Application of Water Quality Index for Pollution Detection at Luton Hoo Lake

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***Abstract*—This study investigated contamination problems through physical and chemical surface water monitoring. The physical parameters were temperature, conductivity and turbidity while the chemical parameters were dissolved oxygen, pH and ammonium. These parameters were measured at two locations on the lake to monitor the water quality and possible sources of contamination. We evaluated the relationship of the measured parameters to contamination sources and its effect on the water quality. The collected data from the installed multi parameter sensors were analyzed to assess the difference in values at the different sensor locations based on a water quality index.**

Keywords; Water qulity index, sensors, pollution

I. INTRODUCTION

Various environmental effects are fast depleting the quality of fresh water resources, this has triggered the drive for the development of water quality monitoring programs [3, 4]. The monitoring schemes typically employ sensors for monitoring the water quality. However, there is the difficulty in evaluating and qualifying the water quality from this large amount of sensor data usually for different parameters [5].

An efficient way of handling large sensor data is mathematical computational modeling of the river. This requires knowledge of hydrodynamics and hydraulics to create an efficient model that needs an extensive validation. Water quality indices solve this problem by giving decision makers and interested parties relevant information in a summarized form on water quality to help monitor the changes and trends exhibited by the water body [5, 6]. The main aim of water quality indices is to give a single value to the water quality of a source which reduces multiple parameters into a simple and logical expression that easily interprets the monitored data. This has been proposed by so many authors in the water quality monitoring area [1, 2, 3]. Water quality index is one of the most appropriate ways to describe water quality as it considers the suitability of the water sources like lakes, rivers, ground water for human consumption [2].

This paper reviewed previous work done in water quality index (WQI) and examined their calculation methods. We discussed results from our own data analysis using the box plot analysis and WQI using the WQI minimum method.

II. PREVIOUS WORK

Horton (1965) tried to categorize water based on its purity level in United States using 10 water quality variables which are commonly used to assess water quality [1, 2]. This index was widely accepted and applied in countries within the European Union, Africa and Asia [2]. There have been many water quality indices formulated around the world which have been used to effectively judge the overall water quality in different situations [1, 2]. They are mostly based on the comparison of the parameters measured for water quality monitoring and the environmental regulatory standards available. Whilst they may consider the same physical and chemical parameters they differ in the integration and interpretation of the parameters measured [1, 3]. They included: US National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of Environment Water Quality Index (CCMEWQI) [13], Oregon Water Quality Index (OWQI), Weight Arithmetic water quality index (WAWQI), British Columbia Water Quality Index (BCWQI) [1]

In general, water quality indices depended on the normalization of water quality parameters based on the expected concentrations. These parameters were weighted according to their level of importance to the overall water quality while the index was calculated with regards to the observed weighted average and interpreted on a "good" to "bad" scaling [1, 4]. The parameters were transformed to a scale of 0 – 100 making 100 the best quality attainable by the parameters while 0 was the lowest quality [4].

Water quality index calculation method generally involved following three steps (a) Parameter Selection (b) Determination of Quality Function (Curve) for each parameter considered as the sub-index (c) Sub-indices Aggregation with mathematical expression [2]. Currently there is no universally accepted water quality index and interested parties still make use of the available indices with little modifications [2].

A team of 142 experts in water quality [7] based their WQI on 9 parameters that are - dissolved oxygen, fecal coliform, pH, biochemical oxygen demand, temperature, total phosphate, nitrate, turbidity and total solids. Each parameter was assigned a quality value which was then multiplied by the weighting factor of each parameter with regards to its level of importance. A summation of the weighted values was given as the WQI which showed the quality of the water and the calculation steps were as follows [7]:

1. Assigning of weights Aw_i to the parameters within a range of 1 – 4 which was based on the opinions from the experts with respect to previous research work. A value of 1 indicated the parameter is least significant while value of 4 was seen as the most significant.

2. Calculation of relative weight RW was based on the following equation

$$RW_i = \frac{Aw_i}{\sum_{i=1}^{n} Aw_i} \quad (1)$$

where RW_i is the relative weight, Aw_i is the assigned weight and n is the number of parameters

3. Quality rating scale was assigned by dividing the parameter concentration in water sample by its respective standard and multiplying by 100

$$Q_i = \left[\frac{C_i}{S_i}\right] \times 100 \quad (2)$$

Except for pH and dissolved oxygen which was calculated as

$$Q_{pH}, DO = \left[\frac{C_i - V_i}{S_i - V_i}\right] \times 100 \quad (3)$$

where Q_i is the quality rating, C_i is the value of water quality parameter, S_i is the value of the parameter based on WHO standards and V_i is the ideal value for pH=7.0 and DO = 14.6

4. Calculation of the sub-indices for each of the parameter was done using

$$SI_i = RW_i \times Q_i \quad (4)$$

And the WQI computed in the form of

$$WQI = \sum_{i=1}^{n} SI_i \quad (5)$$

WQI was calculated by [3] using the following equation

$$WQI = \frac{\sum_{i=1}^{n} C_i * P_i}{\sum_{i=1}^{n} P_i} \quad (6)$$

where *n* is the number of parameters, C_i is the normalized value of the parameter and P_i is the relative weight of the parameter based on its relevance to aquatic life. This was a calculation of the weighted sums of the individual parameter sub index scores.

The European Union standard of 1975 through the Council Directive 75/440/EEC for clean water was used as a reference for the calculation of the water quality index with respect to the acceptable limits for parameters used [4 , 9]. This was further strengthened by the Directive 2006/44/EC of the European Parliament which stipulated quality of fresh water that supports fish life [10]. These values were reflected in the normalization table as in Table 1.

In carrying out WQI for surface waters certain parameters are considered directly or indirectly. Dissolved oxygen is very important as a water quality indicator and stands as a key factor for aquatic life. Ammonia in un-ionized form at very low concentrations is very toxic to aquatic life whereas conductivity shows the extent of the presence of dissolved ions beyond the natural levels stipulated. Temperature and pH are important as they affect the aquatic system based on human changes to the natural patterns [3].

Another empirical equation used by Pesce and Wunderlin in [4] for WQI calculation was:

$$WQI = k\frac{\sum_i C_i P_i}{\sum_i P_i} \quad (7)$$

where k is a constant based on visual access of the water body with a maximum of 1 for good quality water and a value of 0.25 for polluted water. *Ci* is the normalized value of the parameter while *Pi* is the relative weight assigned to each parameter with a maximum value of 4 for the most relevant parameter with regards to aquatic life. [4]

A minimal WQI developed by Pesce et al [5, 8] used only three parameters namely turbidity, dissolved oxygen and either conductivity or dissolved solids.

$$WQI_{min} = \frac{C_{DO} + C_{cond} + C_{turb}}{3} \quad (8)$$

where C_{DO} is the value of the dissolved oxygen after normalization based on Table 1, C_{cond} is the value due to conductivity after normalization and C_{turb} is the value of turbidity after normalization.

The parameters selected for the calculation of the *WQImin* were assumed to be the most important indicator parameters and can be easily evaluated. Whereas dissolved oxygen is a very important factor for aquatic life and a necessity for survival, low levels of dissolved oxygen are an indication of pollution and bacterial contamination while conductivity shows the presence of salts and mineral acids discharged to the water body [5,8]. Natural weathering of some rocks with industrial and sewage effluent may result in high conductivity [7]. *WQImin* can be used for periodic monitoring and analysis as it gives a clear view of the trend analysis.

Authors [11, 12, 13, 14] have applied different water quality indices modified to meet the requirements for various surface water bodies. Table 2 gives us an overview of the WQI values with the extent of pollution.

Table 1: Parameters with normalization value [3, 4, 8]

Parameter	**Relative weight Wi**	**Normalization value Ci**										
		100	90	80	70	60	50	40	30	20	10	0
Ammonia	3	<0.01	<0.05	<0.10	<0.20	<0.30	<0.40	<0.5	<0.75	<1.00	≤1.25	>1.25
Conductivity	2	<750	<1000	<1250	<1500	<2000	<2500	<3000	<5000	<8000	≤12000	>12000
Dissolved oxygen	4	≥7.5	>7.0	>6.5	>6.0	>5.0	>4.0	>3.5	>3.0	>2.0	≥1.0	<1.0
pH	1	7	7.0 – 8.0	7.0 – 8.5	7.0 – 9.0	6.5 – 7.0	6.0 – 9.5	5.0 – 10.0	4.0 – 11.0	3.0 – 12.0	2.0 -13.0	1.0 – 14.0
Temperature	1	21/16	22/15	24/14	26/12	28/10	30/5	32/0	36/-2	40/-4	45/-6	>45/<-6
Turbidity NTU	2	<5	<10	<15	<20	<25	<30	<40	<60	<80	≤100	>100

Table 2: Rating scale for quality of water [6]

Value of WQI	Quality of water	Extent of pollution
90 – 100	Excellent	Clean
70 – 90	Good	Slight pollution
50 – 70	Medium	Moderate pollution
25 – 50	Bad	Excess pollution
0 – 25	Very bad	Severe pollution

III. METHODS

Our study investigated contamination problems through physical and chemical water monitoring in a lake in Luton, UK. The physical parameters monitored regularly were temperature, conductivity and turbidity, the chemical parameters were dissolved oxygen, pH and ammonium.
These parameters were measured at two locations on the lake (sensor locations shown in Figure 1) to help monitor the water quality and possible sources of contamination.
We evaluated the relationship of the measured parameters to contamination sources and its effect on the water quality. The collected data from the installed multi parameter sensors were analyzed to assess the differences in values at the different sensor locations

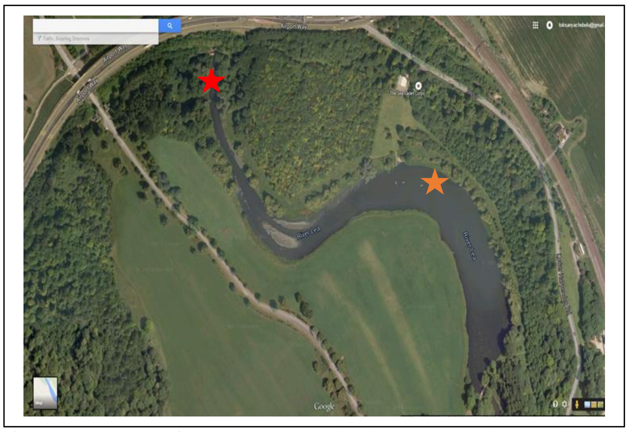

Figure 1: *Map of Luton Hoo Lake (maps.google.co.uk) with the red star showing Location 1 and orange star showing Location 2*

In order to have a full view of the trends for the different parameters, box plot analysis was carried out over the period of monitoring from September 2014 to April 2015 for the two sensor locations as shown in Figures 2-7. A water quality index (See Figures 8) was computed based on equation (8) that examined the extent of pollution on the lake based on the European Union guidelines.

IV. RESULTS AND DISCUSSION

For the purpose of this work, the Environment Agency has made available 30 months multi parameter sensor data for location 1(indicated with a red start in Figure 1) on the Luton Hoo Lake and Luton airport has made available 7 months data for location 2 (indicated with an orange star in Figure 1) on the lake. This multi parameter sensor probe measured the values for the water quality parameters which were dissolved oxygen, ammonia, conductivity, temperature, pH and turbidity. The readings were captured every 15 minutes.
To analyze the trends for values from the sensor data, box plot analysis was employed as a statistical tool to examine the distribution of parameter values. Figures 2 – 12 show the various distributions at the two sensor locations for the individual parameters.
There was a normal distribution of dissolved oxygen for location 1 in Figure 2 based on available standards from review. It can be seen from Figure 3 that the distribution of dissolved oxygen value at location 2 dropped within Jan 2015 to March 2015 which can be attributed to the use of de-icers at the airport which was close to the sensor location. The pH values at both locations as in Figure 4 and 5 remained within the specified level suitable for aquatic life by the European Union Water Framework Directive.
The distributions of the sensor data values on conductivity were above the 50 - 200µS/cm expected permissible level for aquatic life. This suggested the presence of salts which become intolerable for fishes thereby posing a health hazard. Figure 6 and 7 shows the result of the analysis at location 1 and 2 respectively
Having a single value to represent the various parameters to help assess the water quality was the main aim of calculating the water quality index. This will enable decision makers to take rapid actions towards mitigating pollution incidents. The WQI minimum adopted for this work used three of the measured parameters which were dissolved oxygen, conductivity and turbidity for the calculation as in (8). This was seen as a low cost way of reflecting the quality of the surface water body as it considers three important parameters that affect water quality in the environment. Developing countries could explore this as a cheaper way of keeping track of their water bodies with low stress on the country's finances.
Analysis of the plots for location 1 in Figure 8 show a 60% to 80% water quality index based on suitability for aquatic life. This splits between the "Medium" and "Good" water quality rating. It fell to a "Bad" water quality of 42% at the top of the March 2015 winter month. Location 2 in Figure 8 experienced a 50% - 65% water quality index that could be described as a moderately polluted period while it degraded to a severe pollution period with lower index of 23.3% - 30% within the Jan 2015 to March 2015 and classified as a "Bad" water quality period. This trend reflected the downward trend distribution of dissolved oxygen from the box plot analysis and further stresses the importance of dissolved oxygen as an indicator of water quality.

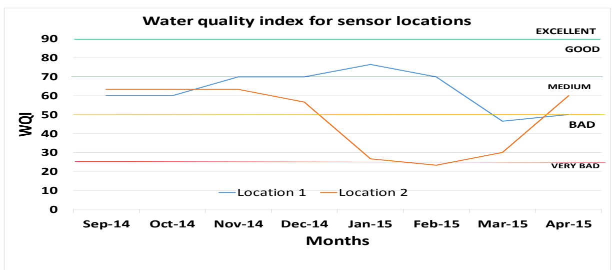

Figure 8: Water quality index for sensor locations

CONCLUSION

Trends have been visualized based on the results of the water quality index using three parameters. It is evident that these parameters measured follow a seasonal pattern. Calculating the Index using WQI_{min} makes it easier and less time consuming while giving a great range of what is happening within the lake. The index achieved will act as an input towards the prediction of water quality trends and possible contamination predictions.

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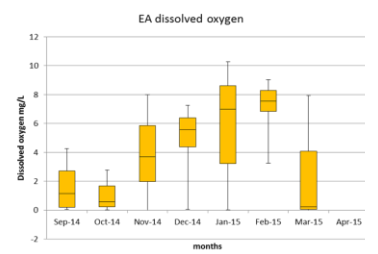

Figure 2: Location 1 DO box plot analysis

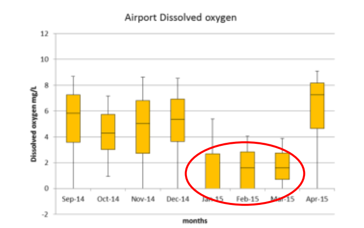

Figure 3: Location 2 DO box plot analysis

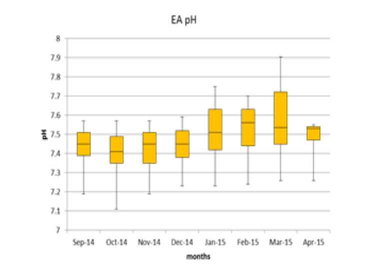

Figure 4: Location 1 pH box plot analysis

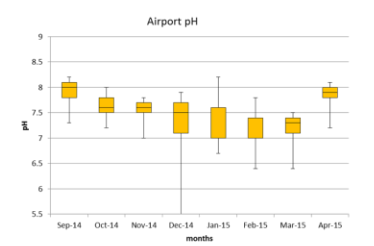

Figure 5: Location 2 pH box plot analysis

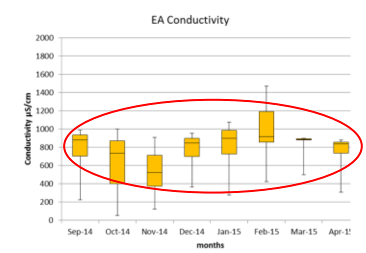

Figure 6: Location 1 Conductivity box plot analysis

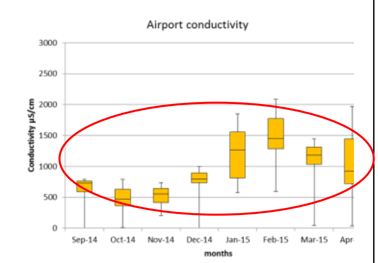

Figure 7: Location 2 Conductivity box plot analysis