FEASIBILITY OF USE OF DUCKWEED FOR TREATMENT OF SLUDGE WATER

A Thesis Submitted
In partial fulfilment of the requirement
For the degree of

MASTER OF TECHNOLOGY

In Civil Engineering
(Environmental Engineering)

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2018-19

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CERTIFICATE

Certified that the project entitled **"*FEASIBILITY OF USE OF DUCKWEED FOR TREATMENT OF SLUDGE WATER* "**submitted by Abhishek Sinha **(1160469001)**in the partial fulfillment of the requirements for the award of the degree of Masters of Technology (Environmental Engineering) of Babu Banarsi Das University is a record of students' own work carried under our supervision and guidance. The project report embodies results of original work and studies carried out by students and the contents do not form the basis for the award of any other degree to the candidate or to anybody else.

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DECLARATION

We hereby declare that the project entitled "***FEASIBILITY OF USE OF DUCKWEED FOR TREATMENT OF SLUDGE WATER***"submitted by Abhishek Sinha **(1160469001)** in the partial fulfillment of the requirements for the award of the degree of Masters of Technology (Environmental Engineering) of Babu Banarsi Das University is record of our own work carried under the supervision and guidance of Mr. Kamal Nabh Tripathi, Assistant professor Department of Civil Engineering, BBDU

To the best of my knowledge this project has not been submitted to Babu Banarsi Das University or any other University or Institute for the award of any degree.

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ACKNOWLEDGEMENT

I am extremely grateful and remain indebted to my project guide **Mr. Kamal Nabh Tripathi** for being a source of inspiration and for their constant support in the formulation, implementation and evaluation of project. I am thankful to him for his constant constructive suggestions, which benefited us a lot in developing this project. They had been a constant source of inspiration and motivation for hard work .Through this column, it would be my utmost pleasure to express our warm thanks to them for their encouragement, co-operation and constant support without which we might have not been able to accomplish this project.

I would also like to express my gratitude to **Mr. Faheem Ahmad Khan** (Asst. Prof, CE department BBDU) for being their whenever I needed his help. The head of department Civil engineering BBDU, Lucknow; **Mr. Anupam Mehrotra** has always been a great inspiration for all the students and a mentor to me

I am highly obliged to the whole **department of civil engineering**, for showing their keen interest in our project and helping in every stage of it.

I also express my gratitude to the university for providing the infrastructure to carry out the project and to all staff-members who were directly or indirectly instrumented in enabling us to stay committed for project.

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ABSTRACT

Ponds and lakes are used as water reservoir to store water and further use it for the daily needs such as for irrigation and domestic purposes. At present these ponds and lakes are being considered as a waste dumping site by the people living nearby and no maintenance work is being done to improve the quality of the water present in it. It is a true fact the water is depleting at a faster rate and we will be running short of it very soon. The recharge produced by these ponds and lakes will no longer be acceptable by the human body if left untreated. We will have to preserve it and utilise it sustainably. Most of the lakes and ponds are polluted by the human intervention and lack of public awareness. As a result of these human activities the lakes and ponds have became a source of unhealthy environment. The cases of water borne diseases such as Malaria, Dengue and other diseases have increased in the past few years. Studies have shown that the increasing number of diseases are a result of the degraded quality of water of these ponds and lakes since these are continuously polluted by the waste dumped and the pollution caused by the human activities. Since the water in ponds and lakes is very less as compared to river bodies, treatment of the same is possible

This thesis deals with the experimental study based on the use of 'Duckweed' in pond water. The experiments were performed on the pond water for about 2 months with a total 5 number of samples taken after 15 days interval. Various important parameters such as DO (dissolved oxygen), Nitrate, Ammonia, Phosphate, Turbidity, pH, Total Suspended Solids, COD (Chemical oxygen demand), BOD (Biochemical oxygen demand) were analysed. These results will be very much useful in understanding the removal efficiency of pollutants from the water sample by Duckweed.

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CHAPTER 1 INTRODUCTION

One of the major problems with waste water treatment methods is that none of the available technologies has a direct economic return. The available technologies are unaffordable due to high capital and maintenance costs. With no economic return, local authorities are generally not interested in taking up treatment of waste water, thereby causing severe health hazards and environmental pollution. In India out of about 4700 towns / cities, only 232 have the sewerage system, and that too only partial(ENVIS Centre on Hygiene, Sanitation, Sewage Treatment Systems and Technology). Most of the untreated waste water is, therefore, discharged into rivers or other water bodies. In rural areas it is a common practice to discharge waste water/sullage without collection. There is no question of treatment/recycle or even reuse of waste water/sullage as people are not aware of this technology.

Recently the Sulabh has successfully developed demonstration projects on duckweed-based cost-effective waste water treatment in rural and urban areas with direct economic returns from pisciculture. Although duckweed is found in ponds and ditches, due to almost complete absence of any know-how of this technology in the country, the potential of duckweed for the waste water treatment, its nutrient value and economic benefits have not been fully exploited.

Duckweed is basically a small free-floating and fast growth aquatic plant-has great ability to reduce the BOD, COD, suspended solids, bacterial and other pathogens from waste water. It is a complete feed for fish, and due to the high content of proteins and vitamins A & C, it is also a highly nutritious feed for to 3 times when fed with duckweed, than with other conventional feeds in ponds. Reduction of BOD, COD in effluents varies from 80-90% at the retention time of 7-8 days. The first project funded by the Ministry of Environment & Forests, Govt. of India, was successfully completed in collaboration with the Central Pollution Control Board, New Delhi. Based on the R & D outputs of the project, the CPCB has made guidelines on the use of duckweed for waste water treatment.

The Lemnaceae family consists of four genera (Lemna, Spirodela, Wolffia&Wolffiella) and 37 species have been identified so far. Compared to most other plants, duckweed has low fiber content (about 5%), since it does not require structural tissue to support leaves and stems. Applications of Lemnagibba L (duckweed) in wastewater treatment was found to be very effective in the removal of nutrients, soluble salts, organic matter, heavy metals and in eliminating suspended solids, algal abundance and total and fecal coliform densities. Duckweed is a floating aquatic macrophyte belonging to the botanical family Lemnaceae, which can be found world-wide on the surface of nutrient rich fresh and brackish waters (Zimmo, 2003). The nutrients taken up by duckweed are assimilated into plant protein. Under ideal growth conditions more than 40% protein content on dry weight basis may be achieved (Skillikorn et al., 1993). According to SaschaIqbal(1999) two basic principles for pond design and operation are used for duckweed treatment, namely plug-flow and batch systems. Duckweed plug flow design seems to be the more suitable treatment option for larger wastewater flows originating from communities and (peri-)urban areas, as it ensures an improved and more continuous distribution of the nutrients. A plug-flow design also enhances the contact surface between wastewater and floating plants, thereby, minimizing shortcircuiting. To ensure plug-flow conditions, a high plug-flow length to width ratio of 10:1 or more is necessary (Hammer 1990). Alaerts et al. (1996) reported excellent treatment results with a length to width ratio of 38:1. Moreover, a narrow, channel-like design allows easier access to the water surface for operation and maintenance work. Batch-operated ponds are a feasible option for introduction of duckweed aquaculture in villages where already existing ponds can often be used and, thus, save capital costs for extra earth work. The HRT is dependent on the organic, nutrient and hydraulic loading rate, depth of the system and harvesting rate (Metcalf and Eddy 1991). To ensure acceptable pathogen removal and treatment efficiency, comparatively long retention times in the range of 20 to 25 days are postulated for duckweed (plug-flow) systems (Metcalf and Eddy 1991). Reported pond depths range from 0.3 to 2.7 m up to even 5 m (Lemna Corp. 1994). Average organic loading rates expressed in terms of BOD5 for plant systems without artificial aeration should not exceed 100 to 160 kg/ha•d in order to obtain an effluent quality of 30 mg BOD/l or less (Metcalf and Eddy 1991, Gijzen and Khondker 1997). The choice of harvesting technique is dictated by system design and by labour and equipment costs. For shallow ponds, the most simple harvesting techniques include manual skimming of the plants from the pond. Two people were reported to require 3.5 hours for manual harvesting of duckweed from a 0.3 ha pond in Taiwan. Large-scale harvesting in industrialized countries is carried out with mechanical harvesting machines requiring, however, deep ponds. Duckweed growth rapidly declines at temperatures above 31 °C to 35 °C (Iqbal 1999). TSS are removed mainly by sedimentation and biodegradation of organic particles in the pre-treatment and duckweed pond system. A minor fraction is absorbed by the roots of the duckweed fronds, where organic particles undergo aerobic biodegradation by microorganisms, and part of the degraded products is assimilated by the plants (Iqbal 1999). Landolt and Kandeler (1987) reported the direct uptake of small hydrocarbons by duckweed, however, heterotrophic growth probably plays a minor role in total BOD removal. Existing results suggest that approx. 50 % (± 20 %) of the total nitrogen load is assimilated by duckweed, while the remaining nitrogen is removed by indirect processes other than plant uptake of which nitrogen loss to the atmosphere by denitrification and volatilisation of ammonia are suggested to play a major role (Alaerts et al. 1996, Gijzen and Khondker 1997, Koerner and Vermaat 1997). In a duckweed treatment system, phosphorous is normally removed by the following mechanisms: plant uptake, adsorption to clay particles and organic matter, chemical precipitation with Ca2+, Fe3+, Al3+, and microbial uptake (Iqbal 1999). As aforementioned, Lemnaceae can tolerate and accumulate high concentrations of heavy metals and organic compounds. Abou el- Kheir et al. (2007) conducted an experiment to study the efficiency of duckweed (Lemnagibba L.) as an alternative cost effective natural biological tool in wastewater treatment in general and eliminating concentrations of both nutrients and soluble primary treated sewage water systems (from the collector tank) for aquatic treatment over eight days retention time period under local outdoor natural conditions. Samples were taken below duckweed cover after every two days to assess the plant's efficiency in purifying sewage water from different pollutants and to examine its effect on both phytoplankton and total and fecal coli form bacteria. Total suspended solids, biochemical oxygen demand, chemical oxygen demand, nitrate, ammonia, ortho-phosphate, Cu, Pb, Zn and Cd decreased by: 96.3%, 90.6%, 89.0%, 100%, 82.0%, 64.4%, 100%, 100%, 93.6% and 66.7%, respectively. Phytoplankton standing crop decreased by 94.8%. Total and fecal coliform bacteria decreased by 99.8%. Dry and wet weights and protein content of Lemnagibba increased with increasing treatment period. Ozengin N, Elmaci A.(2007) performed the studies in which growth of duckweed was assessed in laboratory scale experiments. They were fed with municipal and industrial wastewater at constant temprature. COD, total nitrogen (TN), total phosphorus (TP) and orthophosphate (OP) removal efficiencies of the reactors were monitored by sampling influent and effluent of the system. Removal efficiency in this study reflects optimal results: 73-84% COD removal, 83-87% TN removal, 70-85% TP removal and 83-95% OP removal.In the experiment of Shammout et al, (2008), duckweed (Lemna sp.) has been used to upgrade the quality of wastewater at Khirbet As-Samra wastewater treatment plant, which is the largest in Jordan. It was originally designed to receive 68,000 m?/day but it is currently receiving 160,000 m^3/day. Laboratory experiments showed that the average percentage removal efficiency of Total Coliform (TC) was 68%, Faecal Coliform (FC) 69%, Total Viable Count (TVC) 75%, BOD5 51%, NO3− 56%, TN 48%, organic nitrogen 46%, PO43− 56% and total phosphorus 50%. At the experimental site of Khirbet As-Samra, the results were 57, 59, 50, 44, 30, 26, 25, 28 and 26%, respectively, and the removal efficiency of NH4+ was 27%. Experimental results showed that Lemnagibba could be used to upgrade the quality of the pond effluent with respect to pathogens, biological oxygen demand, nitrogen and phosphorus. The results of this project will be the first of its kind in Jordan and it will establish a baseline for future research on the use of duckweed for wastewater treatment. Jafari et al. (2011), Lahive et al. (2011), investigated the capacity of three Lemna species namely L. minuta, L. minor, and L. trisulca to purify waters polluted with Zn. Percentage removal by Lemna spp. for 1, 5, 10, 15, and 20 mg/l Zn treatment for 10 day incubation was found to be highest by L. trisulca (97%) as compared to L. minuta (89%) and L. minor (83%). Another studies conducted with Lemna minor to treat water polluted with cadmium shows that lemna minor is a good cadmium accumulator and able to remediate cadmium polluted water, especially at 13 and 22µM concentration (Bianconi et al. 2013). Lemnapolyrrhiza was also found to be very good bio accumulator of heavy metals. When this plant was exposed to 10 mg/l of the Zn, Pd and Ni for four days accumulated 27.0, 10.0 and 5.5 µg/mg of Zn, Pd and Ni respectively (Sharma et al, 1994).Bioaccumulation of various trace element by Lemnagibba was well documented (Jain et al., 1988; Ernst et al., 1992; Hasar and

Öbek, 2001; Kara et al., 2003). Lemnagibba can also accumulate arsenic, uranium and boron from secondary effluent and the preferential sequence is As > B > U (AhmetSasmaz&ErdalObek . 2009). Nayyef M. Azeez&Amal A. Sabbar.(2012) tested the efficiency of duckweed in improving the quality of effluent from oil refinery. The heavy metal removal efficiency was found to be 99.8%, 99.6%, 98.7% and 72% for Copper, Cadmium, Lead and Zinc, respectively.

Although polluted, village ponds are rich source of nutrients like nitrate and phosphate which can be recovered by phyto-remedition. It is an affordable technology utilizing plants as environmental cleansers in wastewater management. On one hand manure and fertilizers are getting costlier day by day and on the other hand we have resources like village ponds where the much needed nutrients are lying free of cost. Therefore, recovering this valuable nutrient resource and recycling into some productive system makes sense both ecologically and economically.

CHAPTER 2 LITERATURE REVIEW

2.1 Characteristics of Duckweed

Duckweed is a small, free floating aquatic plant belonging to Lemnaceae family (Cheng et al., 2002). The Lemnaceae family consists of four genera (Lemna, Spirodela, Wolffia & Wolffiella) and 40 species have been identified (Leng, 1999). They are green and have a small size (1-3mm), with short but dense roots (1-3cm) (Altay et al., 1996).

Duckweed fronds grow in colonies that, in particular growing conditions, form a dense and uniform surface mat (Hasar et al., 2000). Duckweed found world-wide on the surface of nutrient rich fresh and brackish waters (Zimmo, 2003) but the greatest diversity appears in subtropical and tropical areas. Their habitat comprises still or slowly moving fresh or polluted waters of only a few mm to 3m depth. In particular nutrient-rich and sheltered small ponds, ditches and swamps, e.g. down-stream from sewage works, often contain duckweed (Leng, 1999).

Compared to most other plants, duckweed has (about 5%) low fiber content (Leng, 1999), since it does not require structural tissue to support leaves and stems. Due to the high protein content of duckweed (29-41%, Culley and Epps, 1973) duckweed has a high potential for protein production. The relatively high protein content of duckweed is generating interest in animal feed applications of this aquatic plant.

Figure 1 Pictures of Lemna minor

2.2 Factors Affecting Duckweed Growth

Duckweed reproduces both vegetatively and sexually with sporadic and unpredictable flowering. Vegetative propagation occurs through clonal budding of new daughter fronds from two pockets on each side of the mature frond (Leng, 1999). Parameters affecting duckweed growth in natural environments include temperature, light intensity, other climatic conditions, pH and availability of nutrients in the water. Under ideal conditions in terms of water temperature, pH, incident light and nutrient concentrations, biomass can double within 48 hours, competing with the most productive terrestrial plants and even exceeding biomass accumulation of field crops such as corn (Cheng and Stomp, 2009a; Leng, 1999). Inhibition occurs at high nutrient (ammonia) concentrations (Caicedo *et al.*, 2000).

2.2.1 Temperature and Wind

Duckweed can grow between 6 and 33°C water temperature, with a positive correlation of growth rates and increasing water temperature up to around 30°C (Leng, 1999). It is therefore less sensitive to cool temperatures than other macrophytes (Iqbal, 1999), but extreme (low and high) temperatures adversely affect its growth (Edwards, 2010). Optimal temperature lies between 20 and 30°C, which should be considered when designing duckweed ponds because in shallow waters the temperature can quickly leave this range (Leng, 1999).

Studies in temperate and cold climates have shown that under natural conditions, duckweed growth is significantly reduced or completely stopped during winter months (Leng, 1999). When the temperature drops too low, duckweed can persist until favorable conditions return by producing starch filled structures or turin which are denser than the fronds so that the plants sink to the bottom (Leng, 1999). Duckweed is sensitive to wind and is therefore not suitable to be grown in windy regions (Iqbal, 1999).

2.2.2 Light

The utilization rate of solar energy for wild plants is only 0.5%, and that of crops 0.5-1%. Algae and duckweeds, however have a much higher utilization efficiency in the range of 3- 5% (Wang, 1991). This has attracted more and more farmers in developing countries to construct ponds to grow various species of macrophytes with high production rate. High light intensity and direct exposure to sunlight can impede duckweed growth; shading is preferred (Edwards, 2010). Duckweed tend to cover the water surface and block out the passage of light to the water below, denying algae the energy to grow and reproduce.

2.2.3 PH

Duckweed can survive at a pH between 5 and 9 but grows best in the range of 6.5-7.5. High pH values lead to NH3 in solution which can be toxic and also lost through volatilization (Iqbal, 1999; Leng, 1999).

2.3 Application of Duckweed for Wastewater Treatment

2.3.1 Wastewater Characteristics

Sewage or wastewater is a dilute mixture of various wastes from residential, commercial, industrial and other public places. The amount and composition of wastewater produced in households is influenced by the behavior, lifestyle and standard of living of the inhabitants. The quality of wastewater is determined by many factors. Before we can decide about the line of treatment and disposal, it is essential to know its composition, quality and characteristics. The characteristics or properties of wastewater can be classified as physical, chemical and biological characteristics.

The most important physical characteristic of water is its total solids content, consisting of floating matter, matter in suspension, colloidal matter and matter in solution. Other physical characteristics are: (i) smell or odor (ii) color and (iii) temperature.

Important chemical characteristics of sewage are: (i) pH value, (ii) chloride content, (iii) nitrogen content, (iv) fat, grease and oil content, (v) sulfides, sulfates and H2S gas, (vi) dissolved oxygen, (vii) chemical oxygen demand and (viii) biochemical oxygen demand.

Biological characteristics relate to various micro organisms found in wastewater, some of which may be pathogenic. But all bacteria present in wastewater are not harmful; some of these help to treat the wastewater and reduce the cost of treatment plants. The organic matter in sewage consists of urea from urine, proteins, carbohydrates, fats and soaps. These undergo continuous decomposition and in that process, pass through several stages, resolving into simpler elements such as nitrogen, hydrogen, carbon and oxygen with small quantities of sulfur and phosphorous. These elements ultimately combine by means of chemical and biological actions to form inorganic substance.

Wastewater can be characterized by its main contaminants (Table 2.1) which may have negative impacts on the aqueous environment in which they are discharged. The amount and composition of the wastewater are of prime importance to designers and operators of a treatment facilities. The objective of wastewater treatment is to reduce the concentrations of specific pollutants to the level at which the discharge of the effluent will not adversely affect the environment or pose a health threat.

The most important parameters in assessing the strength of a given wastewater as described by Ronald (1997) are: BOD, COD, TSS, nutrients (N, P), pathogens, pH and temperature.

Table 2.1 Typical characteristics of domestic wastewater (adapted from Metcalf)

Parameter	Concentration		
	Strong (mg/L)	Medium (mg/L)	Weak (mg/L)
BOD 5	400	220	110
COD	1,000	500	250

TKN	35	15	8
NH_3-N	50	25	12
Total-P	15	8	4
Total Solids	1,200	720	350
Total Suspended Solids	350	220	100

2.3.2 Duckweed Based Wastewater Treatment

Ducweed wastewater treatment systems have been studied for raw and diluted domestic sewage (El-Shafai *et al.* 2007, Korner, 2003), dairy waste lagoons (Culley *et al.* 1981), secondary effluents (Gurtekin *et al.* 2008) and waste stabilization ponds (Dalu *et al.* 2002, Zimmo *et al.* 2005). Several full-scale systems are in operation in Taiwan, China, India, Bangladesh, Belgium, and the USA (Zirschky and Reed 1988, Alaerts *et al.* 1996, Koerner *et al.* 1998).

Different authors have proposed to use duckweed ponds for the efficient and low-cost treatment of domestic and industrial wastewater at urban or rural levels (Diederik et al., 2011). The duckweed plant has been used in stabilization pond systems for wastewater treatment, which represent an important class of wastewater treatment systems in developing countries because of their cost-effectiveness (Gijzen, 2001b). Waste stabilization ponds are low cost wastewater treatment systems producing high-quality effluents that allow water reuse in irrigation (Zimmo et al. 2004).

The duckweed treatment plants installed so far almost exclusively treat domestic or agricultural wastewaters. Available literature is limited on the treatment of specific industrial wastewaters (Gijzen and Khondker 1997). Potentially, duckweed may also be applied for the treatment of industrial wastewaters, provided their nutrient content is high enough. Effluents with both a high BOD and nutrient load may require adequate primary treatment to reduce the organic load. The upper BOD limit of tolerance for duckweed growth is unknown (Gijzen and Khondker 1997). Industrial wastewaters with a high BOD load and low nutrient content are less suitable to favour duckweed growth. Mdamo (1995) reported that duckweed growth on paper mill effluents was only observed when BOD was relatively low (150 mg/L) and nutrients were added externally. High BOD removal of over 98 % was observed when 2 mg per m^2 of both N and P were added daily. Without the addition of nutrients, almost no duckweed growth was observed on the paper mill wastewater. Neither did wastewater with a very high BOD level (2900 mg/L) promote duckweed growth. However, Skillicorn *et al.* (1993) reported that a simple rule of thumb for dilution of primary effluent is to ensure that BOD_5 plug-flow treatment system is maintained below 80 mg/L.

Apart from high BOD concentrations, fatty acids, oil and grease were reported to have a negative effect on duckweed growth. This is probably due to adsorption to the plants' submerged surfaces and subsequent inhibition of nutrient uptake. Duckweed is reported to tolerate rather high concentrations of detergents (Gijzen and Khondker 1997). Skillicorn *et al.* (1993), however, suggested that high concentrations of detergents may destroy the duckweed's protective waxy coating, thereby rendering the plant more vulnerable to diseases.

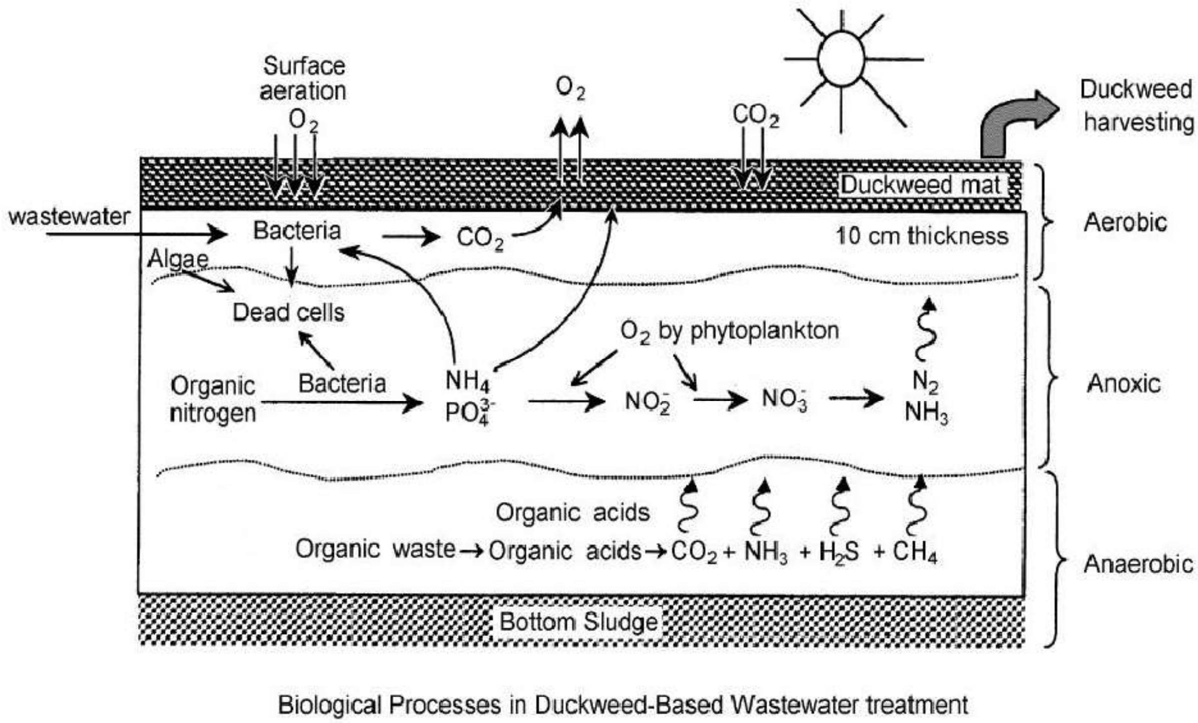


Figure 2.2. Biological Process in Duckweed Based Wastewater Treatment System

2.3.3Removal Mechanisms of Pollutants by Duckweed

The removal mechanisms of DBWWT systems for TSS, BOD, nitrogen, phosphorous, heavy metals, organic toxins and pathogen as assumed by various authors briefly described and discussed below.

2.3.4 TSS Removal

Total Suspended Solids are removed mainly by sedimentation and biodegradation of organic particles in the pretreatment and duckweed pond system. A minor fraction is absorbed by the roots of the duckweed fronds, where organic particles undergo aerobic biodegradation by microorganisms, and part of the degraded products is assimilated by the plants. Two characteristics of duckweed treatment systems are believed to play an important role in TSS removal. A complete mat of duckweed inhibits penetration of sunlight and subsequent growth of algae. Large amounts of algae contribute significantly to TSS concentrations. Though algae take up considerable amounts of N, P and other nutrients and may, therefore, contribute to their removal, the nutrients are released again by biodegradation when algae settle, die off and become available again for algal growth.

A dense mat of duckweed can, therefore, reduce algal contribution to TSS. This is one of the reasons why a complete duckweed cover is essential for treatment efficiency of duckweed systems. Compared to facultative ponds, a second, more uncertain factor favoring sedimentation of TSS in duckweed systems is attributed to the quiescent conditions prevalent in the water column under the duckweed cover, as a consequence of the more consistent vertical temperature profile.

2.3.5 BOD Removal

The role of duckweed in BOD removal is far from being fully understood. Generally, it can be indirect effects through provision of surface and subsurface for bacterial growth which changes the physicochemical environment in the water (Godfrey et al., 1985). The direct uptake of small hydrocarbons by duckweed as reported by Landolt and Kandeler (1987) indicates sedimentation and heterotrophic activity in the water column are probably the main mechanism in total BOD removal.

Duckweed possess a relatively small surface area for attached growth of mineralizing bacteria compared to other aquatic macrophytes with larger submerged root and leaf surfaces (Zirschky and Reed 1988). The dense cover of duckweed on the water surface would also inhibit both oxygen from entering into the water from the air by diffusion, and photosynthetic production of oxygen by phytoplankton as a result of the poor light penetration (Culley and Epps 1973). According to Zirschky and Reed (1988), BOD removal could even decrease in ponds covered with duckweed because of the limited oxygen transfer into the water.

Alaerts *et al*. (1996), however, found that with a BOD loading rate of 48-60 kg/ha·d, a water depth of 0.4-0.9 m and a HRT of about 20 days, the water column in a duckweed- covered sewage lagoon system always remained aerobic. Surprisingly, Srinanthakumar *et al.(*1983) calculated an aeration rate through the duckweed-covered surface of 3-4 gO_2/m^2, which is slightly higher than oxygen transfer through an uncovered surface. This leads to the conclusion that aerobic conditions occur at least in the top layer of a duckweed pon within and under the plant cover due to photosynthetic production of oxygen and surface aeration. Interesting results were also observed by Koerner *et al.* (1998) who reported that COD removal was significantly faster in the presence of duckweed than in its absence. They believe that the structure of duckweed surface and the way oxygen is supplied are important elements, since the positive influence of a living duckweed population on COD removal could not be simulated by artificial plastic duckweed surfaces and oxygen pumps.

Duckweed-covered pond system can become anoxic to anaerobic depending on the organic loading rate, water depth, HRT and the prevalent redox conditions. In this case, the main factors responsible for BOD removal in duckweed treatment systems are probably similar to the anaerobic zone of facultative ponds (Reed *et al.* 1988).

2.3.6 Nitrogen Removal

Nitrogen in raw wastewater is mostly organic and ammonia nitrogen form (called Kjeldahl nitrogen). Mineralization of organic matter produces most of the inorganic nitrogen compounds ($N0_3^-$, NH_4^+) which are immediately taken up by plant or microbial biomass for the production of protein. A fraction of the total amount of organic nitrogen is re- circulated to N_2 via denitrification. The reuse of fixed sources of nitrogen such as nitrate, nitrite, and ammonia, therefore contributes to higher energy efficiency in biological systems.

Research on nitrogen removal in duckweed-based treatment has listed the main mechanisms of removal as: plant uptake, ammonia volatilization, ammonia assimilation into algal biomass, and biological nitrification coupled with denitrification (Zimmo et al. 2000). Körner and Vermaat (1998) claim that only a quarter of total nutrient losses were not directly or indirectly attributed to duckweed.

Existing results suggest that approx. 50 % (± 20 %) of the total nitrogen load is assimilated by duckweed, while the remaining nitrogen is removed by indirect processes other than plant uptake of which nitrogen loss to the atmosphere by denitrification and volatilisation of ammonia are suggested to play a major role (Alaerts *et al.* 1996, Gijzen and Khondker 1997, Koerner and Vermaat 1997).

Laboratory experiments were carried out by Korner and Vermaat (1998) in shallow (3.3 cm), 11-batch systems to assess the contributions of duckweed to nitrogen removal in domestic wastewater. They showed that depending on the initial concentrations, the duckweed covered systems removed 73 - 97% of the initial Kjeldahl nitrogen in three days. Also duckweed was directly responsible for 30 - 47% of the total nitrogen loss by the uptake of ammonium.

In ponds with aerobic and anaerobic environments favouring microbial nitrification and denitrification, ammonium (NH_4^+) is first oxidised to nitrite (NO_2^-), then to nitrate (NO_3^-) and subsequently reduced to atmospheric nitrogen (N_2) which is released from the system. Bacteria of the genus *Nitrosomonas* perform the first oxidation step to NO_2^-, whereas bacteria of the genus *Nitrobacter* perform the second oxidation step to NO_3^-. Denitrification microorganisms as indicated by reaction (3) below use the nitrate and nitrite as a hydrogen acceptor and release the nitrogen as N_2 gas.

$$NH_4^+ + 1.5\,O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2H+ + H2O \qquad (1)$$

$$NO_2^- + 0.5\,O2 \xrightarrow{\text{Nitrobacter}} NO_3^- \qquad (2)$$

2.3.7 Phosphorous Removal

Phosphorus (P) in wastewater is typically present as orthophosphate, polyphosphate and organic phosphorus compounds (Surampalli et al., 1997). It is highly mobile and present in solution, in particles and detritus, or in the cells of aquatic organisms. Like nitrogen, phosphorus is an essential macronutrient for the growth of plants and other organisms and besides other factors, responsible for eutrophication processes.
According to Metcalf & Eddy Inc. (1991) the following phosphorus concentrations are typical for domestic raw wastewater:

Total phosphorus (TP):

- Low strength wastewater: 4 mg/L
- Medium strength wastewater: 8 mg/L
- High strength wastewater: 15 mg/L Inorganic phosphorus:
- Low strength wastewater: 3 mg/L
- Medium strength wastewater: 5 mg/L
- High strength wastewater: 10 mg/L

Phosphorus removal from aquatic macrophyte systems is due to plant uptake, microbial immobilization into detritus plant tissue, retention by underlying sediments and precipitation in the water column (Anonymus, 1998).
In a duckweed wastewater treatment system, phosphorous is normally removed by the mechanisms of: plant uptake, adsorption to clay particles and organic matter, chemical precipitation with Ca^{2+}, Fe^{3+}, Al^{3+}, and microbial uptake (Diederik et al.2011). Except for plant uptake, the latter three mechanisms cause storage of phosphorous in the system (Gijzen *et al.,* 2001). As no volatile intermediates such as N_2 or NH_3 as in the case of nitrogen are formed, ultimate phosphorous removal is only possible by plant harvesting and dredging of the sediment.

The plants' uptake capacity depends largely on the growth rate, harvesting frequency and available *ortho*-PO_4^{3-}, the favored form of phosphorous for duckweed growth (Shah *et al.*, 2014). In the warmer season when the growth rate is highest, phosphorous removal rate is also highest. The uptake of phosphorous by duckweed is enhanced by frequent harvesting and adequate pretreatment of raw wastewater to release organically bound *ortho*-PO $^{3-}$

Besides plant uptake, adsorption and precipitation are probably the other dominant mechanisms for phosphorous removal in a duckweed treatment system (Alaerts *et al.* 1996). Aerobic conditions contribute to the precipitation of phosphorous through oxidised forms of Fe and Al. However, phosphorous is again released under anaerobic conditions prevailing in the sediments.

2.3.8 Duckweed for Phytoremedation

Phytoremedation is the utilization of plants accumulation capabilities to remove contamination from water, soil and air. The capacity of aquatic plants to remove pollutants from water is well documented (Demirezen *et al*., 2004).The recent application of phytoremediation technology by duckweed in wastewater treatment and management is quite interesting and revealing. Phytoremediation systems by duckweed are one of the options that have been widely applied for combined handling of wastewater with the nutrients used for poultry and aqua-cultural projects Naphi *et al.* (2003).

Heavy metals are effectively removed from wastewater by duckweed which has the capacity to accumulate metals such as Cr, Mn, Fe, Co, Cu, Zn, Cd, Pb, Al and even Au (Leng, 1999; Iqbal, 1999). Duckweed can tolerate and accumulate with accumulation factors ranging between 10^2 and 10^5 (Landolt and Kandeler, 1987). This fact suggests a possible use of duckweed for efficient removal of metals from wastewaters. Zayed (1998) found that under experimental conditions, duckweed proved to be a good accumulator of Cd, Se, and Cu, a moderate accumulator of Cr, and a poor accumulator of Ni and Pb. The author concluded that duckweed is promising for the removal of Cd, Se and Cu from contaminated wastewater since it accumulates high concentrations of these elements. Further, the growth rates and harvest potential make duckweed a good species for phytoremediation. It should be known that duckweed produced in this way under no circumstances be used in food production (Gijzen and Khondker 1997).

As reported by Diederik et al. (2011), duckweed has a high metal uptake capacity specifically for Cr, Zn and Pb. The efficient absorption of heavy metals and other (organic) toxic compounds could be used for extraction of such toxins from industrial wastewaters. It is, however, important that the biomass is harvested at regular intervals, otherwise, the toxins will settle on the sediments with the decaying plants. The harvested plants should be burnt and/or disposed of in sealed landfills.

2.3.9 Pathogen Removal

Pathogen removal from duckweed covered lagoons treating domestic wastewater is important in order to produce an effluent quality that allows for further re-use in agriculture and/or aquaculture. The most common indicators of the level of waterborne pathogen contamination in water are the coliform group: Total Coliforms and Faecal Coliforms (USEPA, 2000).The effluent guidelines of less than 0.1 helminth eggs and less than 1000 faecal coliforms/100ml (WHO, 1989) should be met to ensure safe effluent reuse.

Duckweed restricts light penetration and may inhibit disinfection in the maturation ponds. Efficient removal of coliforms is known from conventional lagoon treatment systems without floating aquatic macrophytes. Direct sunlight and an increase in pH due to algal growth are believed to be possible factors responsible for coliform die off in such systems. These beneficial effects are not prevalent in a pond system completely covered by duckweed which cuts off light and suppresses algal growth. A study in Egypt by Dewedar and Bahgat (1995) showed no decline in faecal coliforms under a dense duckweed cover over a period of (only) 5 days. However, an analysis of studies on removal performance of *E. coli* in lagoons covered by various species of floating macrophytes (Alaerts *et al.* 1990) suggests that water temperature and hydraulic retention time are more determining factors. The effects of sunlight, pH and other parameters on bacterial and viral removal have to be investigated further in comparative studies using ponds with and without duckweed (Gijzen and Khondker 1997). Overall retention time required in a DWT system will vary depending on a range of factors including the influent nutrient levels, temperature and the discharge standards that must be met. In general, 20 days hydraulic retention time would appear to be a minimum guideline for DBWWT to achieve acceptable discharge standards and pathogen reduction in municipal sewage treatment (Skillicorn et al. 1993).

Islam *et al.* (1996), who monitored faecal coliforms in a plug-flow lagoon covered with duckweed, observed a reduction from $4.57x10^4$/ml in the raw wastewater to values below 10^2/ml after treatment with duckweed (99.78 % removal).

2.3.10 Mosquito and Odour Control

The results of several studies on the effects of duckweed on mosquito breeding appear to be contradictory (Gijzen and Khondker 1997). Positive, negative and no effects were reported by the references in Landolt and Kandeler (1987). A positive effect of a duckweed cover on the decrease of mosquito larvae was reported by Iqbal (1999). The authors suggest that a complete duckweed cover acts either as physical barrier and hinders the mosquito larvae from reaching the surface for oxygen uptake, or that the plants release compounds which are toxic to the larvae. A possibly reducing effect of duckweed on mosquito breeding may positively contribute to the acceptance of duckweed farming systems in areas where mosquitoes are a nuisance and a vector of serious human diseases like malaria or dengue. The gaseous products resulting from anaerobic decomposition in the sediment and water column are responsible for odour development.

It is assumed that the aerobic duckweed mat acts as chemical and physical barrier against odours. Hydrogen sulphide (H_2S) oxidises for example to sulphuric acid (H_2SO_4) within the aerobic plant mat (Lemna Corp. 1994).

2.4 Design Considerations

In practice, pond depth, the organic surface loading rate, sewage temperature, and the hydraulic retention time are crucial design parameters of duckweed ponds. Type and quantity of wastewater to be treated are decisive factors in the design of duckweed treatment systems and for infrastructural requirements necessary to ensure daily nutrient inputs and use of biomass.

Metcalf and Eddy (1991) suggest that duckweed systems, exploiting mainly the wastewater treatment aspect of duckweed, can be designed as conventional stabilization ponds with the addition of a floating grid system to control the effects of wind. However, reliable design and operation guidelines aiming at the dual use of duckweed in wastewater treatment and optimum biomass production are lacking. They can be operated as batch or plug-flow (continuous flow) systems. Easy access to the pond surface for operation and maintenance should be ensured in site selection and design of a duckweed treatment pond system.

Therefore, a narrow, channel-like pond design is more convenient than wider ponds.

2.5 Primary Treatment of Raw Wastewater

Primary treatment of raw wastewater is essential for initial separation of some of the settleable fraction of pathogens, solids and floating material. This can be achieved in conventional deep anaerobic ponds that encourage the fermentation and breakdown of settled solids by bacterial processes into simple organic and inorganic molecules. Duckweed could enhanced primary treatment in these ponds by maintaining anaerobic conditions and reducing odour nuisance (Skillicorn et al. 1993). In addition, conventional anaerobic ponds, while effective at reducing BOD, anaerobic pretreatment promotes the release of organically bound NH_4^+ and o-PO_4^{-3}, the favored forms of nutrients for duckweed growth (Caicedo et al. 2000), so duckweed assimilation will enhance the nutrient removal capacity of these anaerobic systems.

High levels of ammonification occur in primary treatment systems which may be toxic to duckweed. Cheng et al. (2002) found that a range of duckweed species tested could tolerate and grow at high ammonium levels of 240 mg/L in swine wastewater - the best performer being a Queensland native, Spirodella punctata (recently renamed Landoltia punctata). Phan (2002), however, found that duckweed may need an acclimatization period to adapt to the very high N levels in raw agricultural wastewaters.

Most researchers, however, suggest that efficiency gains using DBWWT are greater in secondary and tertiary treatment of effluent where organic sludge has already been removed or converted into simple organic and inorganic molecules that can be used directly by duckweed (Alaerts et al. 1996; Caicedo et al. 2000; Smith and Moelyowati 2001). Use of conventional earthen anaerobic sedimentation ponds is an efficient, low-cost and easy manageable alternative for primary treatment, especially in low-income countries.

2.5.1 Pond Design Consideration

As aforementioned, two basic principles for pond design and operation are used for duckweed treatment, namely plug-flow and batch systems. A plug-flow (continuous flow through) design seems to be the more suitable treatment option for larger wastewater flows originating from communities and (peri-) urban areas, as it ensures an improved and more continuous distribution of the nutrients. A plug-flow design also enhances the contact surface between wastewater and floating plants, thereby, minimizing short circuiting. To ensure plug-flow conditions, a high plug-flow length to width ratio of 10:1 or more is necessary (Hammer 1992). Alaerts *et al.* (1996) reported excellent treatment results with a length to width ratio of 38:1. Moreover, a narrow, channel-like design allows easier access to the water surface for operation and maintenance work.

In a plug-flow system, duckweed productivity, nutritional value and nutrient removal efficiency decline gradually with increasing retention time. Depletion of nutrients causes plants to visually become brownish at some stage in the plug-flow runway, to grow slower and take up less nutrients per time than plants in the initial stages of the plug-flow. Furthermore, their protein content drops and their fibre content increases. At this point, the two so far parallel running processes of efficient wastewater treatment and high duckweed production begin to diverge. Yet, if this occurs at the very end of a duckweed plug-flow system and if the required effluent standards are met, the objective of combined wastewater treatment and production of high quality feed is attained. However, reliable design guidelines are missing to dimension a duckweed plug-flow lagoon in such a way that nutrient starvation occurs at the very end of the system. The system could, therefore, either be oversized if effluent standards are already met at early fractions of total retention time, leaving most of the system's surface underused with regard to protein production, or undersized where effluent standards are not met at the end of the plug-flow.

2.6 Hydraulic Retention Time (HRT)

The hydraulic retention time is the average time that water remains in the DBWWT system. HRT has major effects on the efficiency of any treatment system. A longer hydraulic residence time allows for more of the treatment processes to be completed. In duckweed ponds, the HRT is dependent on the organic, nutrient and hydraulic loading rate, depth of the system and harvesting rate (Metcalf and Eddy 1991). To ensure acceptable pathogen removal and treatment efficiency, comparatively long retention times in the range of 20 to 25 days are postulated for duckweed (plug-flow) systems (Metcalf and Eddy 1991). However, to reduce BOD to 30 or 20 mg/L depending on the influent concentration, residence time of 10 to 20 days is proposed by Smith and Moelyowati (2001). Bal Krishina *et al*. (2008) proposed a retention time of 10 days for optimum operating condition of DBWWT systems in tropical areas.

2.7 Water Depth

The critical factor with respect to water depth is to ensure vertical mixing in the pond to allow the wastewater to be treated to come into contact with the duckweed fronds for nutrient uptake and BOD degradation through attached microbial populations. An outlet structure is recommended in order to vary the operating depth (Metcalf and Eddy 1991). Reported pond depths range from 0.3 to 2.7 m up to even 5 m (Lemna Corp. 1994). The majority of authors report an optimal depth ranging from 0.4 to 0.9 m, implying that a maximum depth of one meter is sufficient for acceptable temperature buffering. Higher depths are also a feasible option for systems with relatively low BOD loads, a low recirculation rate and high land costs. Shallow system depths are, however, better suited for high organic loads, a high recirculation rate and for regions with inexpensive land prices.

2.8 Organic Loading Rate (OLR*)*

Organic loading rate is one of the determining factors for efficiency of duckweed based treatment system. Average organic loading rates expressed in terms of BOD for plant systems without artificial aeration should not exceed 100 to 160 kg/ha·d in order to obtain effluent quality of 30 mg BOD/l or less (Metcalf and Eddy 1991, Gijzen and Khondker 1997). Odours can develop at lower loading rates, especially where the sulphate concentration in the wastewater is greater than 50 mg/L. It seems that duckweed is less suitable for the treatment of wastewaters containing high BOD loads.

2.9 Wind Protection

Duckweed is very susceptible to wind drifts and water currents, which needs stabilization of the plants on the water surface. In regions with moderate winds, drifts are prevented through floating grids dividing the pond surface into cells or compartments. Floating bamboo poles divided into small square or rectangular areas of 2 to 5 by 4 to 8 meters are most commonly used. The size of the grid is determined by mean wind conditions and, in the case of flow through systems, by maximum projected flow velocity in the system. The higher the wind and flow velocities, the smaller the cells and the higher the system's costs.

2.10 Harvesting and Potential Uses of Duckweed

The quantity and frequency of duckweed harvesting plays a major role in the treatment efficiency and nutritional value of the plants. Regular harvesting ensures that the accumulated nutrients or toxins are permanently removed from the system. Because younger plants show a better nutrient profile and higher growth rate than older plants, regular harvestig is important to maintain a healthy and productive crop. Laboratory results (Willet, 2005) revealed that under conditions of high nutrient loading, an increase in the cropping rate resulted in improved nutrient removal. At lower nutrient loading rates, the cropping rate should be reduced. An almost complete cover should remain on the pond surface after plant harvesting.

The standing crop density, which realises the highest duckweed productivity, will determine the harvesting frequencies and amounts. The correlation between standing crop density and absolute biomass productivity peaks at some optimal density and gradually declines as increasing density inhibits growth through crowding. Optimal standing crop densities are site-specific and have to be determined through practical experience (Willet, 2005).

Alaerts *et al.* (1996) reported a standing crop density of 1600 g (wet wt)/m^2 for a duckweed-covered sewage lagoon in Bangladesh. Lower standing crop densities of 400 to 800 g (wet wt)/ m^2 were reported by Skillicorn *et al.* (1993). Each cell should be harvested back to optimal standing crop density at rates dependent on the plants' productivity.

2.11 Comparison of Duckweed Systems with Other Natural Treatment Systems

In aquaculture and constructed wetlands, macrophytes (plants) are grown to suppress algal growth by shielding the water column from light, by absorbing the nutrients and by assisting the oxygen transfer into the water (Koerner et al. 2003). The floating plant duckweed (Lemnaceae), is particularly promising for aquaculture because it grows abundantly and can easily be harvested. In constructed wetlands, wastewater is made to flow either horizontally or vertically through the root zone of a permeable soil planted with vegetation. The plants, if regularly harvested, create a sink for the nutrients by their uptake and assimilation of N and P. Importantly, they also provide niches for bacteria that reduce BOD, and that enhance nitrification and denitrification. They also provide niches for predator organisms that contribute to pathogen removal. Such wetlands offer good prospects for small-scale operation in remote tropical areas.

Generally, TSS, BOD and pathogen removal undergo the same process as with WSPs and thus, duckweed-based wastewater treatment systems are enhanced lagoon systems (Bonomo *et al.*, 1997). Nutrients (N, P) are generally sequestered in the plant biomass and are removed through harvesting (Bonomo *et al.*, 1997).

Compared to water hyacinth, duckweed-based wastewater treatment systems play a smaller role in BOD removal, but are efficient in the removal of nutrients and can play a significant role in TSS reductions (Zirschikly and Reed, 1988; Brix and Schierup, 1989).

Duckweed usually forms a dense mat covering the entire water surface, which provides some special characteristics for the treatment system:

(i) Duckweed mat can prevent the growth of micro-algae by restriction of light penetration (Willet, 2005). The dense duckweed mat also prevents mosquito larvae from reaching the water surface (Culley and Epps, 1973).

(ii) Duckweed mat makes the water column largely anaerobic by restriction of gas- liquid oxygen transfer together with lacking photosynthetic oxygen by phytoplankton (Brix and Schierup, 1989). While the oxygen produced by photosynthetic on duckweed mat can be transferred into the water column to form a thin aerobic layer in duckweed root zone (Zirschky and Reed, 1988). The aerobic layer favors oxidation of rising odor gas produced from anaerobic water column below.

(iii) Evaporation from a duckweed-based pond system is restricted (Oron et al., 1984).

2.12 Environmental and Economic Benefits of DBWWT

Discharge of untreated wastewater in to the environment causes the deterioration of ground and surface water quality, as well as air and land pollution. The impact depends on the composition and strength of wastewater discharged into the environment.

Among others, some of the environmental and economic benefits of wastewater treatment using duckweed wastewater treatment systems are:

- Contribute to avoid or minimize pollution of ground and surface water sources caused by discharge of untreated wastewater;
- Avoidance of public health hazard from exposure to pathogen in sewage;
- Harvesting wastewater-grown duckweed helps to remove surplus nutrients, which might otherwise be released into aquatic environments by wastewater treatment plants (Oron et al., 1988);
- Duckweed systems evaporate 20% less water compared to other open water systems (Oron et al., 1986);
- In developing countries like Ethiopia where fertilizer is scarce and expensive for the small farmer, duckweed collected from local wastewater treatment ponds and wetlands can provide a cheap and effective fertilizer for rice and other crops (Ahmad et al., 1990).
- Duckweed cover restricts sunlight penetration into the water body, limiting algal development and consequently lowering of TSS levels are expected in the final effluent;
- Duckweed system may generate economic return via the commercialization of biomass for fodder, and effluent for irrigation (Willett, 2005).
- Duckweed may provide a source of mosquito anti-larval compounds that could have public health significance;

2.13 Limitation of DBWWT

Duckweed based waste water treatment systems have the following limitations.

- They require large areas of land that may not be available near urban areas;
- In temperate climates duckweed growth slows in the winter. This may restrict the use of such treatment systems in cooler climates;
- Duckweed-based treatment systems may be most useful in treating secondary effluents from small communities where land costs are low (Dalu and Ndamba 2003);

2.15 Use of Duckweed as a Food Source

If grown on domestic wastewater free of heavy metals, duckweed can be used as an animal fodder and green fertiliser (Oron, 1990; Bonomo *et al.*, 1997).

The nutrients taken up by duckweed are assimilated into plant protein. Under ideal growth conditions more than 40% protein content on dry weight basis may be achieved (Skillikorn *et al.*, 1993). Duckweed value, in terms of protein content, is similar to soybeans (Oron, 1990, 1994). Duckweed protein has a better array of essential amino acids than most vegetable proteins and more closely resembles animal protein (Hillman and Culley 1978). It is, therefore, a source of high quality protein to be exploited for domestic animal production. Duckweed grown on nutrient-rich water has a high concentration of trace minerals, K and P and pigments, particularly carotene make duckweed meal an especially valuable supplement for poultry and other animals, and it provides a rich source of vitamins A and B for humans.
Research at Louisiana State University demonstrated the value of using dried duckweed fronds as a feed source for dairy cattle and poultry (Culley et al., 1981). Research results of Texas Tech University was indicated that duckweed species have potential as a feed ingredient for cattle, sheep, and pigs (Moss, 1999).
The value of duckweed as a source of feed for fish and poultry has been promoted by the World Bank, especially in developing countries (Skillicorn et al., 1993). Duckweed used at a level of up to 15% in broiler diets can represent an important alternative source of protein for poultry feeds in countries where soybean or fish meal is unavailable (Haustein, 1990). When dried duckweed (*Lemna* spp) was fed to crossbred meat ducks as a substitute for soybean meal

there was no significant difference in the carcass traits between treatments (Bui et al., 1995). Perhaps the most promising use of duckweed is as a feed for pond fish such as carp and tilapia. Ponds for duckweed production can be located next to fish culture ponds, eliminating the need for expensive drying to produce a dried feed. Nile tilapia and a polyculture of Chinese carps fed readily on fresh duckweed added to their ponds and the nutritional requirements of these cultured fish appear to be completely met by duckweed (Skillicorn et al., 1993).

Research on using duckweed in the diets of domestic animals has been surprisingly scarce, perhaps because of the difficulties of growing sufficient duckweed under experimental conditions.

Since the protein content of duckweed was found to be almost as high as that of soybean meal, duckweed production provided both a means of wastewater purification and a source of livestock feed as well (Johnson, 1998).

2.16 Criteria for Proper Wastewater Disposal

Proper disposal of sewage and other wastewater is necessary not only to protect the public's health and prevent contamination of groundwater and surface water resources but also to preserve fish and wildlife populations and avoid the creation of conditions that could detract from the attractiveness of a community, tourist establishment, resort, and recreational areas.

As described by Salvato et. al. (2003), the following basic criteria should be satisfied in the design and operation of an excreta, sewage, or other wastewater disposal system:

1. Prevention of microbiological, chemical, and physical pollution of water supplies and contamination of fish intended for human consumption;
2. Prevention of pollution of bathing and recreational areas;
3. Prevention of nuisance, unsightliness, and unpleasant odors;
4. Prevention of human wastes and toxic chemicals from coming into contact with humans, grazing animals, wildlife, and food chain crops or being exposed on the ground surface accessible to children and pets;
5. Prevention of fly and mosquito breeding and exclusion of rodents and other animals;
6. Strict adherence to standards for groundwater and surface-water protection and compliance with federal, state, and local regulations governing wastewater disposal and

water pollution control.

Table 2.2 European Community guidelines for wastewater discharged to sensitive surface water bodies based on typical raw wastewater composition.

Variable	Raw sewage composition	EU guideline	Percentage removal (%)
BOD_5 (mg/L)	250	25	90
Total N (mg/L)	48	10	80
Total P (mg/L)	12	1	90

Source: CEC, 1991

There are no environmental quality standards for ensuring environmental well being in the country. However, the Ethiopian Environmental Policy underlines that environmental quality standards are indispensable instruments to ensure the well being of human beings as well as other living things and therefore provisional standards were set in 2003. Table 4.6 indicates provisional quality standards for selected parameters relevant to this study.

Table 2.3 Ethiopia's EPA (2003) Provisional Discharge Standard

Parameter	Unit	Ethiopia EPA (2003) Standard
BOD_5	mg/L	80
COD	mg/L	250
TSS	mg/L	100
TKN-N	mg/L	60
TP	mg/L	10
$PO4^{3-}$	mg/L	5
NH_4^+-N	mg/L	5

$NO_3^{-}N$	mg/L	20
FC	CFU/100ml	400
Temp	^oC	40
pH	$-\log[H^+]$	6-9

2.17 Gap in Research Area

The first project funded by the Ministry of Environment & Forests, Govt. of India,for Duckweed Based Waste Water Treatment was successfully completed in collaboration with the Central Pollution Control Board, New Delhi. Based on the R & D outputs of the project, the CPCB has made guidelines on the use of duckweed for waste water treatment. And various other countries are also performing experiments for the same.

Still in India not much have been done in this field. The potential of duckweed for the waste water treatment, its nutrient value and economic benefits have not been fully exploited.

2.18 Objective of Research

To evaluate the treatment efficiency, wastewater samples using duckweed.

The parameters which will be checked are:-

- pH
- Dissolved Oxygen (DO)
- Total Chemical Oxygen Demand (COD)
- Biochemical Oxygen Demand (BOD)
- Total Suspended Solids (TS)
- Turbidity
- Total Nitrogen
- Phosphorus
- Ammonia

2.19 Significance of the Study

Duckweed based wastewater treatment system effectively recover nutrients from domestic wastewater. This enables to recycle nutrients through production of aquatic biomass called duckweed which is a fast-growing and easy to harvest plant that can be utilized for animal feed, primarily for fish and poultry. On the other hand, treated wastewater eliminates environmental pollution that would have been caused by untreated wastewater discharges. Compared with other conventional wastewater treatment technologies, DBWWT system doesn't require high technology, skilled manpower, energy and other resources so as making it a sustainable wastewater treatment system for tropical developing countries. The fact that it realizes the recovery and reuse of nutrients, people can contribute to the cost of wastewater treatment with great interest. DBWWT enables nutrient recovery from wastewater so as to utilize it for feeding of animals, thereby contributing to food security.

In addition, the output of this study will be relevant to design and use of environmentally sound duckweed based wastewater treatment ponds at small and medium scale in India. Above all, the finding may trigger further studies and researches to develop efficient duckweed based wastewater treatment system suitable for local condition.

CHAPTER 3 METHODOLOGY

3.1 Materials

3.1.1 Wastewater and Duckweed

Duckweed plants was purchased from online site due to some shortcomings.

Raw domestic wastewater was collected from kitchen drainage of the house and then batch experiments were carried out to evaluate the performance of duckweed (*Lemna minor L*) to treat the raw and settled wastewater.

3.1.2 Experimental Setup

All the experiments were performed as per relevant IS codes in Amble testing and research Labs (ISO 9001:2015 certified and government approved Lab). The experiment was carries out for two ponds with different quantity of wastewater collected.

Various results for both the ponds were compared to check the quality of waste water as well as suggest the use of treated water.

3.1.3 Sample Collection and Analysis

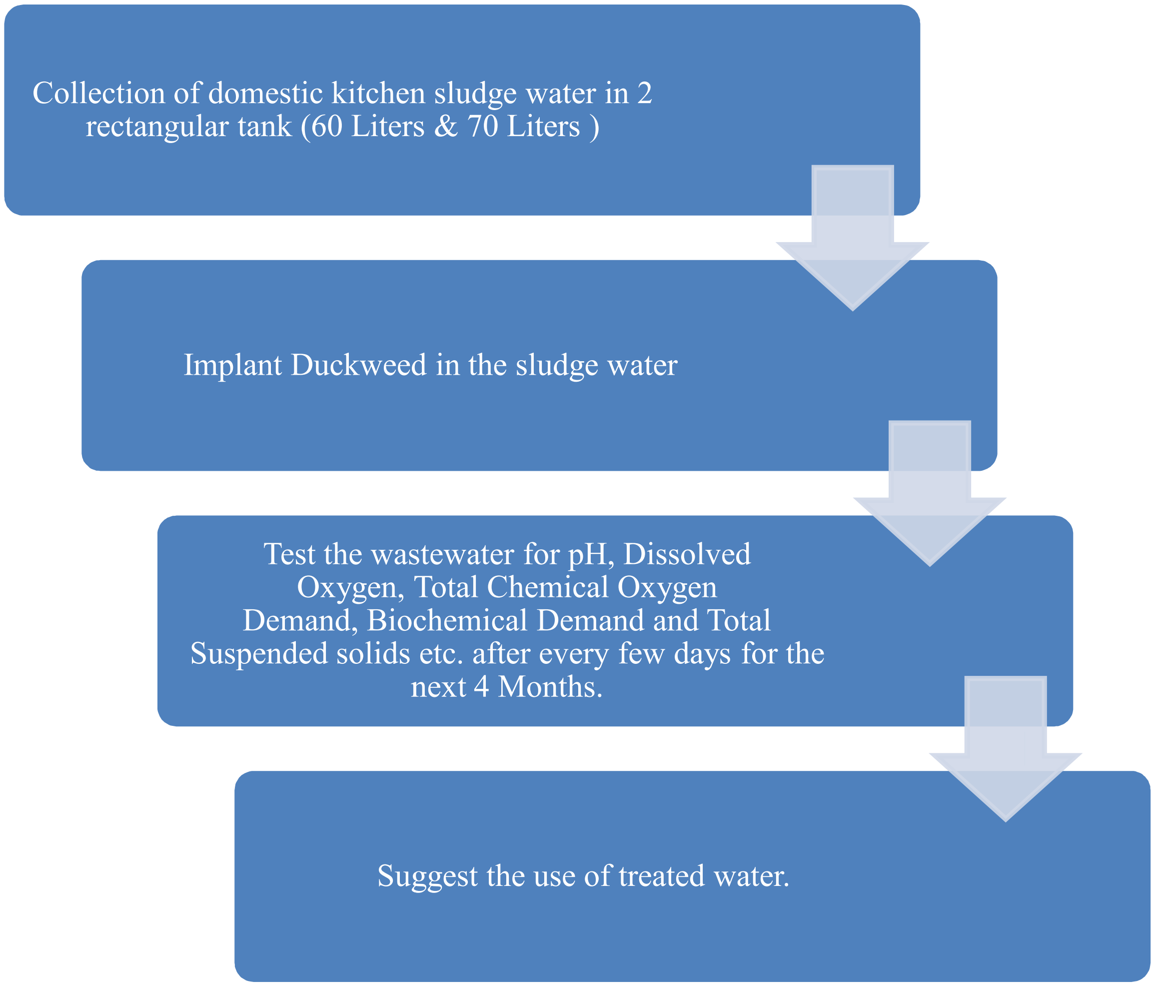
3.1.3.1Duckweed Sampling

Duckweed was purchased from online site due to some constraints.

3.1.3.2 Wastewater Samples

Water for both the ponds was collected from the kitchen drainage of the house. The wastewater of pond 2 was collected a week later from the water collected for pond 1. Further the wastewater samples were carried to Amble testing and research Labs Lucknow for the tests to be performed. Firstly the tests for wastewater water without duckweed were performed, later after addition of duckweed tests were performed for various parameters after more than 20 days.

Methodology



CHAPTER 4 RESULTS AND DISCUSSION

4.1 Wastewater Characteristics of the DBWWTs

Various tests for calculation for calculation of different parameters have been performed on kitchen waste water collected as well as for the wastewater with duckweed implanted. The tests results are listed below in tabular form as well as discussion for each has also been mentioned.

Test results for kitchen waste water collected in both the ponds:-

Table 4.1 Waste water without adding duckweed

S NO.	Parameters	POND 1	POND 2	Test Method
1	pH , at 27℃	11.42	11.48	IS:3025(PT-11)-1983
2	Turbidity(NTU)	167	170	IS:3025(Pt-10)-1984
3	Total Suspended solid, mg/l	105	106	IS:3025(PT-17)-1984
4	Chemical Oxygen Demand (COD), mg/l	290.4	280	APHA 23rd - 2017
5	Biological or Biochemical Oxygen Demand (BOD), mg/l	120	126	APHA 23rd - 2017
6	Dissolved oxygen (DO), mg/l	5.2	5.3	APHA 23rd - 2017
7	Total Nitrogen, mg/l	65	68	IS:3025(PT-34)-1988
8	Phosphorus, mg/l	1.9	1.8	IS:3025(PT-31)-1988
9	Ammonia, mg/l	2.01	1.09	IS:3025(PT-31)-1988

Table 4.2 Sample 1 after addition on Duckweed

S NO.	**Parameters**	**POND 1**	**POND 2**	**Test Method**
1	pH , at 27℃	10.8	10.6	IS:3025(PT-11)-1983
2	Turbidity(NTU)	170	172	IS:3025(Pt-10)-1984
3	Total Suspended solid, mg/l	104	102	IS:3025(PT-17)-1984
4	Chemical Oxygen Demand (COD), mg/l	245.2	241.3	APHA 23rd - 2017
5	Biological or Biochemical Oxygen Demand (BOD), mg/l	103.5	105.6	APHA 23rd - 2017
6	Dissolved oxygen (DO), mg/l	5.8	5.7	APHA 23rd - 2017
7	Total Nitrogen, mg/l	45	43	IS:3025(PT-34)-1988
8	Phosphorus, mg/l	1.7	1.6	IS:3025(PT-31)-1988
9	Ammonia, mg/l	1.8	1.7	IS:3025(PT-31)-1988

Table 4.3 Sample 2 after addition on Duckweed

S NO.	Parameters	POND 1	POND 2	Test Method
1	pH , at 27℃	9.7	9.7	IS:3025(PT-11)-1983
2	Turbidity(NTU)	152	152	IS:3025(Pt-10)-1984
3	Total Suspended solid, mg/l	104	104	IS:3025(PT-17)-1984
4	Chemical Oxygen Demand (COD), mg/l	220.4	220.4	APHA 23rd - 2017
5	Biological or Biochemical Oxygen Demand (BOD), mg/l	95.3	95.3	APHA 23rd - 2017
6	Dissolved oxygen (DO), mg/l	6.2	6.1	APHA 23rd - 2017
7	Total Nitrogen, mg/l	42	42	IS:3025(PT-34)-1988
8	Phosphorus, mg/l	1.2	1.2	IS:3025(PT-31)-1988
9	Ammonia, mg/l	0.7	0.7	IS:3025(PT-31)-1988

Table 4.4 Sample 3 after addition on Duckweed

S NO.	Parameters	POND 1	POND 2	Test Method
1	pH , at 27℃	8.4	8.3	IS:3025(PT-11)-1983
2	Turbidity(NTU)	168	150	IS:3025(Pt-10)-1984
3	Total Suspended solid, mg/l	98	99	IS:3025(PT-17)-1984
4	Chemical Oxygen Demand (COD), mg/l	195	191	APHA 23rd - 2017
5	Biological or Biochemical Oxygen Demand (BOD), mg/l	83	81	APHA 23rd - 2017
6	Dissolved oxygen (DO), mg/l	6.8	6.9	APHA 23rd - 2017
7	Total Nitrogen, mg/l	34	32	IS:3025(PT-34)-1988
8	Phosphorus, mg/l	1.15	1.6	IS:3025(PT-31)-1988
9	Ammonia, mg/l	0.5	0.5	IS:3025(PT-31)-1988

Table 4.5 Sample 4 after addition on Duckweed

S NO.	Parameters	POND 1	POND 2	Test Method
1	pH , at 27℃	8.1	8	IS:3025(PT-11)-1983
2	Turbidity(NTU)	165	145	IS:3025(Pt-10)-1984
3	Total Suspended solid, mg/l	95	92	IS:3025(PT-17)-1984
4	Chemical Oxygen Demand (COD), mg/l	167	161	APHA 23rd - 2017
5	Biological or Biochemical Oxygen Demand (BOD), mg/l	70	68	APHA 23rd - 2017
6	Dissolved oxygen (DO), mg/l	7.2	7.3	APHA 23rd - 2017
7	Total Nitrogen, mg/l	34	31	IS:3025(PT-34)-1988
8	Phosphorus, mg/l	1.15	1.15	IS:3025(PT-31)-1988
9	Ammonia, mg/l	0.5	0.5	IS:3025(PT-31)-1988

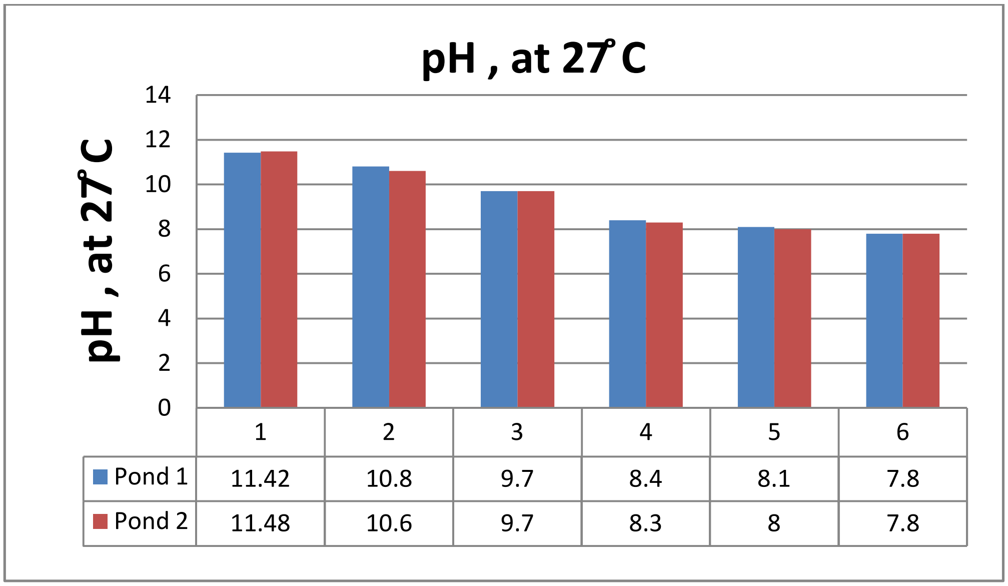
Table 4.6 Sample 5 after addition on Duckweed

S NO.	Parameters	POND 1	POND 2	Test Method
1	pH , at 27℃	7.8	7.8	IS:3025(PT-11)-1983
2	Turbidity(NTU)	160	144	IS:3025(Pt-10)-1984
3	Total Suspended solid, mg/l	92	90	IS:3025(PT-17)-1984
4	Chemical Oxygen Demand (COD), mg/l	153	151	APHA 23rd - 2017
5	Biological or Biochemical Oxygen Demand (BOD), mg/l	55	51	APHA 23rd - 2017
6	Dissolved oxygen (DO), mg/l	7.5	7.5	APHA 23rd - 2017
7	Total Nitrogen, mg/l	33	32	IS:3025(PT-34)-1988
8	Phosphorus, mg/l	1.14	1.15	IS:3025(PT-31)-1988
9	Ammonia, mg/l	0.5	0.5	IS:3025(PT-31)-1988

4.2 Discussion

Variations for both the ponds for different parameters have been compared below:-

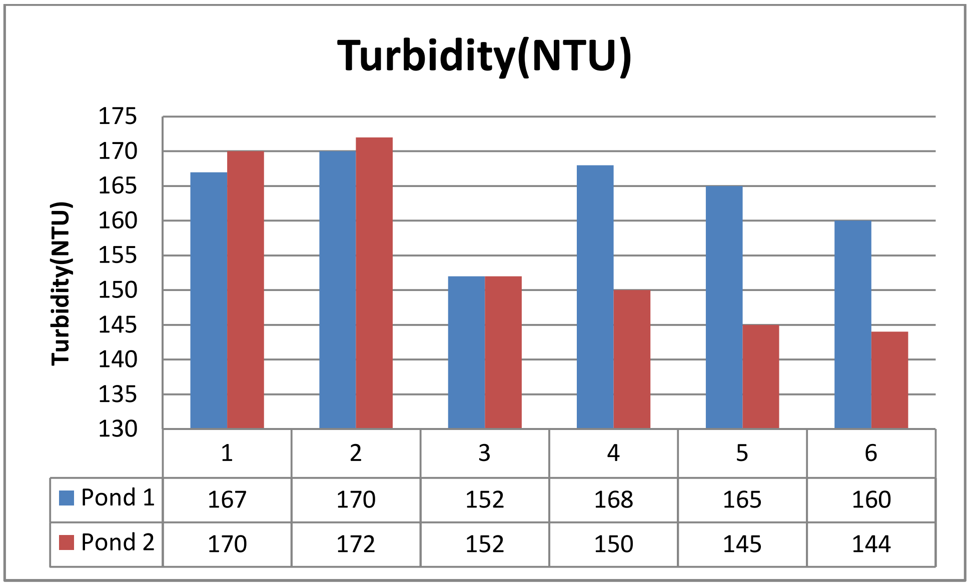
1. **pH , at 27℃**



Discussion

Initially the water collected from kitchen drainage was tested for pH then further the tests performed were for the waste water after addition of duckweed. It was observed that the value of pH has decreased by 32.6% to 7.8 in case of pond-1 and by 32.05% to 7.8 in case of pond-2 the course of four months after addition of duckweed to the waste water. This implies the water quality has improved in terms of pH.

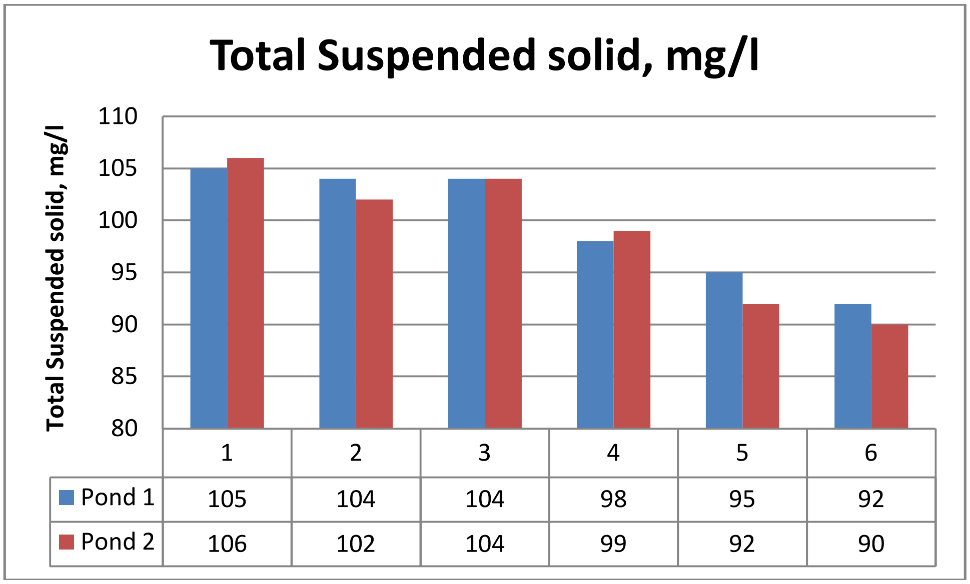
2. Turbidity(NTU)



Discussion

Initially the water collected from kitchen drainage was tested for Turbidity then further the tests performed were for the waste water after addition of duckweed. It was observed that the value has decreased by 4.19% to 160 NTU in case of pond-1 and by 15.29% to 144 NTU in case of pond-2 in the course of four months after addition of duckweed to the waste water.

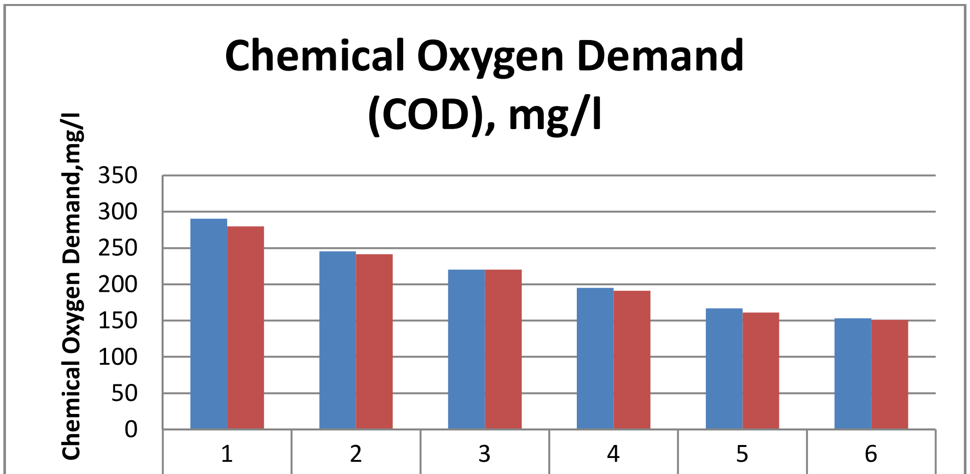
3. Total Suspended solid, mg/l



Discussion

Initially the water collected from kitchen drainage was tested for Total Suspended solid then further the tests performed were for the waste water after addition of duckweed. It was observed that the value of Total Suspended solids has decreased by 12.38% to 92 mg/l in case of pond-1 and by 15.09% to 90mg/l in case of pond-2 in the course of four months after addition of duckweed to the waste water.

4. Chemical Oxygen Demand (COD), mg/l

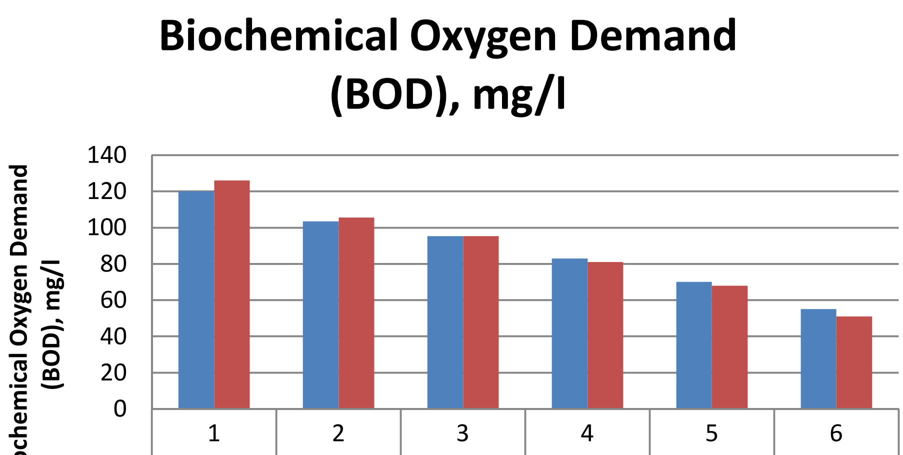


	1	2	3	4	5	6
Pond 1	290.4	245.2	220.4	195	167	153
Pond 2	280	241.3	220.4	191	161	151

Discussion

Initially the water collected from kitchen drainage was tested for Chemical Oxygen Demand then further the tests performed were for the waste water after addition of duckweed. It was observed that the value of COD has decreased by 47.3% to 153 mg/l in case of pond-1 and by 46.07% to 151mg/l in case of pond-2 in the course of four months after addition of duckweed to the waste water.

5. Biochemical Oxygen Demand (BOD), mg/l

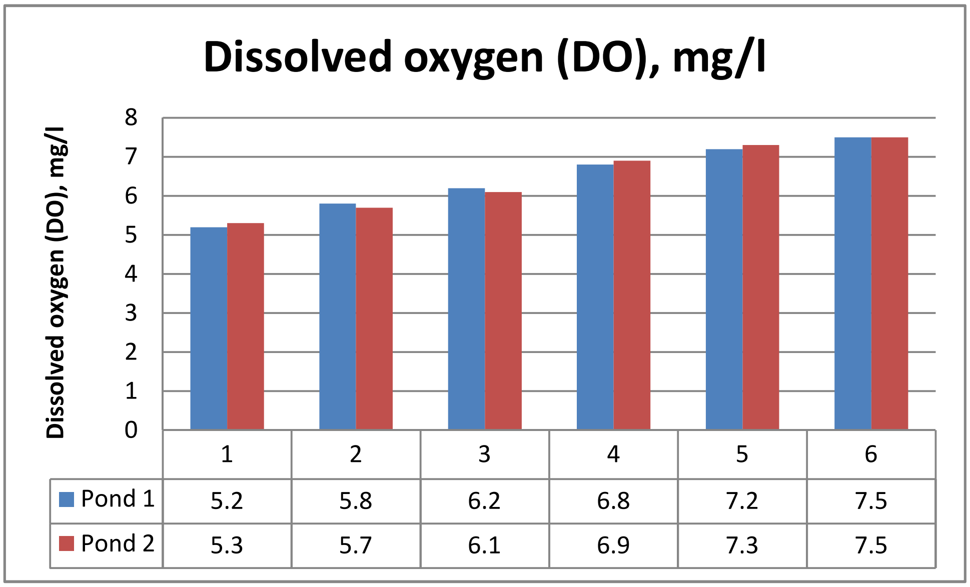


	1	2	3	4	5	6
Pond 1	120	103.5	95.3	83	70	55
Pond 2	126	105.6	95.3	81	68	51

Discussion

Initially the water collected from kitchen drainage was tested for Biochemical Oxygen Demand then further the tests performed were for the waste water after addition of duckweed. It was observed that the value of BOD has decreased by 5.16% to 55 mg/l in case of pond-1 and by 59.52% to 51mg/l in case of pond-2 in the course of four months after addition of duckweed to the waste water.

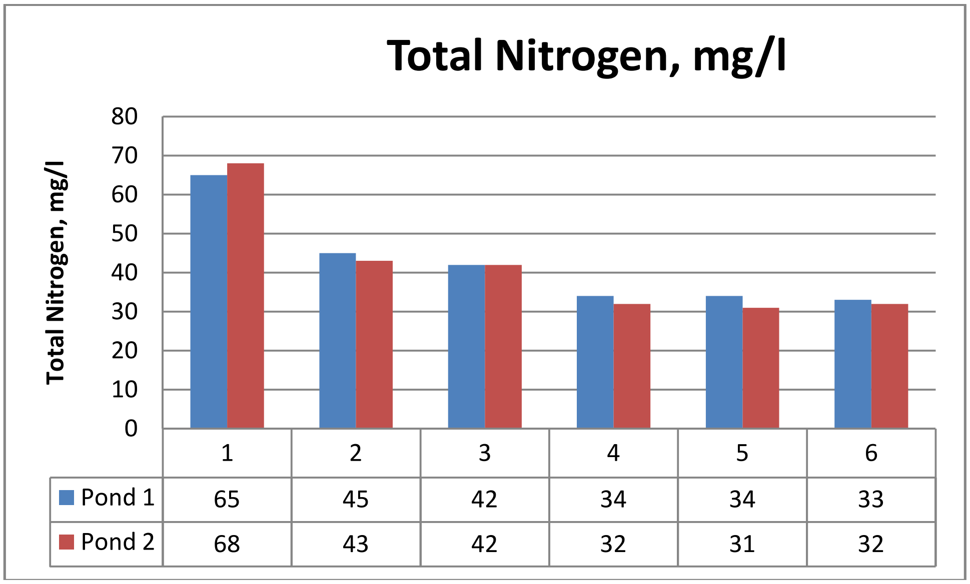
6. **Dissolved oxygen (DO), mg/l**



Discussion

Initially the water collected from kitchen drainage was tested for Dissolved oxygen then further the tests performed were for the waste water after addition of duckweed. It was observed that the value of DO has increased by 44.23% to 7.5 mg/l in case of pond-1 and by 41.50% to 7.5 mg/l in case of pond-2 in the course of four months after addition of duckweed to the waste water.

7. Total Nitrogen, mg/l

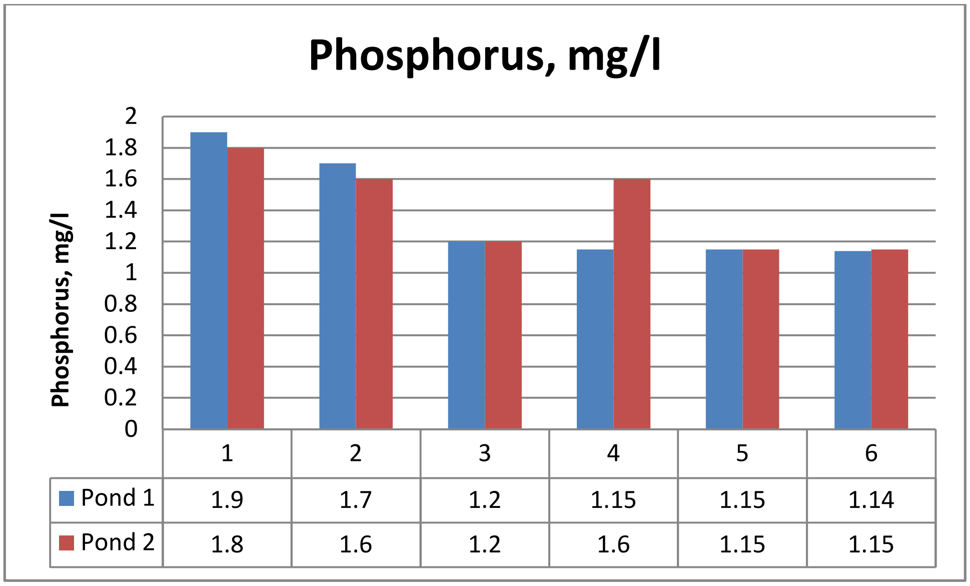


	1	2	3	4	5	6
Pond 1	65	45	42	34	34	33
Pond 2	68	43	42	32	31	32

Discussion

Initially the water collected from kitchen drainage was tested for Total Nitrogen then further the tests performed were for the waste water after addition of duckweed. It was observed that the value of total nitrogen has decreased by 49.23% to 33 mg/l in case of pond-1 and by 52.94% to 32 mg/l in case of pond-2 in the course of four months after addition of duckweed to the waste water.

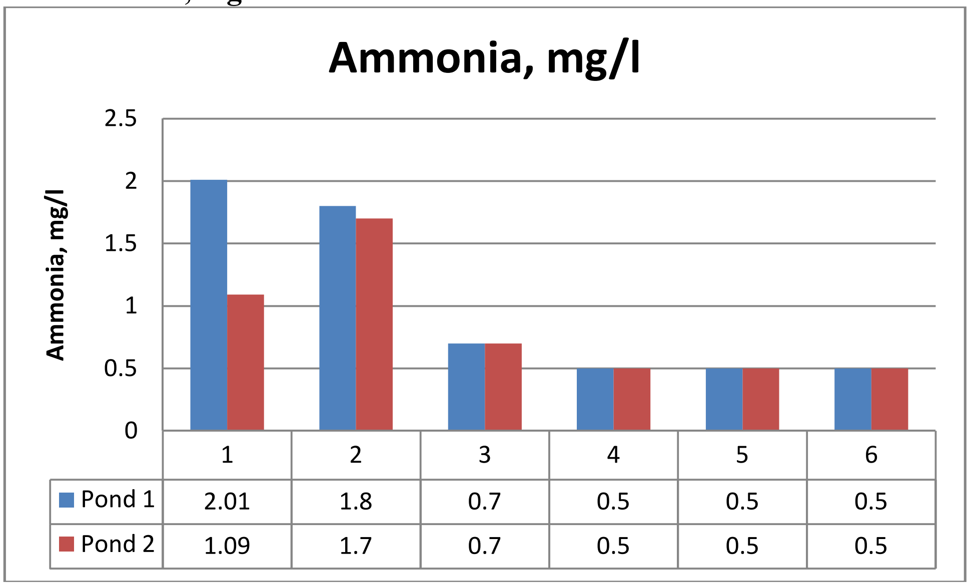
8. Phosphorus, mg/l



Discussion

Initially the water collected from kitchen drainage was tested for Phosphorus then further the tests performed were for the waste water after addition of duckweed. It was observed that the value of phosphorus has decreased by 40% to 1.14 mg/l in case of pond-1 and by 36.11% to 1.15 mg/l in case of pond-2 in the course of four months after addition of duckweed to the waste water.

9. Ammonia, mg/l



Discussion

Initially the water collected from kitchen drainage was tested for Ammonia then further the tests performed were for the waste water after addition of duckweed. It was observed that the value of Ammonia has decreased by 75.12% to 0.5 mg/l in case of pond-1 and by 54.12% to 0.5 mg/l in case of pond-2 in the course of four months after addition of duckweed to the waste water

CHAPTER 5 CONCLUSIONS

The conclusions from the work carried out in the course of four months after addition of duckweed to the waste water are:-

- The value of pH has decreased by 32.6% to 7.8 in case of pond-1 and by 32.05% to 7.8 in case of pond-2 .
- The value of turbidity has decreased by 4.19% to 160 NTU in case of pond-1 and by 15.29% to 144 NTU in case of pond-2.
- The value of Total Suspended solids has decreased by 12.38% to 92 mg/l in case of pond-1 and by 15.09% to 90mg/l in case of pond-2.
- The value of COD has decreased by 47.3% to 153 mg/l in case of pond-1 and by 46.07% to 151mg/l in case of pond-2.
- The value of BOD has decreased by 5.16% to 55 mg/l in case of pond-1 and by 59.52% to 51mg/l in case of pond-2.
- The value of DO has increased by 44.23% to 7.5 mg/l in case of pond-1 and by 41.50% to 7.5 mg/l in case of pond-2.
- The value of total nitrogen has decreased by 49.23% to 33 mg/l in case of pond-1 and by 52.94% to 32 mg/l in case of pond-2.
- The value of Ammonia has decreased by 75.12% to 0.5 mg/l in case of pond-1 and by 54.12% to 0.5 mg/l in case of pond-2

It was clearly observed that addition of duckweed to waste water has improved the water quality.

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