WATER QUALITY CHARACTERIZATION OF MAJOR LAKES IN ANURADHAPURA AND IDENTIFICATION OF MAJOR POLLUTANT SOURCES, POTENTIAL MITIGATION AND MANAGEMENT STRATEGIES

K.L.P.S.Perera[1], N.D.Imbulana[1], K.M.A.T.Kondasinghe[1], K.D.Salwathura[1], I.M.Chathuranika[1], L.B.Ellikewela[1], N.P.Miguntanna[2]

[1]Department of Civil and Infrastructure, Faculty of Engineering, South Asian Institute of Technology and Medicine (SAITM), Sri Lanka. Email: **pasindu.perera@gmail.com**
[2]Senior Lecturer, Department of Civil & Infrastructure Engineering, Faculty of Engineering, South Asian Institute of Technology and Medicine (SAITM), Sri Lanka.

ABSTRACT

This paper discusses the outcomes of a research project conducted to analyze the correlation between the rate of deterioration of water quality of surface water bodies with the level of implementation of Best Management Practices (BMPs) in the form of both infrastructure and via regulations. The research was conducted by obtaining data for water quality parameters for a period of several years and analyzing the trend in their variation and obtaining the relationship with the level of BMP implementation by identifying the pollutant sources and by conducting a community questionnaire at three selected major lakes in the Anuradhapura district which are crucial for providing water for agriculture, daily usage and water treatment for providing the potable water supply for the sacred city. The results indicate that the level of BMP implementation in all three lakes are inadequate, but in the case of Thuruwila Wewa, the measures taken by the regulatory bodies and the communities participation in regular litter cleanup projects,etc indicate that this higher level of BMP implementation has led to Thuruwila wewa being considerably less polluted than the other two. This indicates that by educating the surrounding communities on BMPs and by the implementation of certain BMPs depending on the pollutant sources the water quality can be regulated and hence reduces the effort, money and time required in treating the water to make it safe for consumption.

Keywords: Lakes, Water Quality, Pollution, Best Management Practices

1. INTRODUCTION

Sri Lanka receives about 120 billion m^3 of water annually as rainfall. About 45 billion m^3 annual renewable water resources, part of which can be utilized for different purposes such as domestic consumption, irrigation and industries [1]. The country is divided into a dry zone and a wet zone based on rainfall and evaporation. In the dry zone, annual average evapo-transpiration exceeds the average annual rainfall [2]. Therefore, collection of water in reservoirs in the rainy period is essential for the community in the dry zone to meet their domestic and irrigation water requirements. Deterioration of water quality in such reservoirs or lakes poses a severe threat to the life and livelihoods of the community in the dry zone areas.

The objective of this research was to assess the water quality of selected major lakes in Anuradhapura, to identify the pollution sources and hence to emphasize the importance of implementation of best management practices (BMPs) in improving and maintaining the quality of lake water.

Anuradhapura is a UNESCO world heritage site which attracts a large number of tourists and pilgrims. In addition, the district is a major agricultural area in the country. Therefore there is a considerable amount of agricultural and domestic pollution affecting the lakes in the vicinity of the city. It is evident that when the quality of water in the lake is poor the treatment cost of drinking water supply will rise. Therefore this research is conducted based on the hypothesis that it is more economical and practical to improve the quality of water intake for purification rather than attempting to treat poor quality water which consumes more cost and time

1.1 Site Description

Three major lakes namely Thuruwila Wewa, Thissa Wewa and Nuwara Wewa which are the only three drinking water supplying lakes in Anuradhapura were selected for this research. These lakes provide drinking water supply to areas in Anuradapura East, Anuradapura Central, Mihintale, Thalawa and Thirappane Divisional Secretary administrative divisions in Anuradapura district. Water supply coverage under Thuruwila Wewa, NuwaraWewa and Tissa Wewa is 26000,

15500, 4500 connections respectively.
These three lakes are fed by Mahaweli water through Yoda Ela of Kala Wewa (Figure 1). Table 1 shows the catchment area covered by these three lakes and their storage capacities.

2. METHODOLOGY

The data collection of this research was done mainly in two stages. Firstly, a community questionnaire survey was conducted by visiting random houses from neighborhoods and villages in the immediate vicinity of the lakes**.**
The primary objectives of this survey were to understand the people's perspective on water quality of the lakes, pollution sources, trends of pollution and the extent of the implementation of Best Management Practices in the vicinity of the target lakes. Each participant was questioned on their usage of the lake, their view on the current water quality and whether they have seen any improvement or deterioration of the water quality during the past years and whether they are aware of what BMPs are and whether they are implemented in the area and if so what the implemented BMPs are.

Table 1: Catchment areas and storage capacities (Sources: [3])

Tank	Water spread area	Storage		Connections (to consumers)
	Acre	Ac.ft	Million m3	
Nuwara wewa	3000	36000	44.42	15500
Tissa Wewa	450	2900	3.58	4500
Thuruwila Wewa	1013.13	7539.6	9.3	26000

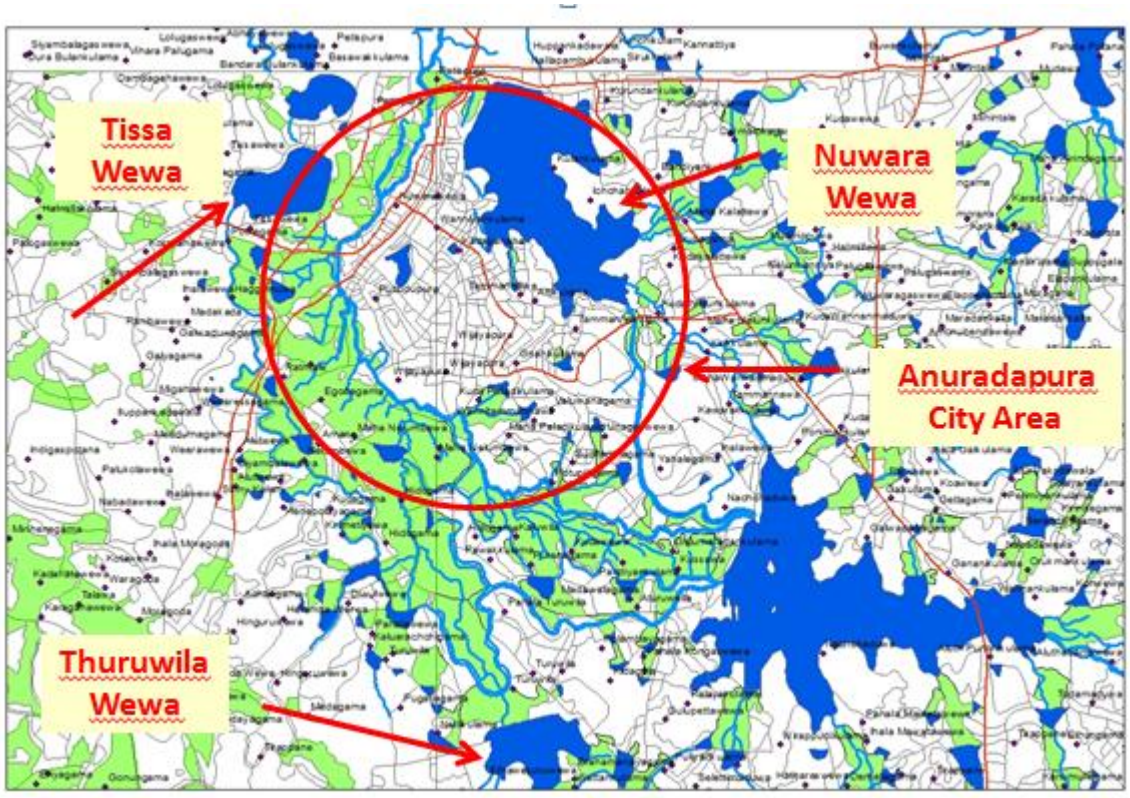

Figure 1: Location map of the selected lakes (Sources: [3])

Secondly, the measured water quality data of range of physical, chemical and biological water quality parameters for different time periods between the years 2001-2013 was obtained from the National Water Supply and Drainage Board, Sri Lanka (NWSDB) in Ratmalana. The water quality parameters selected for this research are Turbidity (NTU), pH, Electrical Conductivity (EC), Chloride (Cl^-), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Total Coliforms E.Coli at 440^0C/100ml, Total Alkalinity, Nitrates (NO_3^-), Nitrites (NO_2^-) and color.

This data has been obtained according to the specified Standard Methods for Examination of Water and Wastewater (APHA, 2001).

The data obtained from the community survey and laboratory testing was then analyzed using the statistical data analysis software Microsoft Access 2010, Microsoft Excel 2010 and StatistiXL Version 1.9.

2.1 Data Analysis Techniques

Data analysis was employed in this research mainly to identify the variation of water quality parameters in the selected lakes with time and to identify the correlation between the trends in the water quality variation and the information obtained from the analysis of the data from the questionnaire survey. Consequently, mainly univariate data analysis techniques which consists of analysis of mean and standard deviation, variation of each water quality parameter with time and the percentage variation of the each BMP implementation in each lake were performed included in the data analysis This was done in three stages, where in the first stage the yearly averages for each water quality parameter was calculated and the variation of those parameters were plotted to find how the parameter had changed during a large time period by eliminating the data points which had exceeded maximum possible values for the given parameter therefore minimizing the effects due to sudden peaks and possible errors in taking the readings. This was done to generate an overall understanding on how the water quality has either deteriorated or become better in the last few years, and in which lakes and what rates.

The second stage involved finding the mean of each parameter for the entire recorded period so that the three lakes could be compared to see which had overall more pollution during the past few years. Thirdly, the questionnaire data was analyzed by finding the percentages implementation of each BMP for each lake in order to compare the three lakes which had different number of questionnaires filled.

3. RESULTS

Table 2 shows the mean and standard deviation of each water quality parameter in each lake and Table 3 shows the percentage implementation of each BMP in each lake whereas the Figure 2 shows the comparison between lakes based on the implementation of each BMP obtained based on the responses of the questionnaire survey. According to Table 2 it is evident that the quality of water in Thuruwila wewa is much better when compared with the other two lakes. This is further supported by the Figure 3 which shows the comparison between each lake based on the responses generated for the question on the satisfaction of water quality in the questionnaire survey. According to Table 3 and Figure 2 Thuruwila Wewa has the overall best implementation of BMPs in the surrounding area. Therefore it is fair to assume that there is a strong correlation between the implementation of BMPs and water quality. According to Table 2 and Figure 4 the turbidity in the Thuruwila Wewa is the least of the three with the lowest standard deviation. This result is further confirmed by the results of the survey as shown in Figure 5.

This is enforced by the high percentage implementation of the BMPs (Figure 2 and Table 3) such as Sedimentation Basins, and Regular litter cleanup activities by the surrounding communities and the maintenance of roads and embankments by the authorities. Since Thuruwila Wewa is one of the main sources for water treatment, and the overall satisfaction of the community is also the highest (Figure 3) due to the overall good water quality.

Table 2: Water Quality Parameters

Parameter	Thuruwila Wewa		Nuwara Wewa		Tissa Wewa	
	Mean	Std.Dev	Mean	Std. Dev	Mean	Std. Dev
pH	7.325	0.468	7.369	0.572	7.333	0.521
Turbidity (NTU)	11.979	9.676	13.797	18.577	14.056	12.464
Electrical Conductivity at 25^{o}C - (uS/cm)	410.687	93.715	391.559	103.535	294.818	92.508
Nitrates (NO_3^-) - (mg/l)	1.411	1.1792	1.600	1.0597	1.451	1.273
Nitrites (NO_2^-) - (mg/l)	0.028	0.097	0.023	0.098	0.034	0.152
E. Coli at 44^{o}C/100ml	32.514	35.018	29.336	34.683	59.056	103.815

Table 3 : Percentage Implementation of BMPs

Lake	Regular Litter Cleanup	Educating people	Awareness Programs	Regular Advisories on water quality	Farming Conservation Practices	Phosphorus free fertilizers	Livestock waste management
Tissa Wewa	72.00	60.00	36.00	20.00	4.00	0.00	4.00
Thuruwila	70.00	54.29	37.14	20.00	55.71	22.86	41.43
Nuwara Weva	57.69	46.15	23.08	0.00	11.54	7.69	7.69

	Regular Maintenance of septic systems	Constructed Wetlands	Sedimentation Basins	Riparian Zones	Permeable Road surface	Adequate Sanitary facilities	Wastewater treatment
Tissa Wewa	12.00	8.00	4.00	28.00	36.00	24.00	4.00
Thuruwila	35.71	17.14	17.14	45.71	4.29	40.00	24.29
Nuwara Weva	15.38	11.54	3.85	46.15	34.62	23.08	7.69

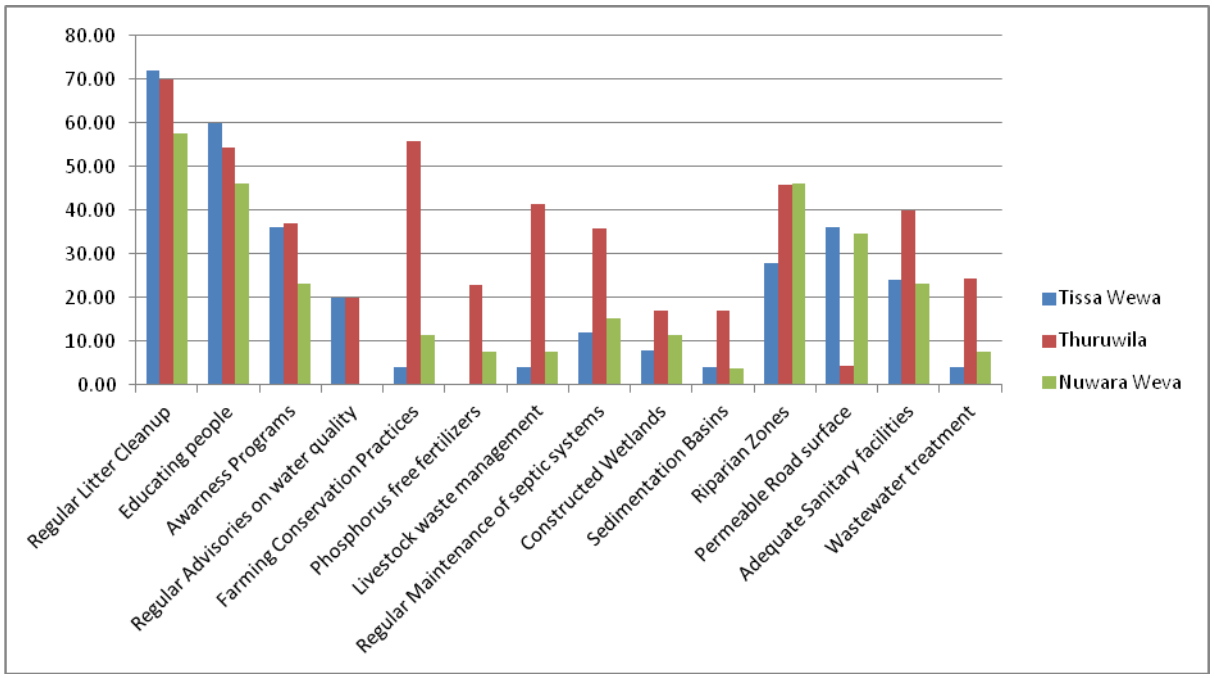

Figure 2: Comparison of BMP implementation

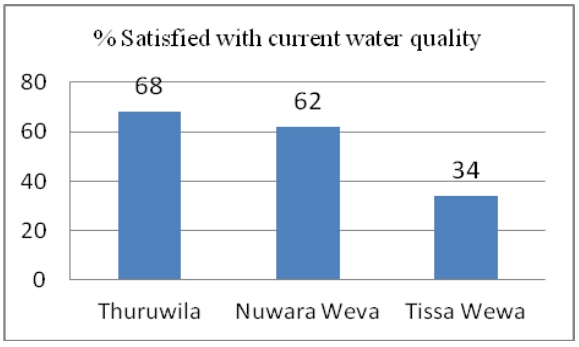

Figure 3: Percentage of community satisfied with current water quality

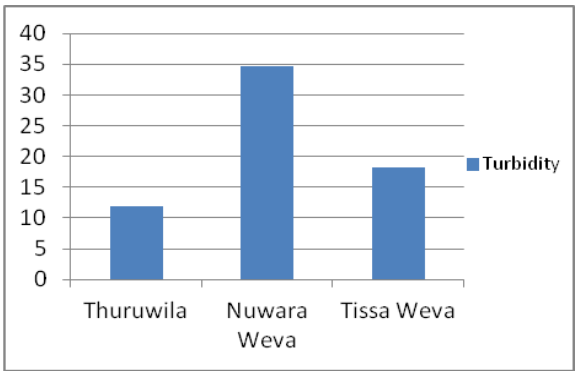

Figure 4: Turbidity reference data from NWSDB

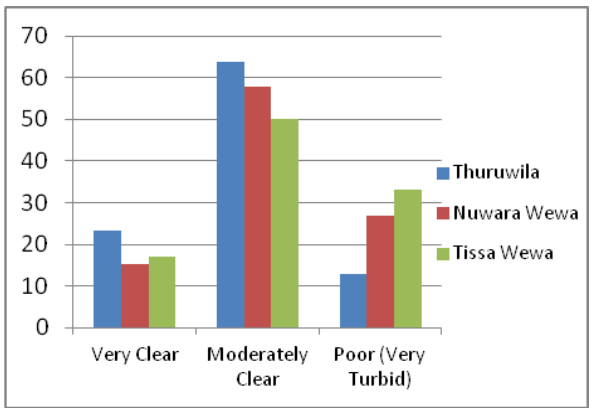

Figure 5: Clarity of lake water-Survey

According to Figure 3 Tissa Wewa shows the highest number of people who are not satisfied with the current water quality. Most of the people interviewed expressed great concern over both the water quality of the lake and the water they receive via the pipeline saying that it is highly undesirable especially for portable usage. This is further confirmed by the data obtained from NWSDB (Table 2) which supports that Thissa Wewa has the highest level of pollution. Looking at the Figure 2 it is evident that the implementation of BMPs is poor in Thissa Wewa compared to Thuruwila Wewa. The location of Tissa Wewa in a highly populated area has caused it to be affected greatly by pilgrims who pollute both the water and the immediate surroundings of the lake. Although there is a high percentage of BMPs such as regular litter cleanups, education and awareness programs (Figure 2), there is not enough adequate sanitary facilities (<25%) , wastewater treatment (<5%), regular maintenance of septic systems (<15%) which leads to the high level of Total Coliforms E.Coli in the lake (Table 2). This can also be attributed to the lack of sedimentation basins and the direct run off of storm water from the main roads to the lake where the turbidity levels are also considerably higher (Table 3).

Another source of pollution to the Tissa Wewa is the presence of a cemetery in the immediate vicinity of the lake's embankment where all the storm water accumulated in the cemetery washes off directly to the lake which can carry sediments, toxic substances and organic matter. Furthermore, as noted in the community survey that the discharge of large amounts of waste matter from a nearby military installation into a gulley which is directly connected to the lake also might contribute to the higher pollution in the Tissa Wewa. Moreover, the lack of proper construction and planning techniques in the neighborhoods has resulted in outhouses and sewage pits being built in the very close proximity to water ways which are drained to the Tissa Wewa.

Figure 6(a) shows the variation of total coliform levels in each lake during the time period from 2010 to 2013. According to this figure it is evident that the total coliform levels in Tissa Wewa have increased substantially during the recorded time period. This is likely due to the lack of BMP's regarding wastewater treatment, livestock management and regular maintenance of septic systems (Figure 2 and Table 3)

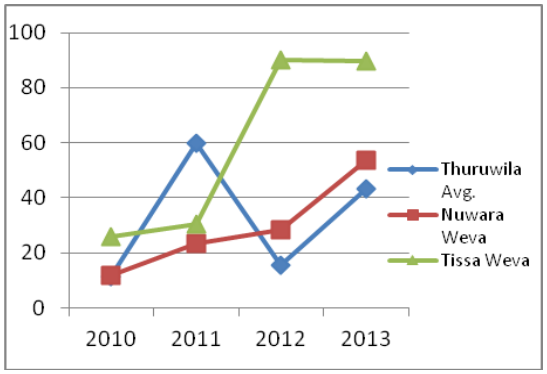

Figure 6(a): Total Coliform annual variation

In the case of Nuwara Wewa, the overall satisfaction of the community is much higher than Tissa Wewa (Figure 3) but the water quality data indicates that the pollution in Nuwara Wewa is also reasonably high. The turbidity level in Nuwara Wewa is also high with a greater std. deviation (Table 2) and the average value for the water quality parameter of color is also the highest in Nuwara Wewa (>70 units). These facts are further confirmed by the respond of the stake holders about the clarity of lake water during the questionnaire survey Figure 5. This can be explained by the lack of sedimentation basins, and low level of cleanup projects (Figure 2 and Table 3). The fact that the drainage area of the lake has been built up with residential areas which have paved surfaces, and hence more run off which leads to greater accumulation of sediments in the lake could also be a another reason.

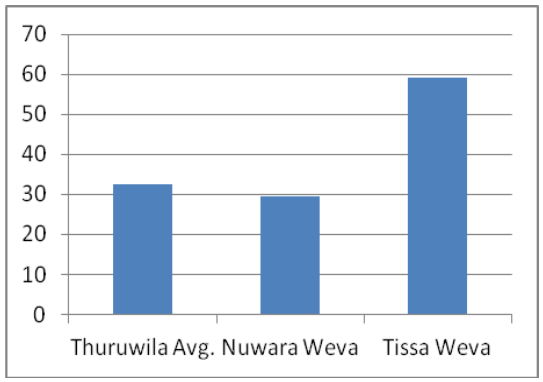

Figure 6(b): Total Coliform Average

According to Figure 6(a) it scan be seen that there has been a massive increase in the total coliform level in Tissa Wewa which has stayed at that high concentration for the next year also. This increase indicates the possible introduction of a pollutant source of waste matter to the lake and this may result in outbreaks of diseases and increases the level of treatment required. This threefold increase in the concentration of a pollutant indicates the dangers of not having sufficient regulations and infrastructure to limit the pollution of these surface water bodies which can lead to the occurrence of problems such as eutrophication which may require large amounts of effort, money and time to be spent on providing remedies.

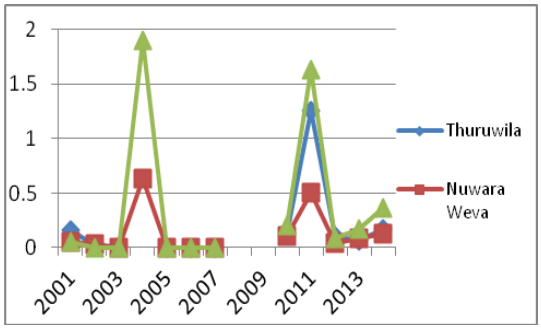

Figure 7(a): Nitrite concentration annual variation

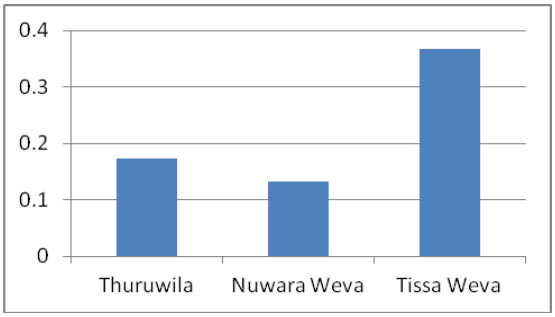

Figure 7(b): Nitrite concentration average

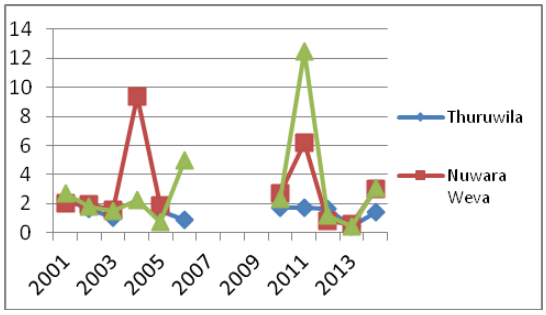

Figure 8(a): Nitrate concentration annual variation

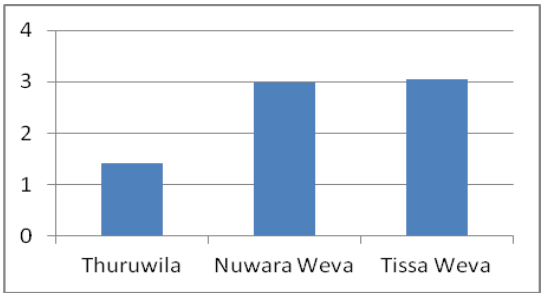

Figure 8(b): Nitrate concentration average

The low level of nitrates and nitrites in the Thuruwila Wewa (Figure 7, Figure 8 and Table 2), although the most agricultural activity is centered around this lake; is explained due to the action of the authorities in implementing BMPs such as livestock waste management, phosphorous free fertilizers and high level of farming conservative practices in addition to educating the users of the lake and giving periodic warnings on the water quality and rehabilitation of people living close to the lake(Figure 2 and Table 3).

4. CONCLUSION

Based on the analysis of the data from the questionnaire survey and the measured water quality data it can be concluded that there is a strong correlation between the implementation of BMP's and the water quality of the lakes. This research enforces the fact that the implementation of BMPs are essential in maintaining a satisfactory level of water quality so that the lake may be used by the community to fulfill their daily needs and also to serve as a viable source for cost and time effective water treatment and remains aesthetically pleasing without being an eyesore to the community and tourists.

The current level of implementation of BMPs in all three lakes is at very low levels and quite a lot of people are even unaware of what BMPs are. This is a situation that needs to be addressed by the regulatory authorities so that it equally benefits both parties. The questionnaire points out that most of the people use the lake for their daily activities and that they are willing to take part in efforts to clean up the lakes. Therefore the community can acquire a greater responsibility in taking care of the water quality of the lakes if they are aware of the measures needed to be taken.

It can be concluded that if the water quality is kept at a safe level then the process of water treatment would require less of both time and money and would give an overall better final treated product.

5. AKNOWLEDGEMENT

We convey our gratitude to the National Water Supply and Drainage Board (NSW&DB) for providing us the relevant data to conduct this research project.

6. REFERENCES

[1] K.A.U.S. Imbulana,, N.T.S. Wijesekara, B.R Neupane., M.M.M Aheeyar,. and V.K. Nanayakkara (eds.). *Sri Lanka Water Development Report*. I&WRM, UN-WWAP, UNESCO, HARTI and University of Moratuwa, Sri Lanka, Paris and New Delhi. 2010.

[2] P. Manchanayake and , C.M. Madduma Bandara *Water resources of Sri Lanka*, National Science Foundation, Sri Lanka,1999.

[3] S. Arumugam, *Water Resources of Ceylon*, Water Resources Board, Sri Lanka, 1969.