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Floating Wetlands for Management of Algal Washout from Waste Stabilization Pond Effluent: Case Study at Hikkaduwa Waste Stabilization Ponds

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Abstract: Waste stabilization ponds are advantageous wastewater treatment processes, especially for developing countries. Nevertheless, in spite of the well known advantages of the implementation of the stabilization pond system, the effluent of this system has a significant amount of algae and high nutrients. Disposing this effluent with high contents algae and nutrients to the receiving waters can hinder the water reuse for a wide range of different applications, it is essential to look for a post treatment method that can provide considerable removal of algae, nutrients and organic matter from the effluent and at the same time, assure that the treatment system as a whole will maintain the advantages of the pond treatment processes. In this context, this research study was planned and intended to introduce a floating treatment wetland in which water hyacinth plants (Eichhornia crassipes) were used as macrophyte or vegetation in the part of the maturation pond area to control algae and nutrients in the effluent.

With the application of the floating wetland the removal efficiencies were found to have increased in the maturation pond in terms of BOD and COD from 13.3% to 62.9% and 13.6% to 57.5%, respectively. In the case of TP and TN there were no significant reductions achieved prior to the establishment of the wetland but, reductions of 74.8% for TP and 55.8% for TN were achieved since the establishment of floating wetland. It was also possible to achieve a reduction of algal cell densities of 900 units/ml to zero unit/ml for the algal species of Spirulina and for Oscillatoria, the reduction was from 290 units/ml to 0 units/ml. In case of Chlorella and Pandorina, density reductions were 830,000 units/ml to 68,000 units/ml and 4300 units/ml to 280 units/ml respectively. Accordingly, the reduction efficiencies for Spirulina, Oscilltoria, Chlorella and Pandorina were reported to be improved from 31.8% to 100% and 4.5% to 100%, 34.2% to 91.8% and 42.2% to 93.5%, respectively. Application of this research can therefore be possible to polish waste stabilization pond effluent economically in order to re-use for various beneficial uses except potable use.

Key words: Algae; Nutrients; Macrophyte; Wetland

1. Introduction

Waste Stabilization Ponds (WSP) are large, shallow basins in which raw sewage is treated entirely by natural processes involving mainly both algae and bacteria. They are used for sewage treatment in tropical climates, and represent one of the most cost-effective, reliable and easily-operated methods for treating domestic wastewater. WSPs are very effective in the removal of faecal coliform bacteria. Sunlight energy is the only requirement for its operation. Further, it requires minimum supervision for daily operation, in terms of simple cleaning of the outlets and inlet works. The temperature and duration of sunlight in tropical countries offer an excellent opportunity for high efficiency and satisfactory performance for this type of water-cleaning system. They are well-suited for low-income tropical countries where conventional wastewater treatment cannot be achieved due to the lack of a reliable energy source. Further, the advantage of these systems, in terms of removal of pathogens, is one of the most important reasons for its use.

WSP systems comprise a single string of anaerobic, facultative and maturation ponds in series, or several such series in parallel.

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In essence, anaerobic and facultative ponds are designed for removal of Biochemical Oxygen Demand (BOD), and maturation ponds for pathogen removal, although a considerable BOD removal also occurs in maturation ponds and some pathogen removal in anaerobic and facultative ponds.

In most cases, only anaerobic and facultative ponds will be needed for BOD removal when the effluent is to be used for restricted crop irrigation and fish pond fertilization, as well as when weak sewage is to be treated prior to its discharge to surface waters. Maturation ponds are only required when the effluent is to be used for unrestricted irrigation, thereby having to comply with the WHO guideline of 1000 faecal coliform bacteria /100 ml.

The WSP does not require mechanical mixing, needing only sunlight to supply most of its oxygenation. Its performance may be measured in terms of its removal of BOD and faecal coliform bacteria.

1.1 Processes in Stabilization ponds

Anaerobic ponds are commonly 2-5 m deep and receive wastewater with high organic loads (i.e., usually greater than 100 g BOD/m3.day equivalent to more than 3000 kg/ha.day for a depth of 3 m). They normally do not contain dissolved oxygen or algae. In anaerobic ponds, BOD removal is achieved by sedimentation of solids and subsequent anaerobic digestion in the resulting sludge. The process of anaerobic digestion is more intense at temperatures above 150C. The anaerobic bacteria are usually sensitive to pH less than 6.2. Thus, Acidic wastewater must be neutralized prior to its treatment in anaerobic ponds. A properly-designed anaerobic pond will achieve about a 40% removal of BOD at 10^0C, and more than 60% at 200C. A shorter retention time of 1.0-1.5 days is commonly used [5].

Facultative ponds (1-2 m deep) are of two types: primary facultative ponds that receive raw wastewater, and secondary facultative ponds that receive particle-free wastewater (usually from anaerobic ponds, septic tanks, primary facultative ponds, and shallow sewerage systems). The process of oxidation of organic matter by aerobic bacteria is usually dominant in primary facultative ponds or secondary facultative ponds.

The processes in anaerobic and secondary facultative ponds occur simultaneously in primary facultative ponds. It is estimated that about 30% of the influent BOD leaves the primary facultative pond in the form of methane [9]. A high proportion of the BOD that does not leave the pond as methane ends up in algae. This process requires more time, more land area, and possibly 2-3 weeks of water retention time, rather than 2-3 days in the anaerobic pond. In the secondary facultative pond and the upper layers of primary facultative ponds, sewage BOD is converted into "Algal BOD," and has implications for effluent quality requirements. About 70-90% of the BOD of the final effluent from a series of well-designed WSPs are related to the algae they contain. In secondary facultative ponds that receive particle-free sewage (anaerobic effluent), the remaining non-settlable BOD is oxidized by heterotrophic bacteria such as (*Pseudomonas, Flavobacterium, Archromobacter and Alcaligenes spp.*). The oxygen required for oxidation of BOD is obtained from the photosynthetic activity of the micro-algae that grow naturally and profusely in facultative ponds.

Facultative ponds are designed for BOD removal on the basis of a relatively low surface loading (100-400 kg BOD/ha.day), in order to allow for the development of a healthy algal population, since the oxygen for BOD removal by the pond bacteria is generated primarily via algal photosynthesis. The facultative pond relies on naturally-growing algae. The facultative ponds are usually dark-green in colour because of the algae they contain. The algal concentration in the pond depends on nutrient loading, temperature and sunlight, but is usually in the range of 500-2000 µg chlorophyll-a/liter [5].

The maturation ponds, usually 1-1.5 m deep, receive the effluent from the facultative ponds. Their primary function is to remove excreted pathogens. Although maturation ponds achieve only a small degree of BOD removal, their contribution to nutrient removal can also be significant. Maturation ponds usually show less vertical biological and physicochemical stratification, and are well-oxygenated throughout the day. The algal population in maturation ponds is much more diverse than that of the facultative ponds, with non-motile genera predominantly be more common. The algal diversity generally increases from pond to pond along the series [5].

Time and temperature are the two principal parameters used in designing maturation ponds. Faecal bacteria die-off in ponds increases with both time and temperature. High pH values (above 9) occur in ponds, due to rapid photosynthesis by pond algae, which consumes CO_2 faster than that can be replaced by bacterial respiration.

The resulting CO_2 is fixed by the algae, and the hydroxyl ions accumulate, often raising the pH to values even above 10. Faecal bacteria (with the notable exception of *Vibro cholera*) die very quickly at pH values higher than 9 [13]. The role of high light intensity and high dissolved oxygen concentration has recently been elucidated in the literature. Light wavelengths between 425-700 nm can damage faecal bacteria from being absorbed by the humic substances ubiquitous in wastewater. They remain in an excited state sufficiently long to damage the cell. Light-mediated die-off is completely dependent on the presence of oxygen, as well as being enhanced at high pH values. Thus, the sun plays a threefold role in directly promoting the faecal bacterial removal in WSP by increasing the pond temperature, and more indirectly by providing the energy for rapid algal photosynthesis. This not only raises the pond pH value above 9, but also results in high dissolved oxygen concentrations, which are necessary for its third role; namely, promoting photo-oxidative damage.

WSPs are widely used as natural treatment systems because of their low cost and simplicity of construction, operation, and maintenance. However, the major operational problem encountered in WSPs is the excessive discharge of particles in the effluent caused by algal activity. The algal cells are produced extensively in facultative ponds and flow progressively to the maturation ponds and are ultimately discharged into inland surface water bodies such as lakes and rivers. These effluents contribute to eutrophication and eventually leading to loss of water resources.

Therefore, it is essential to polish the effluent from the WSPs by removing over-discharged suspended solids (SS), BOD, and nutrients. An effective method to separate algae and other particles from the effluent of WSPs is the use of floating wetland with water hyacinth plants (*Eichhornia crassipes)*. Water hyacinths can remove particles through sedimentation and filtration due to their dense root system. The leaves and stems also help to control algal growth by limiting the sunlight from reaching the water surface.

Beyond their ability to remove suspended matter from the wastewater, several researchers in their studies, have recognized the water hyacinths' role as an additional treatment step to reducing organic matter and nutrients from an effluent stream.

This study examines the potential of developing and applying a novel "floating wetland" concept for the provision of enhanced effluent polishing particularly with regards to prevention of escaping algal cells from WSP effluent.

This concept was therefore tested at the existing sewage treatment plant (STP) in Hikkaduwa of Southern Province of Sri Lanka. It is about 100 km away from Colombo towards the south of Sri Lanka. The sewage treatment method adopted in this STP has been the WSP system.

2. Literature Review

The term "waste stabilization pond" in its simplest form is applied to a body of water, artificially or naturally employed with the intention of retaining sewage or organic wastewater until they are rendered pollution free and inoffensive status for discharge into receiving waters or on land, mainly relying on physical, chemical and biological processes commonly referred to as "self purification" involving the actions of algae and bacteria under the influence of sunlight (photosynthesis) and air. Organic matter contained in the wastewater is stabilized and converted into more stable matter by algal cells simply providing oxygen required for mineralization which thrive in large numbers and find their way with the effluent and hence the term "stabilization pond" [5].

[8] defines WSP as shallow basins into which wastewater continuously flows and from which treated effluent is discharged. [3] explains that the degree of treatment is a function of the number of ponds in series and the retention time of the wastewater in each pond. Although the number of ponds and retention time have a major effect on the quality of the effluent, it is possible to manipulate each individual pond to achieve a desired function [4]. A wide range of pond types therefore exists, allowing flexibility in different configurations to suit different conditions and discharge standards [13].

According to [13] correctly designed ponds can match the effluent quality that could otherwise be achieved by other conventional wastewater treatment technologies.

2.1 Specialized Pond Types

While the above-mentioned three pond types are the most common WSPs in use, there are, however, specialized ponds that are sometimes used for wastewater treatment. These include high rate algal ponds (HRAP) and macrophyte ponds. HRAP is a shallow, paddle wheel mixed pond, which designed to enhance exposure of the algae to sunlight and avoid thermal stratification, thereby maximizing growth, photosynthesis and productivity [11], [12], [3]. This results in surplus dissolved oxygen, high pH as well as a high rate of carbon assimilation and nutrient uptake [11]. All of these contribute to the efficacy of HRAP as a combined secondary and tertiary treatment operation. The function and performance of HRAP will be examined in more detail throughout this study.

Macrophyte ponds remove suspended algae and thus Macrophyte ponds are ponds where aquatic plants are grown, either on the pond surface (free floating macrophyte) such as water hyacinth, submerged such as hydrilla (*Hydrilla spp.*) or attached to the bottom (emergent) such as common reed (*Phragmites australis*) to further reduce BOD and in WSP effluent. Faecal coliform removal is however, negligible [3].

2.2 Roles of Water hyacinth and their roots in effluent polishing

Performance of WSPs depends on the effective use of bacteria for degradation of organic matters, efficient use of algae for maintaining an adequate level of oxygen in the system and especially, separation of algal biomass from the effluent. Excessive loss of algae from the ponds deteriorates the effluent quality. When proper hydraulic residence time is not provided for the WSPs, the content of organic matters in the effluent can even be higher than that of the influent. This has been recognized as one of the most troublesome operational problems [14]. Thus, separation of the algae is essential to produce lower concentrations of SS, and nutrients as well. For removing algal particles from pond effluent, various methods have been proposed in the literatures such as maturation or polishing ponds, [12] fishing ponds, land or wetland treatment with microstraining [2].

From a pilot plant study, [6] examined the individual effects of the water hyacinth leaves, stems and root mat on the algal concentration. The results showed that filtration and settling almost equally contributed to the separation of algal particles. The canopy effect of the leaves and stems, which suppresses algal growth, is equivalent to a considerable amount of algae removed by gravity settling. A portion of the SS in the influent sewage is also removed by settling in the root zone, as it flows through the water hyacinth channel. Another portion of the SS that will not settle by gravity is screened by filtration as wastewater flows through the root mat of the water hyacinth. Because filtration is of great importance in removal mechanism, transport of the wastewater to the root zone is a critical designing consideration in water hyacinth treatment systems.

[4] reported that the key separation phenomenon of algae particles by root surface is similar to adsorption processes. In other words, there is a maximum capacity in a given weight of roots, but effluent algal concentration does not increase at saturation due to the sloughing off of attached particles as a clump from the roots and the continuous reproduction of new attachment sites caused by the growth of roots. In many cases, water hyacinth ponds remain unsaturated, providing thus an efficient method for particle removal [7].

How algal and other suspended particles are retained on the surface of roots is not clearly known yet, the attachment mechanism may include electrostatic interactions and chemical bridging, or specific adsorption, all of which would be affected by chemical characteristics. Microscopic examination of the roots revealed that a gelatinous matter, which covered the root surface, surrounds algal particles. These materials are only assumed to provide an attachment force between roots and particles [6].

3. Study Area

This concept was therefore tested at the existing sewage treatment plant (STP) in Hikkaduwa of Southern Province of Sri Lanka. It is about 100 km away from Colombo towards the south of Sri Lanka. The sewage treatment method adopted in this STP has been the WSP system.
It consists of inlet structure, three treatment lagoons (two facultative ponds and one

maturation pond) and a decanting structure at the outfall for discharge of treated effluent.

STP at Hikkaduwa treats the sewage that is collected by the sewerage system as well as by the septage from tankers. It consists of a number of treatment processes. Inlet works remove grit and gross nonbiodegradable materials such as plastic. In facultative ponds, settlable solids are removed. Polishing and disinfection occurs in maturation ponds. Treated effluent from STP at Hikkaduwa is discharged during the receding tide every day by manual decanting from the maturation lagoon to the Hikkaduwa river.

SPT at Hikkaduwa is equipped with two facultative lagoons with a capacity of 6500 m^3 and 6200 m^3 and one maturation pond with the capacity of 7000 m^3. The normal process train is to operate the three lagoons in series so as to pass sewage after going through the inlet works enters lagoon 1 and is discharged eventually from lagoon 3. Finally all sewage leaves the plant via the manually operated decant structure.

All lagoons are equipped with baffles to support inflow distribution and to avoid short circuiting. The flow from the inlet works (flow splitter) to the facultative lagoons is bifurcated to support inflow distribution in facultative ponds. Floating booms are attached to the top of the baffles so that any floating scum, grease or debris from the sewage feed is trapped and contained for ease of daily removal by STP operators.

4. Research Methodology

This study basically consisted of two components such as establishment of floating wetland and the maintenance of it respectively and the water quality measurements obtained before and after establishment of wetland were then analyzed by means of statistical method to generalize the findings for population.

4.1 Establishment of floating wetland

A wetland was created with wetland plant covering the maturation pond from the inlet up to the first baffle wall. It is approximately 1355 m^2 in extent and selected area is shown in figure 4.1. The macrophyte used for this wetland was water hyacinth (*Eichhornia crassipes*) which is fast-growing plant in fresh waters. They were collected from Bolgoda lake nearby University of Moratuwa premises and were selected as they hold up high nutrient levels, grow faster, contain deeply grown root systems.

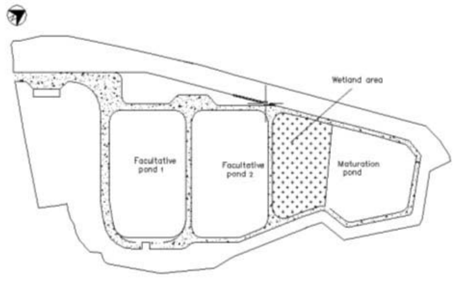

Figure 4.1 -Wetland area

Three truck loads were transported to the Hikkaduwa SPT from predefined areas of Bolgoda Lake taking into account the precautions not to dump them elsewhere. Once established, it took almost two month period to get acclimatized to the new environment without any multiplication of plants.

4.2 Sampling and testing water quality before and after establishment of wetland

To study the variation of influent and effluent water quality parameters and algal diversity and density, six sampling points were selected as shown in figure 4.2. Samples were collected and analyzed every two weeks for a period of approximately six months in order to study the temporal variation of different parameters. For the elucidation of spatial variation, samples from all six locations in the ponds were analyzed at the same time as well. Sample collection and analysis were performed before and after the creation of wetland.

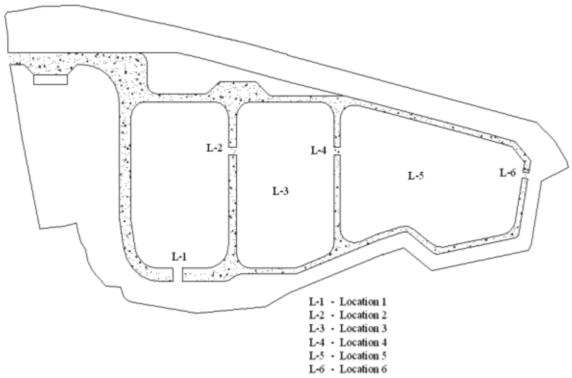

Figure 4.2 -Location map of sampling points

The physiochemical parameters and biological measured were as follows;

i. BOD
ii. COD
iii. Total Dissolved Solids
iv. Total Phosphorus
v. Dissolved Oxygen
vi. Conductivity
vii. pH
viii. Temperature
ix. Salinity
x. Algal diversity and
xi. Algal density.

Testing for TP, TN, BOD and COD were carried out *ex situ* in the Environmental Engineering Laboratory, Department of Civil Engineering at the University of Moratuwa and DO, turbidity conductivity, temperature, pH, TDS and salinity were measured *in situ* by using portable Water Quality Meter (Sensor module – WM5 – 24 – 1 - 01) respectively. Algae enumeration was carried out in the Plant Science Laboratory, Department of Botany at University of Colombo.

A riding boat was used to collect samples from sampling points L-3 and L-5 which were located in the middle of the ponds. Depth samples were not taken mainly due to the fact that all ponds were too shallow (1.2-1.5 m) so as not to cause any depth variation predominately because of wind mixing. Thus, one sample from each sampling point was collected from the top of the water column.

Identification of algae was accomplished with the aid of a microscope, a counting chamber called "Sedgewick rafter" and a tally counter. A sample of 1 ml was placed in the Sedgewick Rafter for counting cells and the enumeration of the organisms was made with the aid of a compound microscope. The magnification used was 100X obtained by means a 10X ocular and 10X objective magnifications. The plankton organisms appearing in 10 fields were counted and from their total, the number of organisms per milliliter of the water sample was calculated. Quantitative records for each genus (isolated cells plus colonies) were reported separately.

4.3 Statistical methods adopted

In order to analyze the rate of reduction of the water quality parameters and algal density due to the introduction of floating wetland, a non-parametric statistical analysis method was used. Since the values of water quality parameters and algal diversity and density measured were not the same as they change due to prevailing climatic conditions and influent quality such as organic loading intensity, pH etc. two sampling points namely, L-4 (just before the entrance to the wetland) and L-6 (final exit point after the wetland) were selected for the statistical analysis.

Hypothesis tests were performed for all parameters collected from these two points using the Mann Whitney test.

5. Results and Discussion

The test results of the water quality parameters and algal diversity and density on the wastewater in the Hikkaduwa SPT before and after establishing the wetland are shown in Table 5.1 and Table 5.2 respectively. Temporal variations according to the sampling dates and spatial variations along the sampling points are represented from Figure 5-1 to Figure 5-15 respectively. Even though pH, DO, temperature, TDS and turbidity were measured, they showed no signs of considerable changes statistically for conditions prevailing before and after the establishment of wetland. However, salinity was monitored throughout the study period, since an increase in the level of salinity above 2 ppt would affect the existence of water hyacinth plants due to toxicity effects.

It was possible to achieve a reduction of algal cell densities of 900 units/ml to zero unit/ml for the algal species of *Spirulina* and for *Oscillatoria*, the reduction was from 290 units/ml to zero units/ml. In case of *Chlorella* and *Pandorina*, density reductions were 830,000 units/ml to 68,000 units/ml and 4300 units/ml to 280 units/ml respectively. Accordingly, the reduction efficiencies for *Spirulina*, *Oscilltoria*, *Chlorella* and *Pandorina* after the addition of wetland were reported to be improved from 31.8% to 100% and 4.5% to 100%, 34.2% to 91.8% and 42.2% to 93.5%, respectively.

The removal efficiencies of organic matter were found to have increased in the maturation pond in terms of BOD and COD from 13.3% to 62.9% and 13.6% to 57.5%, respectively.

In the case of nutrients, the reduction percentage of 74.8% for TP and 55.8% for TN were achieved since the establishment of floating wetland.

In general, the growth rate of algae depends on temperature, photosynthetically active light intensity and limiting nutrient levels respectively. The introduction of floating wetland made the light intensity available for algal growth minimal as shading effect was pronounced due to wetland plants. Further the limiting nutrients such as phosphorous were also utilized by wetland plants making them further restricted for algal growth. Also noted was the reduction of carbonaceous compounds due to microbial activity taking place in the root zone vegetation. These phenomena therefore helped to reduce algal densities drastically in the maturation pond.

Table 5.1 Reduction percentages from inlet to outlet in WSP on 24/4/2012 (before establishing the wetland)

	L-4	L-6	Reduction %
BOD	90	78	13.3
COD	220	190	13.6
TP	4.29	4.91	-1.7
TN	10.29	12.83	-24.7
Chlorella	698,000	459,000	34.2
Pandorina	9000	5200	42.2
Spirulina	2200	1500	31.8
Oscillatoria	1100	1050	4.5

Table 5.2 Reduction percentages from inlet to outlet in WSP on 28/9/2012 (after establishing the wetland)

	L-4	L-6	Reduction %
BOD	70	26	62.9
COD	160	68	57.5
TP	1.55	0.39	74.8
TN	16.35	7.23	55.8
Chlorella	830,000	68,000	91.8
Pandorina	4300	280	93.5
Spirulina	930	0	100
Oscillatoria	290	0	100

Table 5.3: Results obtained by statistical analysis

	Median		Zw	P value
	Before	After		
BOD	14.56	60.56	3.0	0.0407
COD	17.54	55.56	3.0	0.0407
TP	-25.61	74.84	3.0	0.0407
TN	-12.20	51.43	3.0	0.0407
Chlorella density	13.85	78.34	3.0	0.0407
Pandorina density	44.95	73.79	3.0	0.0407

Note: P value – Probability; Zw – Normal approximation for test statistics

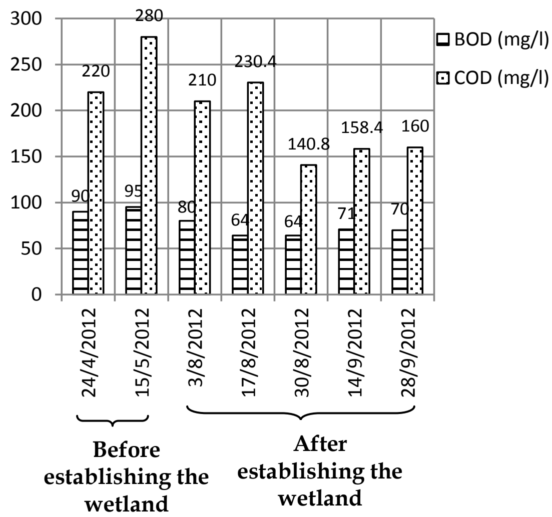

Figure 5.1- Temporal variation of BOD and COD at Location L-4

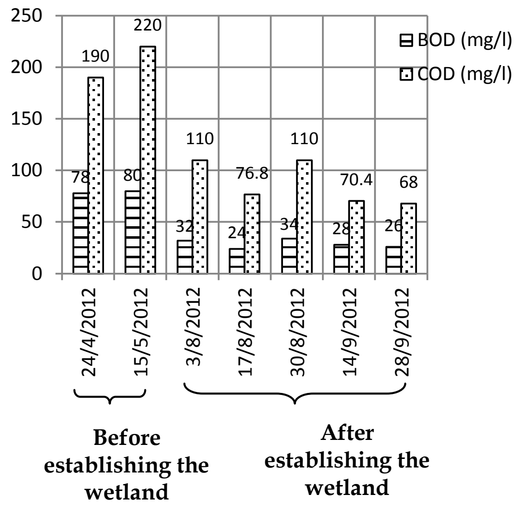

Figure 5.2 - Temporal variation of BOD and COD at Location L-6

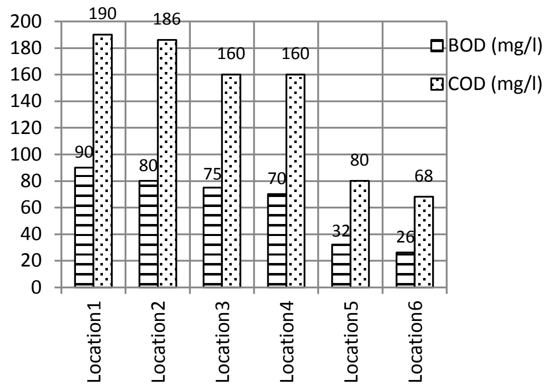

Figure 5.4 - Spatial variation of BOD and COD on 28/9/2012

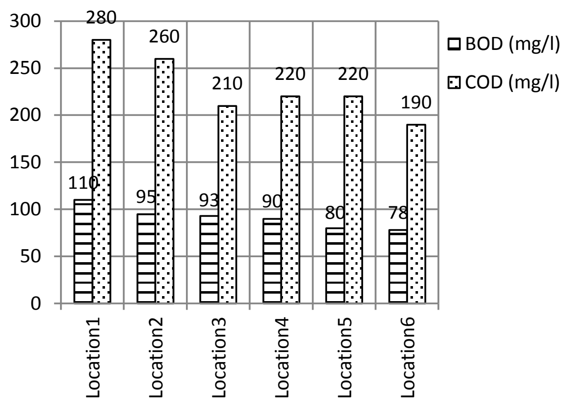

Figure 5.3 - Spatial variation of BOD and COD on 24/4/2012

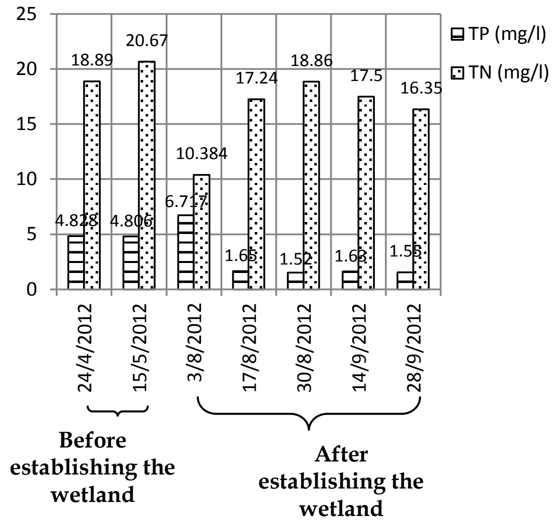

Figure 5.5 - Temporal variation of TP and TN at Location L-4

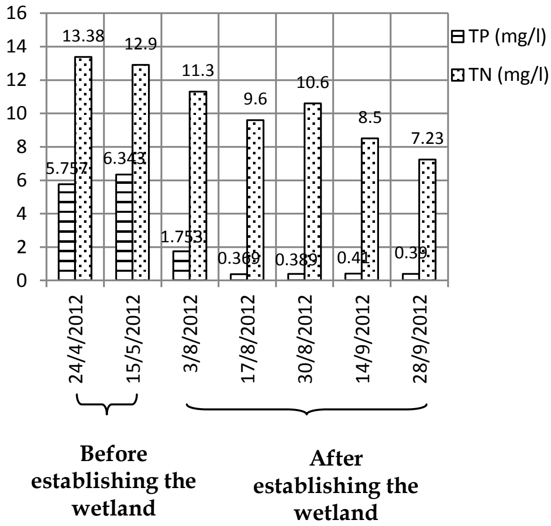

Figure 5.6 - Temporal variation of TP and TN at Location L-6

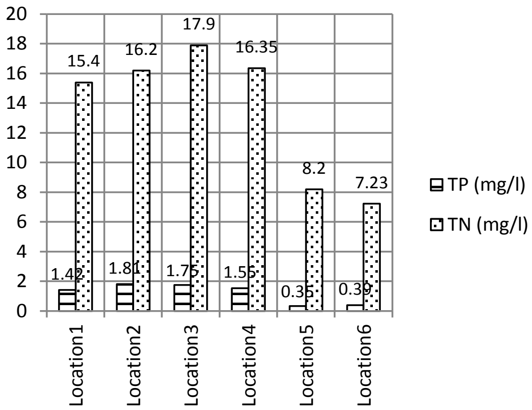

Figure 5.8 - Spatial variation of TP and TN on 28/9/2012

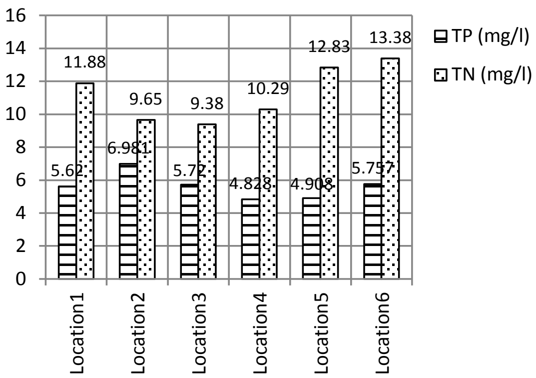

Figure 5.7 - Spatial variation of TP and TN on 24/4/2012

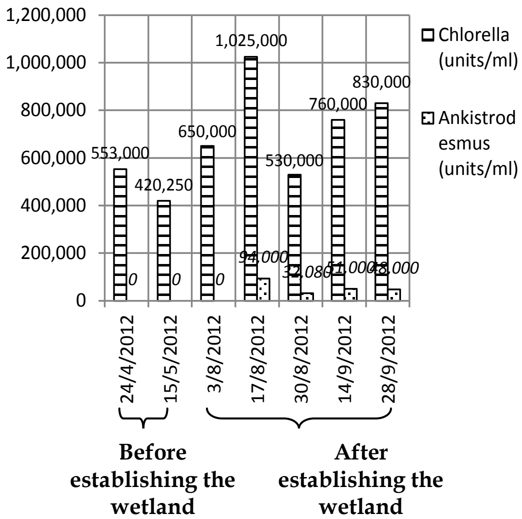

Figure 5.9 - Temporal variation of *Chlorella* and *Ankistrodesmus* at Location L-4

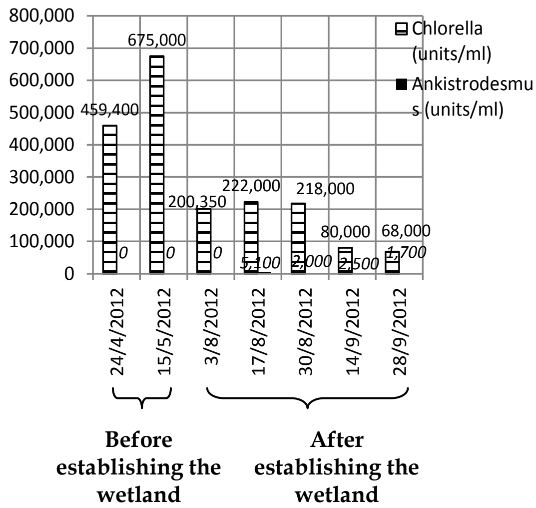

Figure 5.10 - Temporal variation of Chlorella and *Ankistrodesmus* at Location L-6

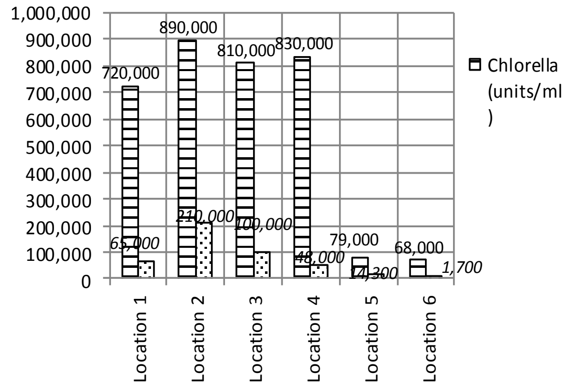

Figure 5.12 - Spatial variation of Chlorella on 28/9/2012

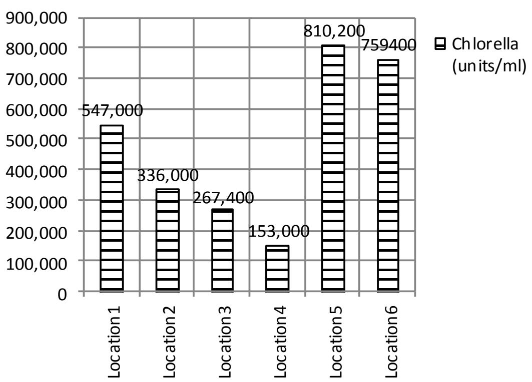

Figure 5.11 - Spatial variation of Chlorella on 24/4/2012

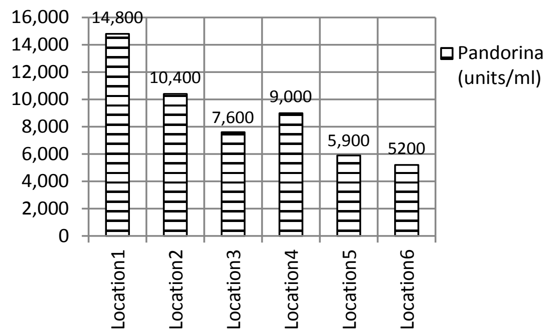

Figure 5.13 - Spatial variation of *Pandorina* on 24/4/2012

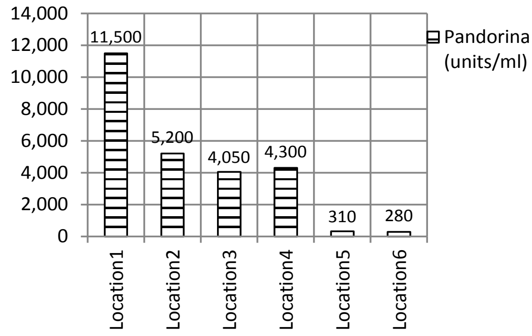

Figure 5.14 - Spatial variation of *Pandorina* on 28/9/2012

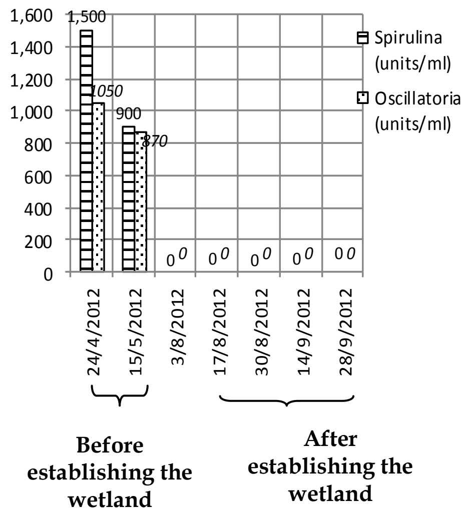

Figure 5.15 - Temporal variation of *Spirulina* and *Oscillatoria* at Location L-6

5. Conclusions and Recommendations

The following conclusions were inferred from the study.

1. It was clear that all types of algae got reduced remarkably with the introduction of the floating wetland. The introduction of wetland causes less solar intensity to be available for algal growth hence reduction in algal densities. Therefore, it can be concluded that a floating wetland consisting of water hyacinth plants is ideal to control washout of algae from waste stabilization ponds.

2. Further, root zone of vegetation cover activated microbial assimilation of carbonaceous compounds thereby reduction of BOD and COD. Hence the introduction of the wetland has proved to be a good technique even to lessen the organic loading flowing into the receiving water body or in other words wetland seems to be good option for polishing effluent quality prior to discharge into water bodies.

3. It has also proved that this is an ideal technique to cut off excessive nutrients from escaping to receiving water bodies which would otherwise contribute to eutrophication incidences in a great deal.

The introduction of carefully designed and maintained floating wetlands inhabiting water hyacinth plants would be recommended for other WSPs of Sri Lanka in order to reduce the algal washouts, to polish or refine the effluent water quality and to reduce the escape of nutrient such as N and P to nearby water bodies with high percentage of success.

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