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ENVIRONMENTAL PROBLEMS

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THE FIRST STEP TO SKETCH THE SPATIO-TEMPORAL EVOLUTION OF BIOCHEMICAL AND PHYSICAL PARAMETERS INVOLVING IN THE HARMFUL ALGAL BLOOMS (HAB) IN MATTATALL LAKE (NOVA SCOTIA, CANADA)

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Abstract. Many watercourses in Nova Scotia (Canada) have recently had algal blooms in a surprisingly increasing way in frequency and diversity without any good understanding or explanation about causes and effects. The blooms triggered in Mattatall Lake (Wentworth, Nova Scotia) have many particular aspects: toxic species domination, nutrients increasing on a monthly basis, and blooms that co-exist with icy conditions. In this paper, we suggest an approach to create a map system with an appropriate interpolation and validation of necessary data in order to deal with this issue in Mattatall Lake and to contribute to the analysis framework and management plan on the entire area. Our long-term objective is aiming to suggest a modeling process for the entire watershed.

Key words: Harmful Algal Bloom (HAB), Mattatall Lake, GIS, Artificial Neural Network (ANN) model.

1. Introduction

There are between 1000 and 2000 species of cyanobacteria (blue-green algae) worldwide that can colonize to form a Harmful Algal Bloom (HAB) (Krogmann 1981). Degraded water quality from increased nutrient pollution promotes the development and persistence of many HABs and is one of the reasons for their expansion and proliferation in aquatic environments. HABs are unfortunately a growing problem in Canada over the last few years. Several cases of blue-green algae blooms have been reported in Manitoba's Lake Winnipeg over the past few years. Algal blooms in Lake Winnipeg have increased in intensity and frequency with accumulation of Phosphorus and nitrogen nutrients in the lake (SMW 2011). Multiple public health advisories have been issued in Quebec due to Microcystin concentrations exceeding the Canadian drinking water guidelines in Missisquoi Bay. The blooms had been appearing since 2000, so a quantitative approach was developed for the detection of cyanobacteria blooms (Fortin et al. 2010). The first documented HAB in Newfoundland and Labrador was blue-green algae in the late summer and early fall of 2007 and in the spring of 2008 (Government of Newfoundland and Labrador 2008). In 2011, Lake Erie, Ontario, experienced a severe harmful algal bloom consisting of the following toxic cyanobacteria genera: *Microcystis and Anabaena* (Michalak et al. 2013). Nova Scotia has documented incidents of algae blooms in lakes including Porcupine Lake (Digby), Fanning Lake, and Parr Lake (Yarmouth) (Environment and Labour 2007); however, there is little research that has been done and there are no monitoring plans set in Nova Scotia.

During the fall of 2014, massive algal blooms appeared in Mattatall Lake, located near Wentworth, Nova Scotia (NS), and persisted until late December. The duration of this phenomenon was extremely unusual. Algal blooms have not been known as coexisting with icy conditions. The dominant species in this bloom was identified to be *Anabaena planctonica*, which may produce the neurotoxin *Anatoxin-a*.

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There are many factors that affect the development of a HAB, all of which can be divided into controllable or uncontrollable parameters. Light intensity, temperature and wind direction are uncontrollable, whereas nutrient availability (especially total Phosphorus) can be restrained. Identifying the nutrient point and non-point sources within the watershed is a key to establish a management plan. Management of nutrient inputs to the watershed can lead to significant reduction of HABs. The more data identified the better and more accurate analysis for a plan of management.

To do so, field experiments are extremely necessary to elucidate various factors that affect microalgae blooms and their proliferation. However, factors that can be determined in field experiments are limited, costly and time consuming. Mathematical models therefore have many advantages for studying fluid dynamic effects coupled with parameters more realistic: nutrients, light and temperature. Acquiring sufficient data is as important in both developing predictive models as well as making accurate predictions. Microalgae dynamics modeling is considered an effective tool for complementing the limitations of field and laboratory experiments, and is an approach that can be used at a minimal cost.

All these arguments allow us to think about the very first step of a long term modeling process for the watershed, including collecting and building a dataset as well as to create a map system with a good interpolation and validation of necessary data, analysis framework and management plan on the entire area. Based on this initiative, mapping and modeling approaches such as Geographical Information System (GIS) and Artificial Neural Network (ANN) will be used.

Multiple scientists have used GIS approaches in their studies on a large variety of problems. We can cite here the work of Biswas et al. (2002) who used remote sensing and GIS techniques to recommend soil and watershed conservation measures for a number of micro-watersheds in eastern India (Biswas et al. 2002). Another example is the work of Mantzafleri et al. (2009) who did a water quality monitoring study to provide information about the geographic distribution of the qualitative parameters to support pollution reduction strategies for Lake Kastoria in the Region of Western Macedonia (Mantzafleri et al. 2009).

Therefore, the GIS approach is not a new approach in the studies related to watersheds. Nevertheless, the novelty of our paper has relied on the fact that we would sketch a ‘standard process’ for data acquisition and mapping for the algal bloom patterns which very recently boomed in the whole province of NS where no physical and chemical data related to this lake have been done systematically. So far, none of the research work is focused on cyanobacteria bloom mapping in Canada. In performing this ‘standard process’, we will use Mattatall Lake as a pilot study to apply to other lakes having the same bloom issues in Nova Scotia and in Canada. Moreover, the mapping results will help us to build our database and to have panoramic viewpoints on the entire watershed, and hence to suggest a correlation between governing parameters of algal bloom pattern as well as to predict possible scenarios for bloom occurrence and proliferation in the future. The objectives of this paper are:

1) To determine the distribution of nutrient levels (especially two important components for algal bloom growths: Total Phosphorus (TP) and Nitrates) within the watershed. This includes: a) nutrients in the lake, brooks and tributaries flowing into the lake and b) the TP in soil samples of the watershed, which might contribute mainly to the high TP level in the lake.

2) To determine the biological consequences of these nutrient levels in the lake and related watershed via two important parameters: *Chlorophyll-a* and *Phycocyanin*.

3) Based on the data determined, interpolated and validated by mapping on the entire study area with the GIS approach, we try to evaluate the spatial temporal evolution of the above-mentioned parameters for the HAB occurrence.

4) The last goal is a trial to predict the future bloom scenarios by using a mathematical modeling approach. As mentioned previously, the pattern of massive blooms was just recently appearing (since 2014) and we just started a systematic sampling process for data since June 2015. With the data for this summer season from June to October, we try to simulate and predict different bloom scenarios for the future based on an Artificial Neural Network (ANN) model.

2. Methodology

2.1. Study area

Mattatall Lake is located on the Cumberland/Colchester County line and is approximately 5-kilometer length (Fig. 1). Mattatall Lake is mainly spring fed with multiple brooks. There is an outlet from the lake draining into the French River, then draining into Northumberland Strait. In 2011 some small blooms were first noticed on the lake by local residents beginning in late June early July; however, they dissipated by September. Over the past 2 years the algal blooms became gradually worse and late September 2014 the bloom totally expanded, covering the entire lake until December 2014.

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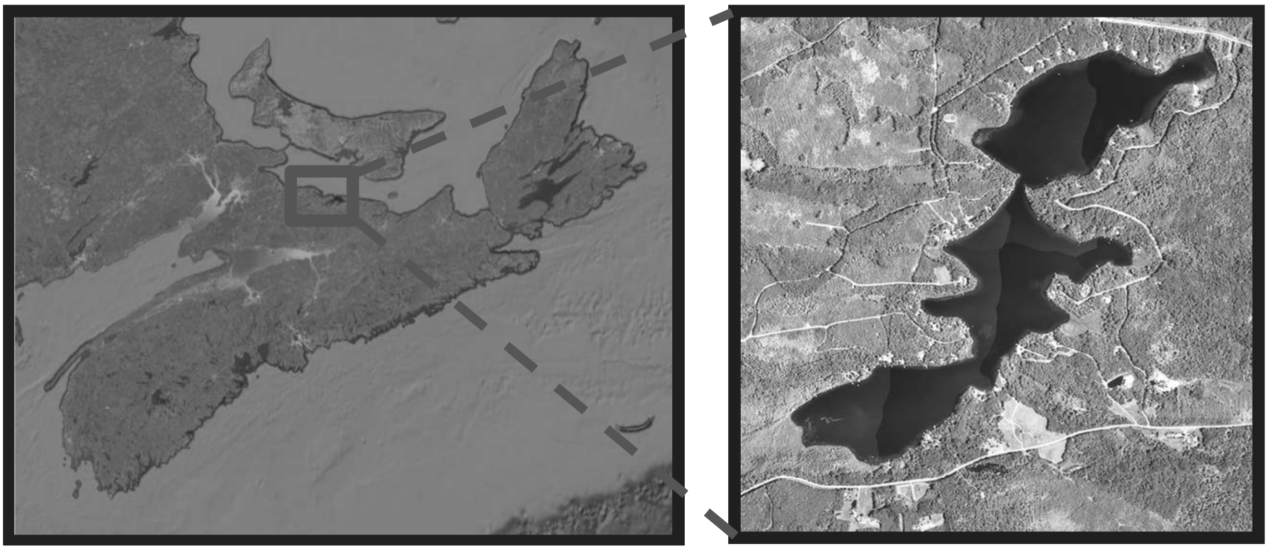

Fig. 1. Google Earth view of Nova Scotia highlighting Mattatall Lake area (left) and Government of Nova Scotia aerial photograph of Mattatall Lake (right)

2.2. Governing parameters involving in our study

2.2.1. Chemical Parameters

Phosphorus is a nutrient that plays a vital role to human, animal, and plant growth. It's one of the most common substances found in nature and indispensable for the low level of ecological food web. Phosphorus occurs unnaturally from various artificial sources such as fertilizers (used in agriculture), cleaners (used in industry) and wastewater (from household sewage). Phosphorus is found in water, solids (detritus), and in the bodies of biological organisms. However, high levels of Phosphorus in nature can create algal blooms causing eutrophication or the premature "aging" of a water body. In other words, HABs may develop in eutrophic water bodies (high Phosphorus and Nitrates) as well as in oligotrophic water (Sorichetti et al. 2014). This eutrophication process decreases sunlight and oxygen levels (hypoxia) thus affecting fish and other aquatic life.

Since Phosphorus loading and phytoplankton production in fresh water bodies are strongly correlated (Anderson et al. 2002), Phosphorus levels in soil within the watershed and in surface water samples will be considered to determine the potential sources of nutrient loading into the lake. Different samples and analyses for TP in brooks and ponds of the Mattatall Lake watershed gave us a panoramic view of nutrient sources streaming to the lake and how they could disperse and redistribute in the lake.

Nitrogen in the lake is detected under the forms of *Ammoniacal Nitrogen*, *Nitrates*, and *Nitrites*. These three types of Nitrogen formed a parameter named Dissolved Inorganic Nitrogen (DIN). This factor DIN couples with the organic form of Nitrogen to define Total Nitrogen (TN). *Total Nitrogen* and *Total Phosphorus* are two of the most important micronutrient components for algal development and hence very important parameters to be used for predicting scenarios of algal bloom occurrence and proliferation.

Unfortunately, due to many reasons such as the lack of an appropriate equipment, Total Nitrogen cannot be easily defined. We can just evaluate the mineral forms of Nitrogen such as Ammoniacal Nitrogen, Nitrites and Nitrates. The term Nitrates (N) which will be used hereafter comprises of two components: Nitrates and Nitrites, and they are main Nitrogen parameters in our study for the development of algal blooms.

2.2.2. Biological parameters

There are two biological parameters representing for the existence and growth of algae in general and cyanobacteria in particular: *Chlorophyll-a* and *Phycocyanin.*

Chlorophyll-a is usually used as a parameter that determines the quantity of primary photosynthetic pigment in cells of aquatic micro plants. Chlorophyll-a is a specific form of Chlorophyll, used in oxygenic photosynthesis. Measurement and determination of this parameter are the basic analysis to evaluate the characteristics of algae blooms in many research works in the world. Unfortunately, Chlorophyll-a represents just the whole quantity of photosynthesis pigment released from all algae and micro-plants present in water, hence it cannot help to distinguish cyanobacteria existence among all living micro plants and algae in the waterbody. To be able to define and confirm the existence of Cyanobacteria species in the composition of aquatic microalgae, another pigment form, Phycocyanin, is used. Phycocyanin is the pigment, which differs cyanobacteria species from another planktonic species, and could give us a real picture of quantity of cyanobacterial genera in the water. Phycocyanin is actually a pigment-protein complex from the light-harvesting phycobiliprotein family, along with

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allophycocyanin and phycoerythrin. It is considered as an accessory pigment to Chlorophyll.

In using the index of Chlorophyll-a to evaluate the risk for water quality, WHO suggested the following criteria:

Chlorophyll-a must be < 3.5 (mg/L) (Drinking Water) and <10 (mg/L) (Recreational Water) (1)

Regarding the Phycocyanin criteria for the risk of water quality, research on this parameter were rare. Brient et al. (2008) cited in their paper the following criteria according to WHO (Brient et al. 2008) for Phycocyanin equivalent to the cyanobacterial number of cells in the waterbody.

Phycocyanin < 30 ±2 µg/L, equivalent to the number of cells < 20 000 cells/ml (Alert level 1) (2)

Phycocyanin > 90±2 µg/L, equivalent to the number of cells > 100 000 cells/ml (Alert level 2) (3)

The pigment Chlorophyll-a is largely associated with phytoplankton biomass in the lake, while the pigment Phycocyanin can confirm the presence of Cyanobacterial species. Hence, in this study, Chlorophyll-a and Phycocyanin from all water samples at the surface and bottom levels will be considered as an estimate of microalgal biomass and cyanobacterial bloom occurrence at the sampling locations and in the waterbody. Both Chlorophyll-a and Phycocyanin are main parameters to be used in the map for estimating and predicting algal bloom patterns.

2.3. Data collection

Water samples and soil samples were taken triweekly or around monthly during the summer time of 2015 in order to monitor all parameters closely and evaluate how they evolved with time. Besides, this frequency of sampling will also indicate the effects of some factors that initiate algal scums, which is useful to establish a management plan for prevention, mitigation and prediction of algal blooms in the future at Mattatall Lake.

The duplicate water samples were systematically taken at 13 different locations (Fig. 2) across Mattatall Lake at three different depths: surface, 2 meters and bottom levels. However, due to the shallow depth of the lake, many sampling locations have the bottom level at around 3 or 4m deep and the variation of measured parameters is not very high between 2-meter level and/or surface or bottom level. Hence, to simplify our analysis, we will just present hereafter the results of the surface and bottom levels. A YSI probe was used to measure multiple *in-situ* parameters including Dissolved Oxygen (DO), pH and water temperature for each depth. All water samples were then analyzed for the presence of Nitrates, Phosphates, Total Phosphorus, Chlorophyll-a and Phycocyanin. Besides, several ponds and brooks, which drain directly into Mattatall Lake, were also sampled at the surface level for testing the presence of Chlorophyll-a, Nitrates, Phosphates and TP (Fig. 3).

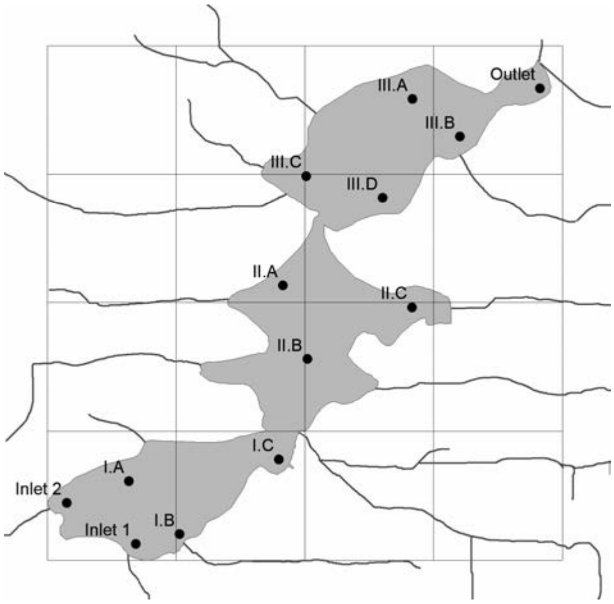

Fig. 2. Water sampling locations in the lake

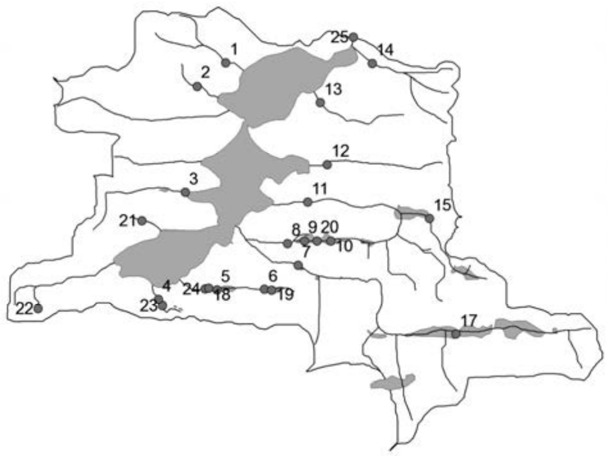

Fig. 3. Water sampling locations at some brooks and ponds

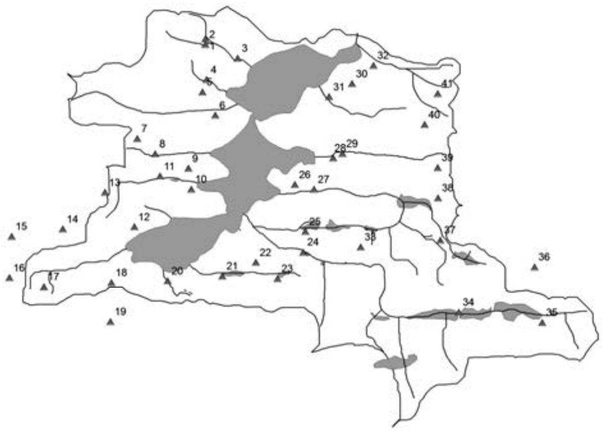

Fig. 4. Soil Sampling locations

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The number of soil samples was systematically defined after the watershed boundary had been delineated. Soil samples were also taken double at the depth of 5 inches from the surface at 41 locations within the watershed (Fig. 4). This is to ensure that samples accurately represent the actual soil conditions rather than reflect the effects of other external factors on the ground surface. Those samples were then analyzed for the presence of total Phosphorus.

2.4. Watershed delineation

The crucial data used to delineate watershed boundary is elevation map. A map of 5-meter contour lines was downloaded from Geographic Information Systems Centre (GISC) at Dalhousie University in order to construct a Digital Elevation Model (DEM) by using the *"Topo to Raster"* tool in ArcGIS. The DEM was then used as input data for watershed delineation. The procedure of watershed delineation is presented in Fig. 5. The Nova Scotia Coordinate Referencing System Viewer (NSCRS Viewer) and field observations of brooks locations were used to validate the number of rivers and watershed boundary generated in ArcGIS.

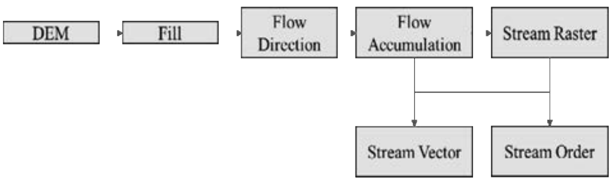

Fig. 5. Flow chart of watershed delineation

2.5. Land-use map

The land use map is indispensable for the natural resource management as well as for the modification of natural environment. Therefore, determining the land use map will help us to identify the sources and causes which might affect most to an increase in nutrients in the lake.

The Landsat 8 imagery produced on June 10th 2015 was used to develop a classification scheme that constructed land use map, and includes 11 bands with 30-meter resolution except for band 8 (15-meter resolution). A composite photograph based on band 5-4-3 was developed and displayed as infrared color, which showed the differences of objectives in practice such as forest, clear-cut, regrowth, buildings, etc. The *Supervised Classification* tool in ArcGIS was used in this process to collect the training samples that distinguished land use types from others. The method is based on the special analysis Maximum Likelihood Classification (ESRI). All three-band values are considered in each pixel during the classification. By creating training samples, a specific range of values is assigned to a single land use type. Therefore, all cells will be classified. The categories used in the classification include blueberry fields, building, grass, regrowth, clear-cut and forest.

The aerial photos downloaded from NSCRS Viewer and field observations were used to validate the land use map generated in ArcGIS. Due to the 30-meter resolution of the Landsat imagery, errors were generated during validation. However, appropriate modifications were made to the land use map to correct those errors.

2.6. Interpolation methods and residuals

The analyzed results from water samples and soil samples were interpolated in Surfer Golden Software to create the distribution maps of the considered parameters such as Chlorophyll-a, Phosphate, Total Phosphorus, and Nitrate which evolve definitely in function of time.

Since only a limited number of samples can be taken over such a large surface area due to the reasons of time and costs, interpolation of each data set is required in order to obtain continuous data over the area of interest. Interpolation is the process where values at locations, with no original data existing, are estimated based on a given data set of some sample points. Therefore, the interrelationship and variability of the examined data across a surface can be determined. Interpolation uses the spatial autocorrelation to determine whether the values are interrelated to find out a spatial pattern (Childs 2004).

From a set of sampling points, the output data is a grid of representation for a surface. It is a continuous surface since for any location with x, y coordinates, a single value of z exists irrespectively on the direction from which that point is approached. A grid consists of rows and columns, which generate an array of equally dimensioned cells. Every cell has a distinct value to express a change in z-value (Childs 2004).

There are two categories of interpolation techniques: *deterministic* and *geostatistical*. Deterministic interpolation techniques create surfaces based on measured points or mathematical formulas and can be divided into two groups, global and local. The global techniques calculate predictions using the entire dataset, whereas the local techniques calculate predictions using measured points within neighborhoods, which are smaller spatial areas within the larger study area. A deterministic interpolation can either force the modeling surface to pass through the data values or not. Geostatistical interpolation techniques utilize the statistical properties of the measured points; quantify the spatial autocorrelation among measured points and account for the spatial configuration of the sample points around the prediction location. Because geostatistical interpolation is based on statistics, these techniques produce not only prediction surfaces but also error or uncertainty, giving an indication of how good the predictions are. An interpolation technique that predicts a value identical to the measured value at a sampled location is known as an exact interpolator. An inexact interpolator predicts a value that is different from the measured value (Childs 2004).

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Four methods of interpolation are used in this study including Inverse Distance Weighted (IDW), Kriging, Minimum Curvature and Natural Neighbor. The same set of input data was interpolated in turn with different methods to produce various results, which were mutually compared to choose the best fit with the dataset based on the minimum residual criterion. The latter is defined as the average of the absolute difference between observed data and corresponding predicted values generated from the interpolation method. The average residual should be close to zero to indicate a good prediction model. Hence, the map representing each parameter was finally produced using the best method selected in the validation process. Equation used to calculate the average residual is shown as follows:

$$\bar{R} = \frac{\sum_{i}^{n} |O_i - P_i|}{n}, \quad (4)$$

where: O_i – Observed value; P_i – Predicted value; $\bar{R}$ – Average residual; n – Number of data used in an interpolation.

Table 1 (a, b, c, d, e) has shown the obtained average residuals for each interpolation method we have calculated. We actually have to choose the method for interpolation with the lowest value of residual and it is clear that the Inverse Distance Weighted (IDW) was our final choice (Table 1 a–e).

Table 1a

Obtained residuals for *Chlorophyll-a* in the lake by each interpolation method (the bold value is the lowest residual)

	Sample ID	Interpolation methods			
		Natural Neighbor	Kriging	IDW	Minimum curvature
Absolute value of residuals	IA	0	6.98E-04	5.83E-06	3.02E-03
	IB	0	1.70E-04	3.80E-07	4.14E-04
	IC	4.70E-04	3.87E-04	7.27E-06	1.84E-06
	IIA	0	3.40E-04	2.53E-06	5.49E-03
	IIB	0	2.75E-03	4.65E-05	6.72E-04
	IIC	8.15E-04	2.59E-05	1.14E-05	1.25E-04
	IIIA	3.55E-03	2.44E-03	4.32E-05	9.02E-04
	IIIB	0	5.29E-04	1.10E-05	1.12E-03
	IIIC	0	6.90E-05	1.82E-06	2.49E-03
	IIID	0	1.01E-04	6.58E-06	1.14E-02
	Outlet	4.50E-03	5.44E-04	4.80E-05	2.40E-03
	Inlet 1	2.77E-04	2.84E-03	8.20E-06	1.34E-06
	Inlet 2	5.50E-04	7.84E-04	2.18E-05	4.49E-03
Average		1.02E-02	1.17E-02	**2.15E-04**	3.25E-02

Table 1b

Obtained residuals for *Phycocyanin* in the lake by each interpolation method (the bold value is the lowest residual)

	Sample ID	Interpolation methods			
		Natural Neighbor	Kriging	IDW	Minimum curvature
Absolute value of residuals	IA	0	6.71E-03	8.44E-04	1.36E-02
	IB	9.75E-03	3.40E-03	2.74E-03	4.54E-03
	IC	0.00E+00	6.06E-03	2.42E-03	1.26E-03
	IIA	1.34E-03	1.50E-03	3.28E-03	3.97E-03
	IIB	3.84E-03	2.31E-03	2.91E-03	2.80E-03
	IIC	1.63E-03	3.66E-03	2.27E-03	2.15E-03
	IIIA	0.00E+00	2.48E-03	3.31E-03	1.73E-03
	IIIB	1.72E-03	1.18E-03	2.27E-03	5.92E-03
	IIIC	4.79E-03	1.83E-03	2.29E-03	3.79E-03
	IIID	9.87E-03	4.05E-03	2.17E-03	7.53E-03
	Outlet	4.55E-03	2.44E-04	4.80E-05	2.04E-03
	Inlet 1	4.77E-04	2.34E-03	2.20E-06	1.34E-06
	Inlet 2	1.50E-04	7.44E-04	1.18E-05	4.05E-03
Average		3.81E-02	3.65E-02	**2.46E-02**	5.34E-02

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Table 1c

Obtained residuals for *Nitrates* in the lake

	Sample ID	Interpolation methods			
		Natural Neighbor	Kriging	IDW	Minimum curvature
Absolute value of residuals	IA	0	1.08E-03	4.79E-05	3.32E-04
	IB	2.86E-03	8.03E-04	4.51E-06	1.41E-03
	IC	1.71E-02	1.67E-03	2.43E-05	1.45E-02
	IIA	0	6.61E-03	7.37E-05	1.43E-02
	IIB	0	2.12E-03	1.14E-05	2.54E-04
	IIC	0	1.64E-02	4.87E-04	8.19E-03
	IIIA	0	5.15E-03	1.05E-04	5.39E-03
	IIIB	5.91E-02	9.77E-03	9.99E-03	1.09E-02
	IIIC	1.00E-02	9.29E-03	1.00E-02	3.48E-03
	IIID	8.36E-03	2.08E-06	1.04E-05	1.04E-02
	Outlet	1.55E-03	3.67E-04	7.80E-05	3.04E-03
	Inlet 1	1.77E-04	5.78E-03	2.78E-05	1.57E-06
	Inlet 2	1.90E-04	6.42E-04	1.82E-05	4.78E-03
Average		9.94E-02	5.97E-02	**2.09E-02**	7.70E-02

Table 1d

Obtained residuals for *Total Phosphorus* in the lake by each interpolation method (the bold value is the lowest residual)

	Sample ID	Interpolation methods			
		Natural Neighbor	Kriging	IDW	Minimum curvature
Absolute value of residuals	IA	0	1.46E-04	1.01E-06	6.30E-04
	IB	0	3.40E-04	3.33E-06	3.19E-04
	IC	4.02E-04	3.09E-04	5.35E-06	5.13E-05
	IIA	0	2.24E-06	9.18E-07	9.80E-04
	IIB	0	7.34E-04	1.34E-05	2.35E-04
	IIC	2.76E-04	5.64E-05	4.14E-06	9.98E-05
	IIIA	7.53E-04	4.99E-04	8.18E-06	4.15E-04
	IIIB	0	5.18E-05	2.23E-06	4.14E-04
	IIIC	0	1.57E-04	2.41E-06	3.49E-04
	IIID	0	8.70E-04	1.57E-05	1.37E-02
	Outlet	7.87E-04	4.87E-04	2.45E-06	6.87E-03
	Inlet 1	1.56E-04	1.56E-03	4.88E-05	1.56E-06
	Inlet 2	6.49E-04	1.67E-04	1.35E-05	6.87E-03
Average		3.02E-03	5.38E-03	**1.21E-04**	3.09E-02

Table 1e

Obtained residuals for *Total Phosphorus in watershed soil* by each interpolation method (the bold value is the lowest residual)

Total Phosphorus in soil	Sample ID	Interpolation method			
		Natural Neighbor	Kriging	IDW	Minimum curvature
1	2	3	4	5	6
Absolute value of residuals	1	0.00E+00	7.63E-02	1.43E-02	5.18E-02
	2	3.39E-01	1.69E-01	2.26E-02	2.73E-03
	3	4.52E-01	2.44E-01	1.33E-02	7.77E-03
	4	1.12E+00	5.81E-01	4.30E-02	1.94E-01
	5	1.52E+00	8.50E-01	7.37E-02	1.28E-01
	6	2.81E-01	3.33E-01	1.87E-02	1.01E-01
	7	1.50E-01	2.72E-01	1.51E-02	6.45E-02
	8	7.86E-01	5.33E-01	3.44E-02	2.41E-01

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1	2	3	4	5	6
	9	2.36E-01	1.88E-01	2.06E-02	1.54E-01
	10	1.86E-02	1.67E-03	7.50E-03	4.95E-02
	11	1.31E-01	1.23E-01	9.60E-03	8.71E-02
	12	3.20E-01	2.86E-01	1.18E-02	1.17E-01
	13	5.60E-02	6.36E-02	5.73E-04	1.98E-02
	14	2.42E-01	2.11E-01	5.22E-03	9.76E-02
	15	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	16	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	17	2.27E-01	5.26E-02	2.47E-03	4.93E-03
	18	3.58E-01	4.22E-01	1.10E-02	7.53E-02
	19	0.00E+00	5.50E-02	1.06E-02	4.51E-01
	20	8.68E-01	4.97E-01	2.95E-02	4.23E-02
	21	5.98E-01	4.25E-01	4.02E-03	1.94E-02
	22	1.05E-01	8.92E-02	6.90E-03	1.99E-02
	23	2.12E-02	8.70E-02	3.67E-03	5.76E-03
	24	1.61E-01	1.46E-01	9.46E-03	1.17E-01
	25	3.35E-01	2.73E-01	1.72E-02	1.44E-02
	26	8.01E-02	1.12E-01	1.11E-02	4.27E-02
	27	1.21E-01	1.10E-01	5.76E-03	1.65E-01
	28	2.46E-01	1.37E-01	1.66E-02	6.93E-02
	29	7.17E-02	9.03E-02	5.79E-03	1.27E-01
	30	1.80E-03	1.17E-02	7.34E-04	5.19E-03
	31	7.46E-02	3.90E-02	2.87E-03	6.50E-02
	32	0.00E+00	1.04E-02	9.52E-04	8.83E-03
	33	9.80E-02	1.01E-01	7.39E-03	1.32E-01
	34	1.79E-01	2.49E-02	2.16E-03	1.55E-02
	35	0.00E+00	1.44E-02	1.15E-03	3.34E-03
	36	0.00E+00	1.53E-02	9.71E-04	2.84E-02
	37	4.29E-03	1.44E-03	1.14E-03	2.12E-02
	38	7.76E-02	5.29E-02	5.54E-04	1.17E-02
	39	6.50E-02	5.97E-02	3.32E-03	2.98E-03
	40	1.13E-01	7.83E-02	2.21E-03	5.50E-02
	41	0.00E+00	9.73E-03	8.68E-04	7.19E-03
Average		2.31E-01	1.67E-01	**1.09E-02**	6.89E-02

2.7. Prediction of algal development by ANN (Artificial Neural Network) model

The mathematical approach can be a powerful tool to deal with the coupling effects of governing parameters in the bloom occurrence issue. In this part, we simply would like to present some preliminary results of the simulation we obtained to predict the algal bloom in Mattatal Lake. The mathematical model we used is the type of Artificial Neural Network (ANN) model. For a more profound version of algal bloom simulation and prediction by ANN model, we will present in another detailed paper in the near future. Also, for one approach using the statistical approach to estimate the risk of algal blooms, we refer to Ndong et al. (2014).

Inspired by the biological nervous system and artificial intelligence (McCulloch and Pitts 1943), the ANN applied in our project consists of a large number of simple processing elements that are variously called neurons or nodes. Each neuron or node is connected to other nodes by means of direct communication links, each with an associated weight function. The weights represent information being used the net to solve the problem. We suggest the back-propagation multi-layer neural network which is the most common and convenient ANN used in engineering sciences. In this network, nodes are arranged into layers: input layer (data observations), hidden layer(s) (intermediate nodes) and output layer (conclusions). An important step in developing ANN models is to select the input variables that have the most significant impact on the model's performance. A good subset of input variables can substantially improve model performance.

Our study herein is based on a set of five main parameters for the input sets: 1) Total Phosphorus; 2) Nitrate; 3) DO; 4) Water temperature; and 5) pH. The only output in this model (for this preliminary step) is

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the quantity of Chlorophyll-a, representing for the growth of algal bloom. The design of this experiment used random sampling to cover all equation surfaces. Data collected in the summer months will be summarized in the input table and will be used to design the ANN model. Table 2 as an example shows ten different values among dataset under the form of inputs/output we used for our simulation by ANN. In fact, we did use a data set with one hundred points to train and validate the model (These points were selected from five different field trips done in last summer-fall terms).

Table 2

Example of ten values of data for inputs and output set inserted in the Artificial Neural Network (ANN) model

Inputs X_1 to X_5					Output
Total Phosphorus (mg/L)	Nitrate + + Nitrite (mg/L)	pH	Temperature (C°)	DO (mg/L)	Chlorophyll-a (µg/L)
0.858	0.26	7.18	17.47	10.39	1.60
0.066	0.16	7.18	17.42	10.38	1.56
0.264	0.64	7.17	17.40	10.83	2.32
0.165	0.64	7.17	17.50	10.27	2.10
0.198	0.44	7.15	17.40	10.97	3.11
0.099	0.18	7.06	16.84	10.89	1.28
0.033	0.58	7.18	17.90	10.29	1.88
0.066	0.16	7.17	17.60	10.60	1.92
0.066	0.4	7.13	11.30	17.40	2.49
0.297	0.54	7.15	10.07	17.90	2.07
…	…	…	…	…	…

Precisely for this study, a neural network was designed with five input nodes and one output node. Five input nodes represented by variables X_i*=1 to 5* stand for five main parameters we mentioned above. One output node is represented by Y standing for Chlorophyll-a (Fig. 6).

3. Results and Discussions

3.1. Watershed boundary and land use map

The delineation of the Mattatall Lake watershed and sub-watershed boundaries resulted in a total area of about 10.3 km^2, including 14 main sub-watersheds (Fig. 7). There are also 14 main brooks flowing directly into the lake. It is noted that the largest sub-boundary is located in the southeast of Mattatall Lake. We also observed that there were multiple natural beaver dams, located in sub-watersheds 1, 8, 10 and 11 (areas numbered in Fig. 7), and some of them contained visible algae blooms.

The land use map generated from satellite images (Fig. 8) indicates that the majority of land in the Mattatall Lake watershed are forest (very light color) and regrowth (dark color). Agricultural areas are minimal within the watershed. However, there is a proportion of a single wild blueberry fields and domestic gardens. According to responses from the conducted survey sent to all lake residents, there has been a rapid urban development within the last four years along the northern shoreline of the lake.

3.2. Distribution of TP in soil within the watershed

To have a general idea about nutrient source in the watershed, we collected the data from soils and build the first distribution map of TP concentration within the watershed in the summer months of 2015 (Table 3 and Fig. 9a). From this TP map for the whole watershed, we can observe that the highest concentration of TP is at the south part where there is a brook linking the beaver dam to the lake (sub-boundaries 6, 7 and 8 in Fig. 7).

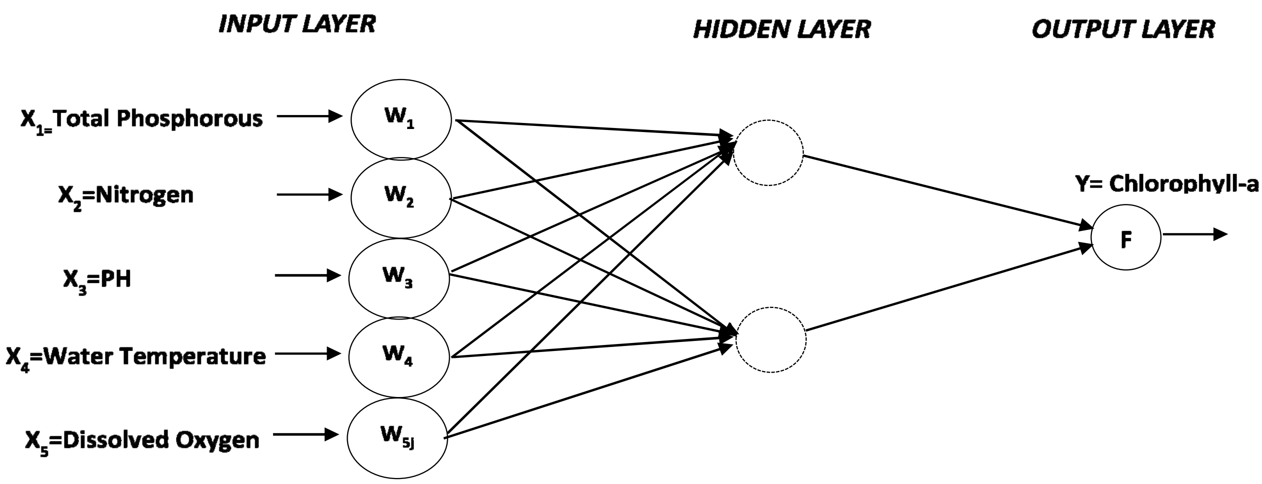

Fig. 6. Multilayer ANN model for Chlorophyll-a development

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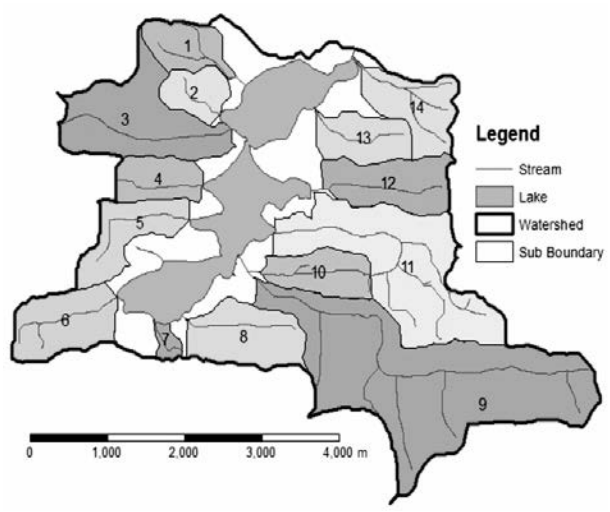

Fig. 7. Resulting map displaying the delineated watershed and sub-boundaries

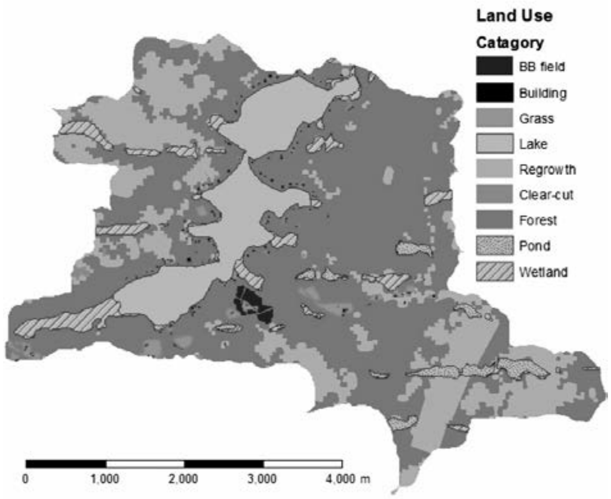

Fig. 8. Land use map of the Mattatall Lake watershed

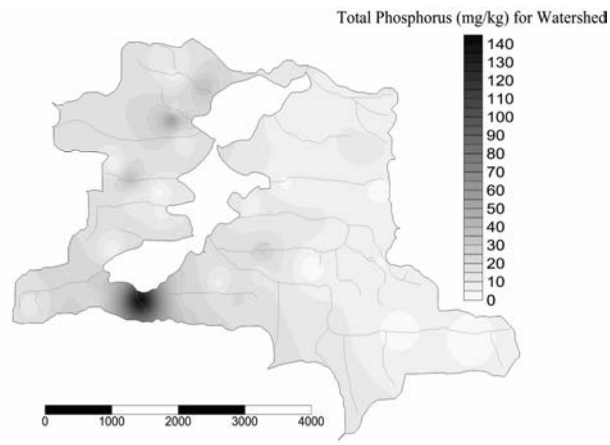

Fig. 9a. Distribution of Total Phosphorus in the entire watershed – Summer 2015

The second section of the high Phosphorus concentration is located in the north-western region, including sub-boundaries one, two and three (Fig. 7).

Table 3

TP measured in the watershed during the summer 2015

Location	X coordinate	Y coordinate	TP (ppm)
1	-7063335.5668	5699774.4844	8.1
2	-7064725.4203	5700313.8283	3.2
3	-7064977.3387	5699891.9604	15.2
4	-7064777.5433	5701140.9174	6.0
5	-7064190.1671	5701566.2360	8.5
6	-7063512.8905	5700762.8217	11.5
7	-7066605.0978	5699893.6714	8.6
8	-7067660.4457	5698631.6207	19.8
9	-7066919.3904	5698654.7648	141.1
10	-7067747.1655	5699848.7580	17.9
11	-7067020.6844	5700068.2965	10.5
12	-7067357.2351	5699384.0826	5.8
13	-7068304.3130	5699354.1847	27.4
14	-7069014.4561	5698698.0167	17.9
15	-7068981.9564	5699253.2239	3.6
16	-7067673.0600	5698106.7820	54.9
17	-7068557.4918	5698576.3478	12.6
18	-7065120.4407	5699042.2549	12.2
19	-7066191.5835	5698720.6711	22.9
20	-7065462.9975	5698686.5268	20.8
21	-7065091.8583	5699318.7729	26.0
22	-7065989.0597	5701662.2879	35.0
23	-7066416.7244	5701925.6991	10.4
24	-7066400.5127	5701372.1207	17.7
25	-7066455.9389	5701205.3266	52.2
26	-7067083.3331	5700368.5995	35.9
27	-7066284.8693	5700889.8169	9.5
28	-7067320.6971	5700574.8233	6.8
29	-7065750.3130	5698905.3699	9.2
30	-7064473.9238	5701316.8157	8.5
31	-7064360.4893	5699109.6073	1.4
32	-7063061.6134	5698232.8176	2.4
33	-7066643.9860	5700174.0686	3.8
34	-7066420.0111	5701849.3222	6.8
35	-7061962.3356	5698093.8891	2.7
36	-7062061.6106	5698842.3129	4.6
37	-7063307.1837	5699203.7911	4.8
38	-7065230.5220	5699953.7039	6.1
39	-7064600.3053	5700373.5478	7.4
40	-7063338.4319	5700184.5446	2.5
41	-7063338.4319	5701184.5447	8.4

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The southeast part corresponding to the sub-boundaries 9, 10 and 11 consisting mainly of forest, a few residences with lawns and a number of ponds and wetlands contribute also to the nutrient source of the lake. Tables 4a and 4b present the indication of brooks and ponds as well as their related data we obtained in the middle of summer.

Table 4a

Brook and pond water sample results for the July 20, 2015 field trip (samples taken during periods of heavy rain)

ID[1]	Sample Name	TP (mg/L)	Chlorophyll-a (µg/L)
1	Brook 1	0.066	0.59
2	Brook 2	0.165	1.11
3	Brook 3	0.099	1.78
4	Brook 4	0.264	2.84
5	Pond 5	0.264	3.96
7	Brook 7	0.231	0.7
8	Brook 8	0.033	7.74
9	Pond 9	0.033	5.38
10	Pond 10	0.132	8.71
11	Brook 11	0.231	2.25
12	Brook 12	0.132	5
14	Brook 14	0.264	3.16

Table 4b

Brook and pond water sample results for the field trip from July 30 to August 17, 2015

ID[1]	Sample Name	TP (mg/L)	Chlorophyll-a (µg/L)
1	Brook 1	0.033	1.0
2	Brook 2	0.099	0.1525
3	Brook 3	0.033	0.881355932
4	Brook 4	0.099	0.582142857
5	Pond 5	0.033	3.277310924
6	Pond 6	0.033	2.531746032
7	Brook 7	0.066	1.563218391
8	Brook 8	0.066	3.130434783
9	Pond 9	0.066	1.747663551
10	Pond 10	0.033	4.55
11	Brook 11	0.066	13.41463415
12	Brook 12	0.033	0.656
13	Brook 13	0.066	0.222222222
14	Brook 14	0.066	0.092771084
15	Pond 15, brook in the pond	0.033	0.807692308
15	Pond 15 algae	0.033	114.3076923
17	Pond 17	0.033	1.979591837
18	Brook 18	0.033	6.373831776
19	Brook 19	0	5.533898305
20	Brook 20	0.066	7.926829268
21	W1	0.462	0.08
22	W2	0.264	6.25
23	W3	0.099	0.76
24	W4	0.198	0.86
25	W5	0.297	0.64

1 Identification given in Fig. 3

A single brook located in the sub-boundary 7 (indicated in Fig. 7) also through that region of high Phosphorus concentration and could be a contributing factor to the consequence of the higher nutrient levels in the southern section of Mattatall Lake.

3.3. Evolution of TP in the lake

Fig. 10 shows the evolution of TP in the lake waterbody during the summer time. It is noticed that the concentration of TP was regular from June to July and dramatically increased in August *(beyond 0.4mg/L)*, especially in October. The high concentration of TP detected since September in the south part of the lake where the inlet of the lake receives the water from brooks with very high levels of TP as well. We were also able to notice the occurrence of many blooms everywhere on the south section of the lake with high concentration of TP. That might be explained by the facts that: 1) the area of watershed, which is adjacent to the lake southern part, has also the high concentration of TP (Fig. 9a); 2) nutrient flows by rainfall-runoff and washed out directly into the lake waterbody. This assumption is confirmed by the fact that the TP continued to increase until October 2015, but the main component of TP was mostly under the organic form. This matter strongly confirms that there is an interrelationship between the lake and its watershed, and the unhealthy situation of the watershed affects significantly on the quality of the lake water. Fig.9b has shown a significant effect of TP from watershed on the TP level in the lake waterbody. The values of TP in the lake (Fig. 9b) were measured on September 10th 2015, after three days of heavy rains since August 27. More specifically, from Fig. 10, we can see that, since September 10th, TP spreads all over the surface of the lake and is concentrated mostly in the north due to the direction of flow South-North into outlet (the outlet is indicated in Fig. 2), with a permanent area of high concentration in the south. On October 4th the concentration in the south increased and spread northwards. There is also a section of the middle (east) with a high concentration. At the end of October, the concentration of TP has spread over the lake, and the high point in the south is still persisting. The highest concentration of TP is located in the north (Section III) area of the lake.

It is interesting to note that by the wind data obtained from our weather station, during the period of September-October in Mattatall Lake, there were no strong winds. The average wind speed was less than 2 m/s with maximum values around 5 m/s in some days. For example, on Sept 7, the maximum wind speed was 4.78 m/s South direction with gust speed over 10 m/s South-East direction; Oct. 10 with maximum speed of 4.28 m/s; Oct.17 and 20 with maximum speed of 4.03 m/s South-East direction). So, the fact that TP increasing and spreading all over the lake may not be associated with circulations by strong winds but possibly with other factors such as algae development and detritus as well as with the nutrient provided from the watershed.

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Surface level Bottom level

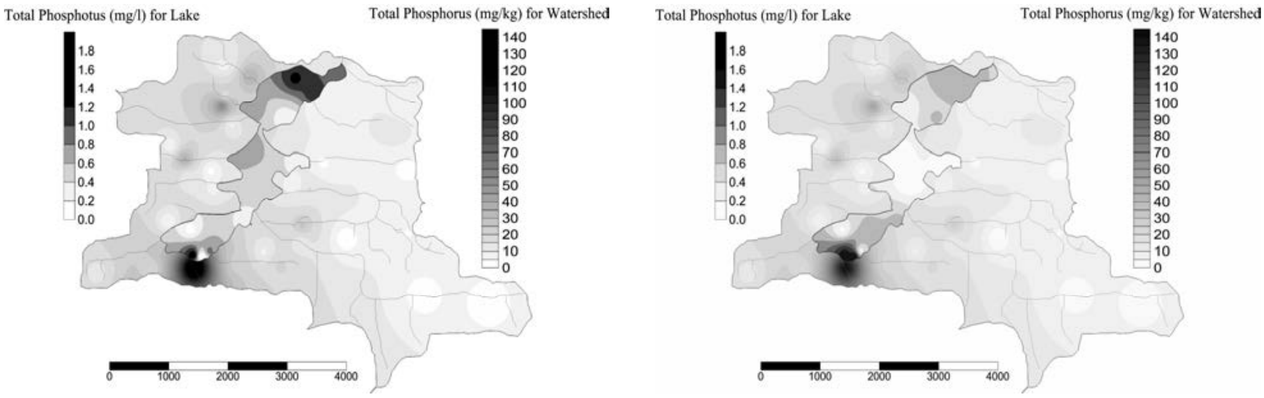

Fig. 9b. Total Phosphorus distribution in the lake waterbody affected by the watershed in September 2015 (Left: TP at the lake surface – Right: TP at the lake bottom)

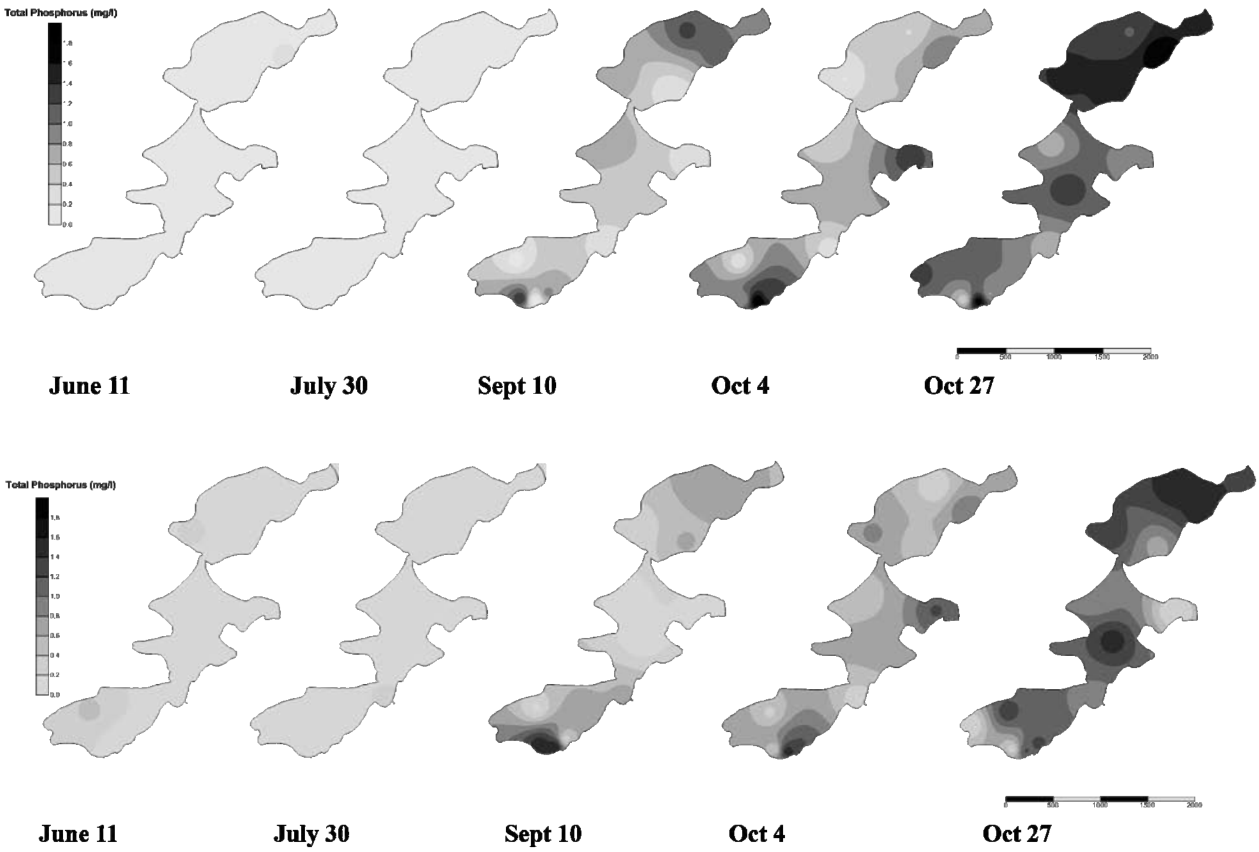

Fig. 10. Spatial and temporal distribution of TP at the lake surface (above) and bottom (below)

At the surface

It is also noted that the point IAI in the South section is very particular because due to the higher values of Phosphates at the surface level comparing to others locations. The values of Phosphates at this point were recorded as 0.3 mg/L (August 17), 0.15 mg/L (Sept 10) and 0.32 mg/L (October 27). That might be explained by the fact that there were some contaminant sources from the watershed side streaming to this location.

At the bottom

Data from June showed small concentrations in the south end of the lake, and in July, those concentrations were gone. In September, the south end of the lake began having a high concentration. There was also a section in the north that had a high concentration. The south concentration appeared to spread north in the month of October, and the middle of the lake had the presence of TP. On October 27th most of the lake had a high concentration of TP, but the highest areas were the north and the middle.

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3.4. Evolution of Nitrates in the lake

The evolution of Nitrate distribution is mapped through Fig. 11. The region of higher Nitrates concentration consists mainly of regrowth and has experienced the most developed urban zone in the past four years.

At the surface

The first results from June showed that the concentration of Nitrates was relatively constant throughout the lake. However, there was a point in the north of the lake (section III) where the concentration was very high. In July, the high concentration in the north was gone. The Nitrate levels were still constant, except there were several small areas of Nitrates on the lake (south, middle and north sections). The concentration remained constant into September, however, in the south area of the lake there was a small area with a still high Nitrates concentration (around 1.00 mg/L), and it could be strongly associated with Brook 1 and beaver dam where we obtained a high Nitrate concentration (2.5 mg/L) on August 17. Nitrate levels in October have stayed the same and even decreased comparing to previous months.

At the bottom

The pattern of Nitrate distribution on the bottom of the lake is similar to the surface in June: the high concentration point in the north end. There were also small areas in the middle and south area of the lake with a higher concentration. Nitrate levels in July were with the highest concentrations. It should be noted that the very high concentrations, more than 1 mg/L, started from point IC going to the North direction to point IIIA. After July, Nitrates decreased significantly and were almost identical to the values measured from June, except for the high point near to the outlet of the North section. The concentration of Nitrates lowered throughout September and October. In those two months, Nitrates spread more evenly over the bottom of the lake, with a slight increase on October 27th.

The very high level of Nitrates accidentally happening in June-July might be explained by the clear-cutting of large areas of forest, affecting the concentration of dissolved nutrients in the runoff water, the beaver damps leaking and many other dissolved organic matters after springtime.

3.5. Evolution of Chlorophyll-a

The maps of Chlorophyll-a distribution are successively displayed from Fig. 12. The results show the low level of Chlorophyll-a (*2µg/L)* at all levels in the waterbody until June 2015. This can be explained by the fact that the weather, water temperatures and PAR (Photosynthesis Active Radiation), even high during May and June, but needed the accumulation time to support the biomass growth. That was why the Chlorophyll started higher in July and some blooms also appeared from this month of July. In Fig. 12, the very dark color displays the high concentration of Chlorophyll-a appearing from July to September 2015. It is interesting to notice that those bloom locations correspond to algae bloom places observed by the lake residents in the fall 2014.

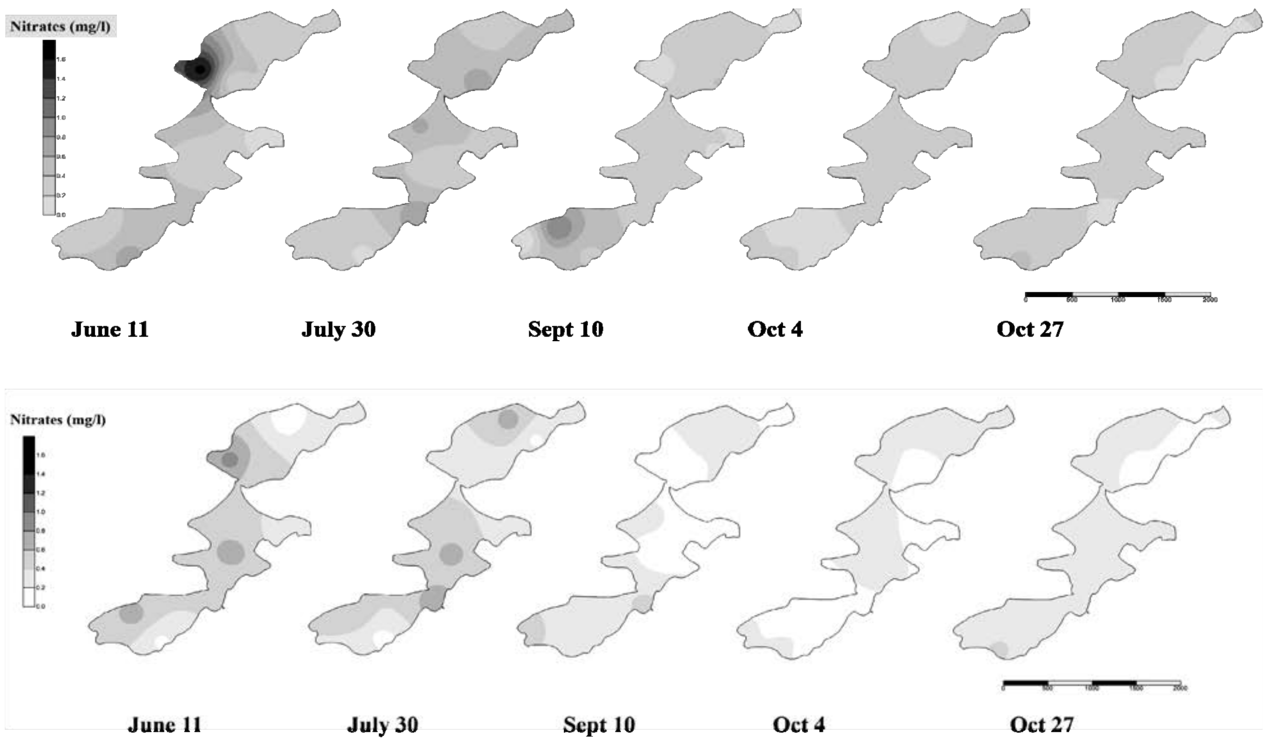

Fig. 11. Spatial and temporal distribution of Nitrates at the lake surface (above) and bottom (below)

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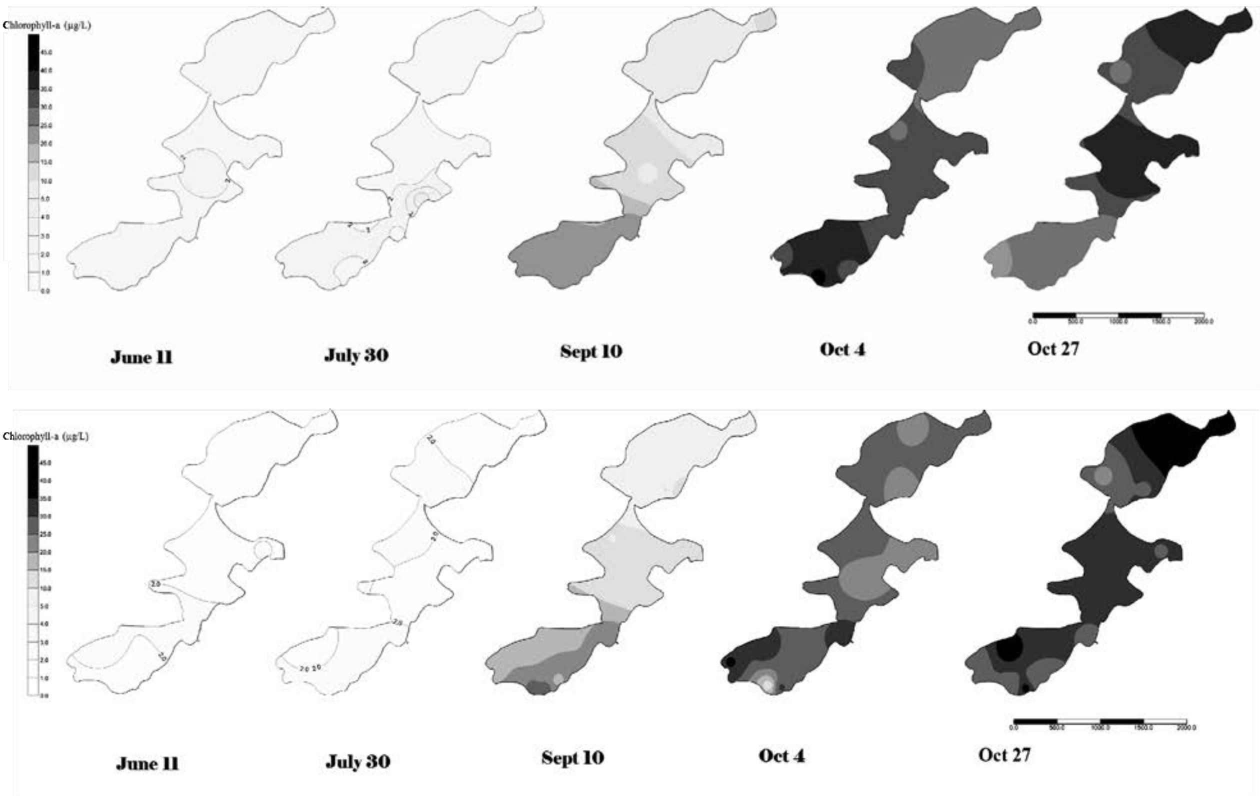

Fig. 12. Spatial and temporal distribution of Chlorophyll-a at the lake surface (above) and bottom (below)

In those areas, a higher supply of nutrients is available for the uptake by algae. The results in September shows that high concentration of Chlorophyll-a everywhere especially the south part of the lake. It was observed that lake water turned in green, and algal blooms were detected over the entire area in this time as well. The high detection of Chlorophyll-a does not suggest the presence of a bloom but rather identifies those locations to have more favorable conditions for the development of an algal bloom. Other tests to identify the biomass species will need to be performed in order to determine the locations of cyanobacteria algal blooms. More specifically from June, we can observe that:

At the surface

The levels of Chlorophyll-a in the lake from June 11^{th} to July 30^{th} were low, less than 2 µg/L. When the lake was tested in September, it was noticed that the Chlorophyll-a concentration increased. The south end (section I) of the lake had the highest concentration on that day. The transition into October showed how the concentration increased and spread northwards due to the domination of South wind. The highest amount of Chlorophyll-a still remained in the south part of the lake. The results from October 27^{th} showed how the Chlorophyll-a concentration continued to travel north, with the highest amount being in the middle and north parts of the lake (Sections II and III).

At the bottom

The bottom of the lake followed the pattern of the surface for the months of June and July: low levels of chlorophyll-a. In September, the concentration was higher in the south section of the lake, similar to the surface, except a smaller area on the bottom. The Chlorophyll-a spread throughout the bottom of the lake in October like other elements (TP and Nitrates) due to strong winds. The concentration of Chlorophyll-a on October 4^{th} is highest in the south part of the lake and from October 27^{th} data the concentration flowed to the north section of the lake. Generally, during the September-October field trips, Chlorophyll-a concentration at the bottom level showed that the development of algae blooms seemed more concentrated from the middle of the lake, the location near inlet parts, and the point IAI. Certainly, wind factors influence on all water column in the lake and due to the shallow depth, strong winds can mix water from the bottom to the surface level and vice-versa.

3.6. Evolution of Phycocyanin

The evolution of Phycocyanin during the summer is presented from Fig. 13. Cyanobacteria occurrence and dominance have increased from June to September. It is found that the southern part of the lake has the highest concentration of Phycocyanin (approximately 50 µg/L), and Phycocyanin presents relatively highly over the lake.

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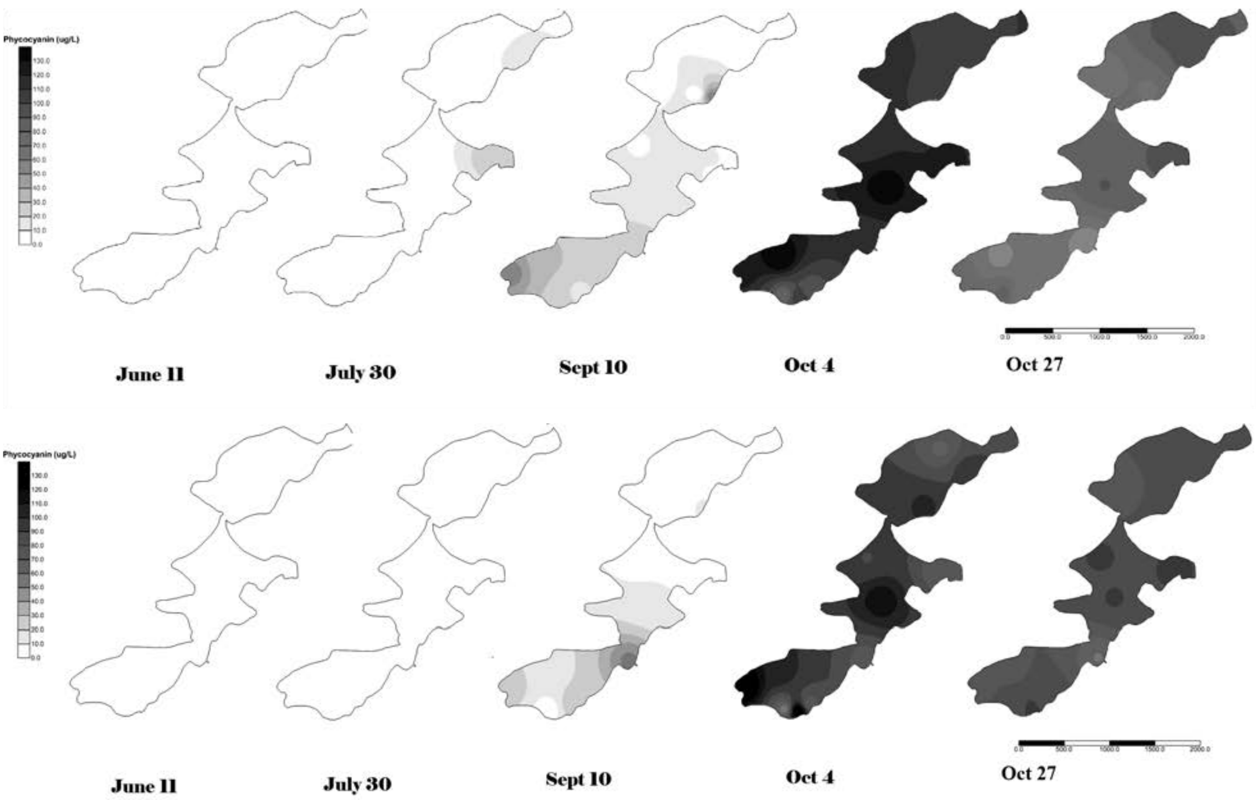

Fig. 13. Spatial and temporal distribution of Phycocyanin at the lake surface (above) and bottom (below)

At the surface

In June, there was little presence of Phycocyanin on the surface of the lake. Phycocyanin was not present until July 30th in the middle-east and north sections of the lake. On September 10th most of the surface was covered with a low concentration except for a small section in the far north. Early October on the lake had the highest concentration of Phycocyanin. The whole lake was covered and the concentration was above 110 µg/L. The south and middle sections of the lake had the highest concentration on October 4th. On the 27th of October the lake was still covered, but the concentration had lowered to approximately 80 µg/L. The highest concentration is in the north of the lake as well as the middle.

At the bottom

There was no presence of Phycocyanin in the lake in June or July. The first appearance was in September. The Phycocyanin was in the south end of the lake and spread into the middle section. The pattern of Phycocyanin on October 4th was very similar to the surface, except the concentration was lower. On the October 27th the concentration was lower than the 4th, and the distribution was still over the bottom of the lake.

The presence of Phycocyanin recorded since the end of July beginning of August has shown an increasing tendency of cyanobacteria in the lake, and the dominant species was identified as *Anabaena planctonia*. The June-July data showed that blooms made the value of Chlorophyll-a increasing, but with no Phycocyanin presence, due to a dominant nontoxic species named *Mougeotia sp*. In other words, algal blooms in Mattatall Lake in the summer time (June to August) were affected by nontoxic species *Mougeotia sp.* while algal blooms in fall and winter time were due to toxic cyanobacteria *Anabaena planctonica*, and hence the *Phycocyanin* increased all over the lake. This scenario, investigated and detected via our field data and shown herein with the mapping process, was well fitting with the results given by our various taxonomic tests. To have a more profound insight of taxonomy in Mattatall Lake, we will present all details in another manuscript which is currently prepared.

3.7. Simulation and prediction of algal development by ANN model

Figure 14 shows the relationship between TP and chlorophyll-a. The simulation has the starting TP value set to 0 mg/L, while the beginning Chlorophyll-a value is approximately 20 µg/L (that was the value of Chlorophyll-a when we started our study in this season). As time passes and TP is increased, the concentration of Chlorophyll-a slowly increases. Once the value of TP surpasses 0.25 mg/L, the concentration of Chlorophyll-a increases fairly sharply. Once the TP value is over 0.7 mg/L, the Chlorophyll-a value plateaus at 90 µg/L.

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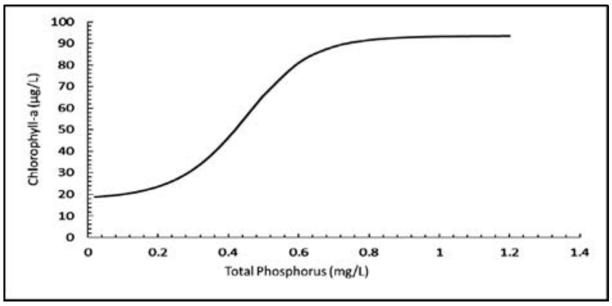

Fig. 14. TP versus Chlorophyll-a development

Fig.15 compares the value of Nitrates to the concentration of Chlorophyll-a. Comparing two figures 14 and 15, it is clear that Nitrates do not have as fast an effect on the Chlorophyll-a as TP does. The level of Nitrate starts at 0 mg/L (again, initial value of the study after winter season), and the predicted value of Chlorophyll-a is 12 µg/L. The concentration of Chlorophyll-a increases slowly until the value of Nitrate is 0.6 mg/L. At this point, the value of Chlorophyll-a increases at a steeper slope until Nitrate reaches 1.6 mg/L.

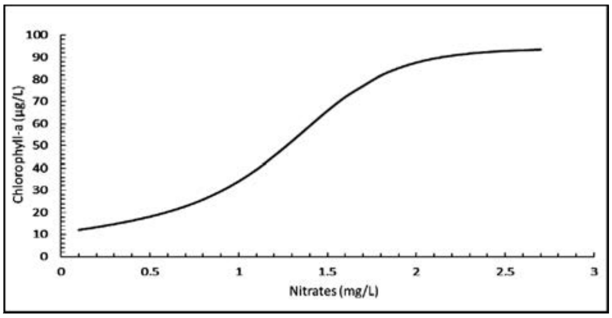

Fig. 15. Nitrates *versus* Chlorophyll-a development

The temperature has a very visible effect on the Chlorophyll-a concentration (Fig. 16). We can see from the simulation if the temperature goes beyond 30 °C, the Chlorophyll-a decreases and tends to zero when temperature reaching 35 °C. It means phytoplankton cannot survive the high temperature above 35 °C. The simulation also shows when the temperature decreases to the low values less than 11 °C, there is a sharp decrease in the value of Chlorophyll-a. The maximum value of Chlorophyll-a in function of temperature obtained by simulation is around 42 µg/L at 11 °C (Fig. 16).

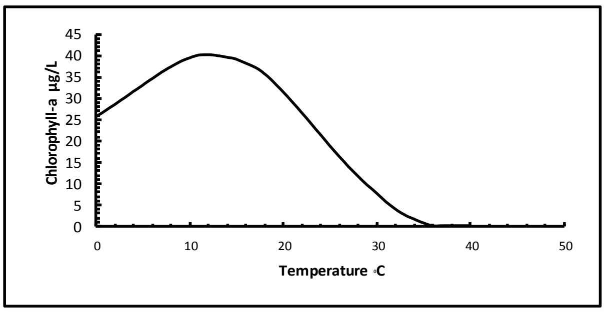

Fig. 16. Water temperature *versus* Chlorophyll-a development

DO is another parameter that effects the levels of Chlorophyll-a. Fig.17 shows the relationship between DO and chlorophyll-a. DO starts at approximately 2 mg/L and Chlorophyll-a at 30 µg/L. As the value of DO is increased, the Chlorophyll-a concentration slowly decreases until DO reaches 8 mg/L. Once the value of DO surpasses 8 mg/L, Chlorophyll-a starts to increase with DO until the maximum predicted value of 37 µg/L is reached when DO is around mg/L. This 'win-win' relationship between DO and Chlorophyll-a showed also an inverse effect, that means when DO can increase by the fact that when the algae develop (Chlorophyll-a increasing), the photosynthesis of diverse species of algae release more oxygen to the waterbody.

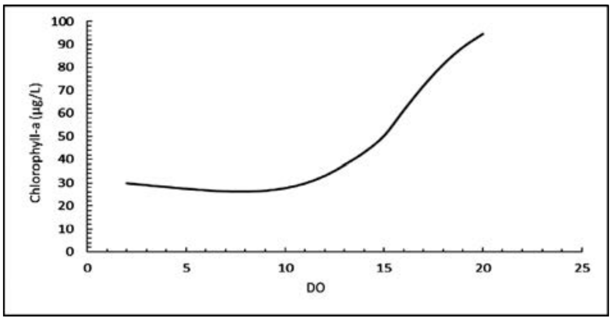

Fig. 17. DO *versus* Chlorophyll-a development

The prediction for pH appears to have an error starting out (Fig. 18). The value of Chlorophyll-a is in the negative numbers until pH reaches the value of 7. Out of all the single effect parameters, pH appears to be one of the top parameters to effect Chlorophyll-a concentration, next to temperature. When the pH value exceeds 7, the Chlorophyll-a concentration sharply increases. This increase stopped once the pH reaches 9, and once that value is exceeded, the Chlorophyll-a concentration slightly decreases to a plateau of 80 µg/L (Fig. 18).

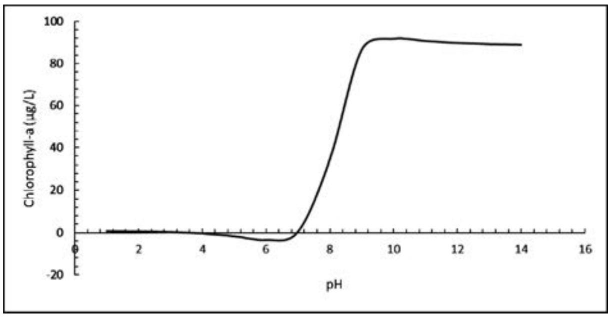

Fig. 18. pH *versus* Chlorophyll-a development

Figs. 19 and 20 show the coupled effects of duo-parameters on Chlorophyll-a concentration. The first figure (Fig. 19) presents the effect of DO and TP on Chlorophyll-a concentration. As both TP and DO are increased, the concentration of Chlorophyll-a increases as well. If the values of TP and DO are set to their maximum (5 mg/L and 13 mg/L respectively) the

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Chlorophyll-a concentration will be at its highest: 70 μg/L. From this simulation, we can see that essentially no high levels of Chlorophyll-a until 375 TP and 10.5 DO, that means if just single effect of TP of DO, we cannot have the Chlorophyll-a values, i.e. no algal development. In other words, the single effect of TP or DO cannot trigger the blooms. The same remark can be made when we consider the duo TP and Nitrates (Fig.20), as they appear to have a stronger relationship than TP and DO. As TP and Nitrates are increased, so is Chlorophyll-a. The maximum value of Chlorophyll-a (100 μg/L) is predicted when TP and Nitrates are at their maximum; 6 mg/L and 1.8 mg/L respectively. Again, the single effect of Nitrates or TP even when they are very high cannot be significant for the Chlorophyll-a quantity hence the bloom development.

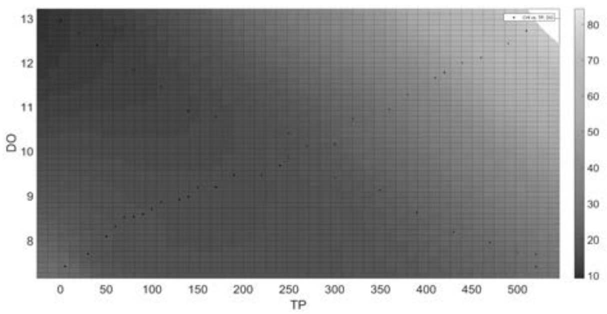

Fig. 19. Duo-effects of TP and DO on Chlorophyll-a development

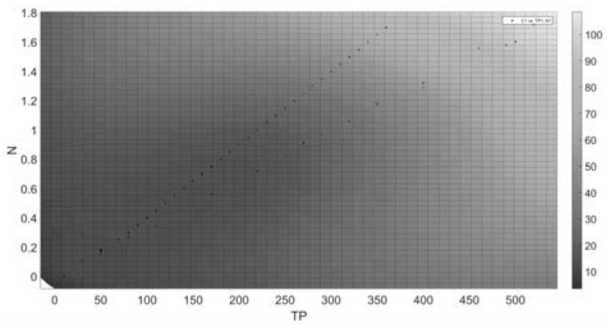

Fig. 20. Duo-effects of TP and N on Chlorophyll-a development

4. Conclusions

Recently toxic massive algal blooms of *Anabaena planctonica* trigged in Mattatall Lake (Canada) in a worrisome way, and persisted until the wintertime. The duration of this phenomenon was extremely unusual: starting from July and coexisting with icy conditions until late December. This issue has caused the lake residents to suffer. This study hence examined the evolution of chemical factors Nitrates and Total Phosphorus and the biological consequences via two parameters Chlorophyll-a and Phycocyanin in water samples collected from the lake and TP in soil samples in its watershed by using a predetermined, regularly spaced, grid sampling design for mapping. With GIS and remote sensing approach, we can gather the useful information regarding land cover change, and compile spatial distribution maps of sampling parameters, which serves as an indicator for algal blooms in the lake. The findings show that there is a strong relationship between Mattatall Lake and its watershed and a mutual effect.

As other lakes, the main supply of Mattatall Lake is from its own watershed including brooks and tributaries. Soils within watershed, which are contaminated by human or natural activities, will certainly affect the water source flowing into the lake. For example, some cottages on the southwestern shore were built at the same level of the lake. Hence, there is a risk of leaching septic tanks into the lake. Other possible reasons making the nutrient level of the lake higher could be the decomposition and defrosting of various organic materials that had been frozen through the winter and spring periods. Multiple brooks flowing into Mattatall Lake pass through the higher Phosphorus concentration areas year round by human activities (clear-cutting, spraying, etc.). Consequently, dissolved nutrients coming from those sources by rainfall-runoff and/or brooks wasting directly into the lake contribute to the growth of nutrient level on the lake waterbody.

It is evident that the south section also was the place where algal blooms were first observed in this season, and hence *Chlorophyll-a and Phycocyanin* are found to be high due to the development of massive algal quantity including cyanobacteria species. However, the reason of the high total Phosphorus concentration in watershed in the south part has not been well determined yet. Changes of the lake and its surrounding environment, especially watershed need to be reliably assessed from further studies to find out the primary causes of algae blooms. One of the future investigations is how to define the *accurate correlation* between nutrients from the watershed streaming into the lake waterbody.

Although the data are just collected consecutively during one summer and fall season (2015), and we need to continue more sampling next several years for a complete database of Mattatall Lake and for a more advanced model of the prediction and prevention. The novelty and innovation of this study rely on a systematic investigation and the suggested methodology for a standard process. This study could certainly serve as a pilot study for many lakes that unfortunately have the same worldwide issue under the global warming and climate change effects. A lake turns green is not good for anyone, not for the residents (they cannot use their own lake for all purposes, and there will be the drop in property values), nor for the visitors (the lake would be closed for their recreational use), and not the municipal councils (loss of tax revenue). The greater the degree of human activity, the greater the risk for the lake water

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quality. Moreover, we hope that the findings of this study should be a good solid scientific evidence and advice to inform the related administrative authorities at *all levels* for many lakes with the same issue.

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