourishing factor of cyanobacteria and this might have led to the bloom conditions in 2002 and 2003. After tank rehabilitation, again these inorganic nutrients have high values in 2009, when the third outbreak has occurred indicating the relationship between water quality and algal blooming.

4. CONCLUSIONS AND RECOMMENDATIONS

This study attempted to develop surface conditions of Kurunegala lake using remote sensing derives indices and band ratios before and after rehabilitation of the lake. The developed band ratios and indices successfully represent conditions of the lake with comparison to the water quality characteristics and reported conditions in the literature. However, further verification of the indices and band ratios for their suitability to assess algal blooming conditions in the lake is needed using comprehensive ground verifications. Rehabilitation of the lake is affected by the changes occurred in the immediate surroundings. It can be recommended that monitoring of the lake can be carried out with the developed indices/ band ratios to identify any possible changes before serious water quality issues are coming up.

5. REFERENCES

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