Effect of Nutrient Concentration and pH on Growth and Nutrient Removal Efficiency of Duckweed (Lemna Minor) From Natural Solid Waste Leachate

Jamshaid Iqbal
Institute of Environmental Sciences and Engineering,
National University of Sciences and Technology
Islamabad, Pakistan
jamshaidiqbal88@yahoo.com

Dr. Muhammad Anwar Baig
Institute of Environmental Sciences and Engineering,
National University of Sciences and Technology
Islamabad, Pakistan

Abstract— **This study aims to investigate the effect of nutrient concentration and pH of leachate on growth and nutrient removal efficiency of duckweed (Lemna minor). A batch experiment was conducted using pH range of 4-10 and two initial leachate dilutions with nutrient concentrations of N (90 and 20 mg L^{-1}) and P (76 and 16 mg L^{-1}) and effect of pH and initial nitrogen (N) and phosphorous (P) contents of natural leachate was investigated on growth and nutrient removal efficiency of Lemna minor. Nutrient removal rates of duckweed increase with an increase in initial nutrient concentration of leachate at all pH levels. At both leachate dilutions, pH range of 6-8 with an optimum of 7.1 is good for nutrient removal efficiency of duckweed from leachate. The highest rates of nitrogen (1.22 g m^{-2} day^{-1}) and phosphorous (0.95 g m-2 day-1) removal were achieved from more concentrated leachate at pH 7.1. Growth rate of duckweed decreases with an increase in initial nutrient concentration of leachate at all pH levels. Maximum growth rate of duckweed (19.6 g m2 day-1) was achieved at pH 7.1 from less concentrated leachate. Nitrogen and phosphorous uptake in duckweed biomass was higher in less concentrated leachate at all pH values. Optimum pH for N and P uptake by Lemna minor is 7.1 at both leachate dilutions. At this pH duckweed showed 94 % and 91 % uptake of N and P respectively from less concentrated leachate.**

Key Words: **Leachate, Duckweed, Lemna Minor, Nutrients, Ph, Removal Rate, Growth Rate.**

I. INTRODUCTION

Leachate is the high strength wastewater. At open waste dumping sites it is produced by percolation of rainwater through solid waste layers [1]. Various physic-chemical and bio-chemical processes in solid waste transfer variety of pollutants from waste streams into percolating rain water [2]. A typical leachate contains high amounts of recalcitrant substances, such as humic and fulvic acids, xenobiotics and pesticides, heavy metals and inorganic macro constituents (Ca, Mg, K, Na, NH4, Cl, HCO3 and SO4 etc.) [3,4]. Unattended leachate poses serious environmental problems such as contamination of surface and ground water, soil contamination and direct and indirect hazards for human health, flora and fauna and ecosystems [5,6].

Nutrients content of leachate may be as high as 13,000 mgL^{-1} of organic nitrogen [6], up to 400-3000 mgL^{-1} of ammonia-nitrogen and 3000 mg L^{-1} of phosphate [7, 8]. In Pakistan, concentrations of nitrogen and phosphorous in leachate is usually higher than national environmental standards [9]. By systematic planning and conditions optimization, the high nutrient content of leachate makes it the favored media for growth of aquatic plants. Aquatic plants convert nutrients in growth media into valuable plant biomass making full use of the postharvest biomass as animal feed, fertilizer and for production of protein rich byproducts [10].

Duckweed is amongst the promising aquatic plants having ability to absorb large amounts of nutrients from eutrophicated wastewater and has high growth rates [11,12,13]. Duckweed is a small floating macrophyte belonging to family *Lemnaceae* of monocotyledon plants. Duckweed has 37 species belonging to 4 genera (*Lemna, Spirodela, Wolffia and Wolffiella)* [14]. It is reported that duckweed based swine lagoon treatment system can remove up to 83.7% and 89.4% of total nitrogen (TN) and total phosphorus (TP) respectively from the media [15]. High level of nutrients tolerance in duckweed is of particular importance for treatment of high strength leachate. *Lemna minor* specie of duckweed has enormous potential of nutrients removal from wastewaters of high strengths [16]. Cheng et al [17] has reported a growth rate of *L. minor* close to 29 g m-2 day-1 and Total Kjeldahl Nitrogen (TKN) and Total Phosphorous (TP) uptake of 90 % and 88.6 % respectively from high strength swine lagoon.

pH is one of the important environmental factors affecting the uptake of chemicals and their distribution in living plants [18]. The pH of the growth medium determines the ratio between the $NH4^+$ (preferred form of nitrogen for duckweed) and un-dissociated NH3 [19]. Some researchers have investigated the effect of pH on duckweed growth using artificial growth media under artificial conditions of light intensity, temperature and humidity [20]. However, the use of natural leachate for duckweed growth under the natural climatic conditions is least explored area so far

IJHM

This study investigates the effect of pH and initial concentrations of nitrogen and phosphorous on nutrient removal and growth of duckweed (*Lemna minor*) grown on natural leachate under the natural climatic conditions of Islamabad, Pakistan. Study provides an input to design the duckweed based leachate treatment system studying the nutrient removal and growth dynamics of duckweed on natural leachate under the natural climatic conditions.

II. MATERIALS AND METHODS

A. Leachate

Leachate used in this research was prepared by the processing of fresh solid waste collected from various residential, commercial and industrial areas of Islamabad and Rawalpindi, Pakistan. About 100 to 120 kg fresh solid waste from each site was collected from pre-determined lowest points at the depths of 0.5 m to 1.5 m [21]. Collected samples were mixed in a plastic tank having an internal diameter of about 1.5m and height of about 1.8 m. A sieve (pore size 1mm) was fixed at an internal height of 10 cm of the plastic tank. Thorough shaking was applied to well mix the waste and achieve a homogenized sample. The homogenized waste was showered with tap water and maintained for 60 days after which, the leachate was collected from bottom outlet. Solid waste was again mixed thoroughly and showered with water. Afterwards, the leachate was collected three times at an interval of 10 days each. Leachate collected from various runs was mixed to form single homogenized sample to be used for this research.

B. Duckweed

Duckweed (*L. minor)* was collected from wastewater pond in Islamabad, Pakistan. Prior to grow on leachate, duckweed was repeatedly washed with excess tap water to remove bacteria, algae and other unwanted compounds.

C. Experimental Setup

A batch experiment was conducted using two initial dilutions of leachate: i) leachate/water: 50/50 % (N: 90 mg L^{-1}, P: 76 mg L^{-1}, COD: 2,685 mg L^{-1}) and; ii) leachate/water: 10/90 % (N: 20 mg L^{-1}, P: 16 mg L^{-1}, COD: 510 mg L^{-1}). Seven initial pH levels of leachate (4, 5, 6, 7, 8, 9, and 10) were adjusted for each leachate dilution and duckweed growth and nutrient removal and absorption by duckweed were determined at each pH. About 50 mg initial fresh mass of duckweed was used. Duckweed was grown in plastic containers of 300 ml capacity. 250 ml of initial volume of leachate was used in each container at the depth of 9.5 cm. Surface area of each container was 25.8cm2.

For each leachate dilution, 28 containers were used. Out of these, 21 containers had duckweed cultures with each pH level from 4-10 in triplicates. Seven control containers at each pH were without duckweed. Duckweed containers were placed within an iron rack in open environment at Institute of Environmental Sciences and Engineering (IESE), National University of Sciences and Technology, Islamabad, Pakistan. Data related to ambient air temperature, solar radiations and day lengths was obtained from Pakistan Metrological Department.

An experiment lasted for 22 days, during which the nutrients concentration of leachates and duckweed and dry weight of duckweed at both leachate dilutions and each pH level was determined at the start and end of the experiment. The pH was measured every day and subsequently adjusted to the initial conditions with 1 M NaOH or HCL solutions.

The average pH during a particular day was assumed to be the average of pH measured just before the pH adjustment, and the pH that was set. The average pH for the total period was calculated by taking the average of the daily average pH values, for the triplicate containers. The pH range was defined as the range between the maximum and minimum daily average values. Average ambient air temperature, solar radiations and day lengths during the experiment was 37.1 ^{0}C, 4.3-4.9 KWh m^{-2} day^{-1} and 14 hours respectively.

D. Laboratory Analysis

Samples from the leachate were analyzed for TKN, NH4-N, TP and o-PO4-P. The dry weight of duckweed was measured after drying the plants at 70 0C until constant weight [22]. Dry biomass of duckweed was analyzed for TKN and TP contents. Chemical analyses were performed using the standard methods of American Public Health Association [23] and US-EPA [24].

E. Statistical Analysis

Measured nutrient removal rates, duckweed growth rates and nutrient uptake by duckweed were evaluated using analysis of variance. The level of statistical significance was set at $P<0.05$. Differences between groups with respect to pH values were assessed by one-way analysis of variance (ANOVA) and differences within groups were further analyzed by all pair wise comparison test at $\alpha=0.05$. All statistical analysis was performed using Statistix-8.1 software and MS excel.

III. RESULTS AND DISCUSSION

Leachate with seven initial pH levels (4, 5, 6, 7, 8, 9 and 10) was used as medium for duckweed growth. Initial concentrations of nutrients in each leachate dilution and in duckweed dry mass were determined (Table 1). Considerable fluctuation in pH was observed in each container despite daily pH adjustment. Table 2 shows the average pH and ranges observed during the experimental period.

At pH 4 (average 3.6) almost all duckweed biomass was dead in both leachate dilutions at the sixth day of experiment. At extremely low pH values electrochemical gradient across plasma membrane is decreased due to an increased influx of H+ ions which is toxic for the growth of floating aquatic plants [25]. At pH 5 (average 4.5), duckweed showed stunted growth and fronds started to become yellowish and wrinkled. Caicedo et al [19] reported that an acidic media with pH less than 5 has direct detrimental effects on physiology of duckweed.

IJHS

A. Nutrient Removal

Nutrient removal rates in both leachate dilutions increase with increasing pH of the media until the maximum rate of removal at pH of 7.1; after which removal rates begin to

decrease in alkaline range but still higher than acidic pH ranges of leachate (Table 3). Overall rate of nutrient removal in both leachate dilutions were higher at neutral to slightly basic pH in the range of 7.1 to 8.1. It is consistent with the duckweed growth rates and nutrient uptake by duckweed which is also higher at this pH range (Fig. 1 and 2). Overall rates of nutrient removal were higher in 50 % leachate dilution as compared to less concentrated (10 %) leachate at all pH levels. This is probably because of microbial activities which were higher in more concentrated leachate. Maximum rates of nutrients removal in 50 % leachate dilution was; TKN: 1.22 g $m^{-2}day^{-1}$, NH_4 –N: 0.79 g $m^{-2}day^{-1}$, TP: 0.95 g $m^{-2}day^{-1}$ and o-PO_4-P: 0.19 g $m^{-2}day^{-1}$. From 10 % leachate dilution, maximum TKN removal (0.27 g $m^{-2}day^{-1}$) was achieved at average pH 8.1. Whereas, the maximum removal of NH_4 –N (0.16 g $m^{-2}day^{-1}$), TP (0.21 g $m^{-2}day^{-1}$) and o-PO_4-P (0.06 g $m^{-2}day^{-1}$) from 10 % leachate was achieved at average pH of 7.1 (Table 3).

At pH range of 7.1-8.1, nitrification and de-nitrification seems to have significant contribution in nitrogen removal from more concentrated leachate media. Effect of nitrification and de-nitrification was less significant in 10 % leachate dilution, where, most of the nitrogen removed from leachate was absorbed by duckweed at same pH range of 7.1-8.1. It shows that nitrification and de-nitrification processes are more prominent in concentrated leachate media as compared to the less concentrated leachate.

NH_4-N is the preferred form of nitrogen uptake by duckweed hence maximum removal of NH_4-N was accounted for uptake into duckweed biomass which is increased with an increase in pH from acidic to more favorable neutral pH range for duckweed growth.

Decomposition of organically and inorganically bounded phosphorous increases with an increase in pH and is highest at neutral pH, resulting in highest removal rate of TP and uptake by duckweed at pH 7.1. In addition to uptake by duckweed biomass, some of the ortho-phosphate-P removal may also have occurred by microbial assimilation which increases with the increase in pH of the leachate media up to pH 7 which is more favorable pH for microbial growth and assimilation of ortho-phosphate [26].

Table I: Initial variable for experiments on nutrient removal from natural leachate by duckweed, *Lemna minor*, duckweed growth and nutrient absorption by duckweed under the natural climatic conditions in Islamabad, Pakistan

Initial pH	Leachate Concentration	Nutrient concentration in leachate (mgL^{-1})				Nutrient concentration in duckweed (mg g^{-1} DM)		Duckweed dry mass (mg)
		TKN	NH_4-N	TP	o-PO_4-P	N	P	4.5
4, 5, 6, 7, 8, 9, 10	50 %	90	52	76	15	57.6	15	
	10 %	20	10	16	4			

Table II: Average pH values (mean ± SD, n=3) and ranges observed in the natural leachate media

Initial pH	Average	Range
4	3.6±0.1	2.9-4
5	4.5±0.2	3.3-5.1
6	5.5±0.3	4.8-6
7	6.0±0.1	5.4-7
8	7.1±0.2	5.9-8
9	8.1±0.2	6.9-9
10	8.6±0.1	8.4-10

IJHS

Table III: Rate of nutrient removal from 50 % and 10 % natural leachate dilutions by duckweed, Lemna. minor (mean ± SD, n=3) at various average pH levels

Leachate dilution	Average pH	Nutrient Removal Rates (g m^{-2} day^{-1})			
		TKN	**NH4-N**	**TP**	**o-PO4-P**
50 % Leachate	4.5	0.41 ± 0.007e	0.26 ± 0.005f	0.30 ±0.007f	0.04 ± 0.002c
	5.5	0.71 ± 0.014d	0.50 ± 0.011e	0.42 ± 0.011e	0.15 ± 0.008b
	6.0	0.93 ± 0.072c	0.70 ± 0.005c	0.65 ± 0.001d	0.19 ± 0.024a
	7.1	1.22 ± 0.011a	0.79 ± 0.004a	0.95 ± 0.002a	0.19 ± 0.007a
	8.1	1.05 ± 0.007b	0.73 ± 0.028b	0.86 ± 0.024b	0.16 ± 0.009b
	8.6	0.93 ± 0.003c	0.68 ± 0.008d	0.79 ± 0.025c	0.15 ± 0.006b
	LSD value	**0.0548**	**0.0226**	**0.0241**	**0.0183**
10 % Leachate	4.5	0.03 ± 0.000e	0.02 ± 0.002d	0.01 ± 0.001e	0.01 ± 0.001d
	5.5	0.12 ± 0.001d	0.08 ± 0.001c	0.06 ± 0.001d	0.03 ± 0.003c
	6.0	0.24 ± 0.002b	0.13 ± 0.000b	0.14 ± 0.002b	0.05 ± 0.007b
	7.1	0.26 ± 0.006a	0.16 ± 0.006a	0.21 ± 0.004a	0.06 ± 0.001a
	8.1	0.27 ± 0.007a	0.15 ± 0.001a	0.14 ± 0.001b	0.05 ± 0.001b
	8.6	0.22 ± 0.001c	0.15 ± 0.001a	0.13 ± 0.003c	0.05 ± 0.002b
	LSD value	**0.0111**	**0.0073**	**0.0059**	**0.0059**

Note: Different letters in the same column indicate statistical significance at $\alpha = 0.05$. TKN = Total kjeldahl nitrogen; NH4-N = Ammonium-nitrogen; TP = Total phosphorus; o-PO4-P = Orthophosphat

IJHS

B. Duckweed growth

pH has significant effect on growth of duckweed at both initial concentrations of nutrients in natural leachate. Significant increase in duckweed growth rate was observed with an increase in pH up to 7.1 after which growth rate started decline. Overall, pH range of 7.1 to 8.1 was found good for duckweed growth at both leachate dilutions. Overall growth rates of *Lemna minor* were higher at less concentrated leachate at all pH levels (Fig. 1).

Overall growth rates of *Lemna minor* were higher at less concentrated leachate at all pH levels (Fig. 1). It indicates the high rate of microbial activity in more concentrated leachate which removed large amount of nutrients from leachate without duckweed uptake. Maximum growth rate of duckweed at pH 7.1 was 19.6 g m^2 day^{-1} at 10 % leachate and 13.7 g m^2 day^{-1} at 50 % leachate dilution. Many researchers have reported that most of the duckweed species including *Lemna minor* show better growth at pH 7 of the growth media which is also consistent with the findings of this study [19, 27]. At pH greater than 7 Inhibitory action of ammonia was more prominent resulting in decreased growth rate of duckweed.

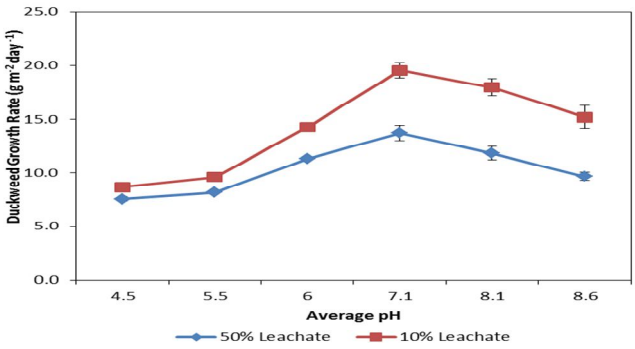

Fig. 1: Growth rates of *Lemna minor* (mean ± SD, n=3) at 50 % and 10 % natural leachate dilutions and six average pH values

C. Nitrogen and phosphorous uptake by duckweed

Figure 2 (a) and (b) show the percentage of total removed nitrogen and phosphorous absorbed by duckweed biomass at 50 % and 10 % leachate concentrations respectively. Overall nutrient uptake by duckweed is higher at less concentrated leachate at all pH levels. It agrees with duckweed growth rate which is higher at less concentrated leachate. It seems that more concentrated growth media may be more favorable for microbial growth than to duckweed growth [17]. Under the natural conditions, nitrogen assimilation by algae and microbes was also probably higher in more concentrated leachate resulting in less absorption of total nitrogen by duckweed.

At both leachate dilutions maximum amount of nitrogen was absorbed by duckweed at pH 7.1 (76 % of total removed from 50 % leachate and 94 % of total removed from 10 % leachate). At pH 7.1, relatively larger amount of NH_4–N is available for uptake by duckweed. Phosphorous uptake by duckweed followed the similar pattern as of nitrogen.

IJHS

Maximum P uptake at both leachate dilutions was observed at pH 7.1 (71 % at 50 % leachate and 91 % at 10 % leachate dilution) [Fig 2 (a) and (b)].

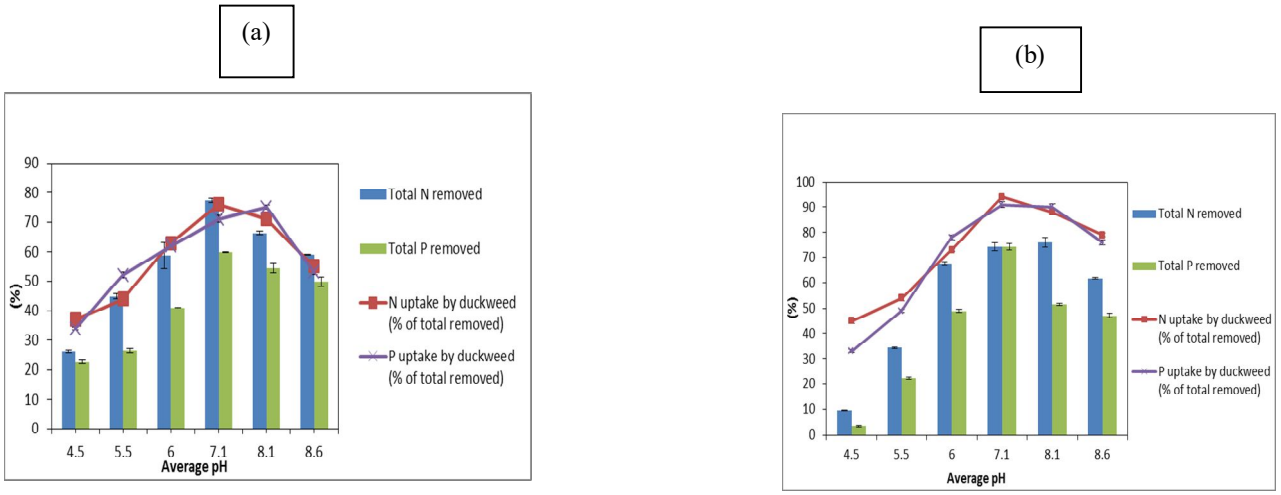

Fig. 2: Uptake of nitrogen and phosphorous (mean ± SD, n=3) by Lemna minor from (a) 50 % natural leachate an (b) 10 % leachate at various average pH levels

IV. CONCLUSIONS

Lemna minor can tolerate larger fluctuations in pH of the natural leachate under natural climatic conditions. Nutrients removal rates from natural leachate increase with increasing the initial concentrations of nutrient in leachate media at all pH levels. A pH range of 7.1-8.1 was found good for nutrient removal from natural leachate at both leachate dilutions. From 50 % leachate the highest rates of nitrogen (1.22 g m^{-2} day^{-1}) and phosphorous (0.95 g m^{-2} day^{-1}) removal was achieved at pH 7.1 while from 10 % leachate the highest rate of nitrogen removal (0.27 g m^{-2} day^{-1}) was achieved at pH 8.1 and highest rate of phosphorous removal (0.21 g m^{-2} day^{-1}) was achieved at pH 7.1.

Duckweed showed better growth at less concentrated natural leachate at all initial pH levels of leachate. A pH range of 6 to 8 is better for duckweed growth with an optimum of 7.1. Maximum growth rate of duckweed was 19.6 g m^2 day^{-1} and 13.7 g m^2 day^{-1}at 10 % and 50 % leachate dilutions respectively. Nitrogen and phosphorous uptake by duckweed was higher in less concentrated leachate at all pH values. Optimum pH for N and P uptake by duckweed is 7.1 at both leachate dilutions. At this pH duckweed uptake 76 % and 71 % of total removed N and P respectively from 50 % natural leachate dilution and 94 % and 91 % respectively from 10 % leachate dilution. On the whole, less concentrated leachate and a neutral to slightly basic pH is more favorable for duckweed growth and its efficiency to uptake nutrients from natural leachate under the natural climatic conditions.

ACKNOWLEDGMENT

Authors are grateful to Higher Education Commission of Pakistan for financial support to accomplish this research.

REFERENCES

[1] G. Kalcíková, M. Vávrová J., Zagorc-Koncan, A. Zgajnar and A. Gotvajn, "Seasonal variations in municipal landfill leachate quality", Management of Environmental Quality, vol. 22(5), pp. 612, 2011.

[2] P. Kjeldsen, M.A. Barlaz, A.P. Rooker, A. Baun, A. Ledin and T.H. Christensen, "Present and long-term composition of MSW landfill leachate: a review", Critical reviews in environmental science and technology, vol. 32(4), pp. 297. 2002.

[3] T.H. Christensen, P. Kjeldsen, P.L. Bjerg, D.L. Jensen, J.B. Christensen, A. Baun and G. Heron, "Biogeochemistry of landfill leachate plumes," Applied geochemistry, vol. 16(7), pp. 659-718, 2001.

[4] C.B. Öman, and C. Junestedt, "Chemical characterization of landfill leachates–400 parameters and compounds," Waste management, vol. 28(10), pp. 1876-1891, 2008.

[5] O. Ohwoghere–Asuma and K.E. Aweto, "Leachate characterization and assessment of groundwater and surface water qualities near Municipal solid waste dump site in Effurun, delta State, Nigeria," Journal of Environment and Earth Science, vol. 3(9), pp. 126-134, 2013.

[6] C.O. Akinbile, M.S. Yusoff and A.A. Zuki, "Landfill leachate treatment using sub surface flow constructed

IJHS

wetland by Cyperus haspan," Waste management, vol. 32(7), pp. 1387-1393, 2012.
[7] [7] H. Robinson, "The composition of leachates from very large landfills: an international review," Communications in waste and resource management, vo. 8(1), pp. 19-32, 2007.
[8] S.Q. Aziz, H.A. Aziz, M.S. Yusoff and M.J. Bashir," Landfill leachate treatment using powdered activated carbon augmented sequencing batch reactor (SBR) process: Optimization by response surface methodology," Journal of Hazardous Materials, vol. 189(1), pp. 404-413, 2011.
[9] H. Iqbal, M. Anwar Baig, M. Usman Hanif, S. Usman Ali and M. Flury, "Leaching of Metals, Organic Carbon and Nutrients from Municipal Waste under Semi-Arid Conditions," International Journal of Environmental Research, vol. 9(1), pp. 187-196, 2015.
[10] M. Ahmed, C.K. Hasan, H. Rahman, M.A. Hossain and S.A. Uddin, "Prospects of Using Wastewater as a Resource-Nutrient Recovery and Energy Generation," American Journal of Environmental Sciences, vol. 11(2), pp. 99, 2015.
[11] Z. Zhao, H. Shi, Y. Liu, Y, H. Zhao, H. Su, M. Wang and Y. Zhao, "The influence of duckweed species diversity on biomass productivity and nutrient removal efficiency in swine wastewater.," Bioresource technology, vol. 167, pp. 383-389, 2014.
[12] X. Ge, N. Zhang, G.C. Phillips and J. Xu, "Growing Lemna minor in agricultural wastewater and converting the duckweed biomass to ethanol," Bioresource technology, vol. 124, pp. 485-488, 2012.
[13] S. Soda, Y. Kawahata, Y. Takai, D. Mishima, M. Fujita and M. Ike, " Kinetics of nutrient removal and biomass production by duckweed Wolffia arrhiza in continuous-flow mesocosms," Ecological Engineering, vol. 57, pp. 210-215, 2013.
[14] J.J. Cheng and A.M. Stomp, "Growing duckweed to recover nutrients from wastewaters and for production of fuel ethanol and animal feed," Clean–Soil, Air, Water, vol. 37(1), pp. 17-26, 2009.
[15] J. Xu and G. Shen, "Growing duckweed in swine wastewater for nutrient recovery and biomass production," Bioresource technology, vol. 102(2), pp. 848-853, 2011.
[16] S.P.H. Wendeou, M.P. Aina, M. Crapper, E. Adjovi, E and D. Mama, "Influence of Salinity on Duckweed Growth and Duckweed Based Wastewater Treatment System," Journal of Water Resource and Protection, vol. 5(10), pp. 993, 2013.
[17] J. Cheng, L. Landesman, B.A. Bergmann, J.J. Classen, J.W. Howard and Y.T. Yamamoto, "Nutrient removal from swine lagoon liquid by Lemna minor 8627," Transactions of the ASAE, vol. 45(4), pp. 1003-1010, 2002.
[18] [18] F. Duman, O. Obali and D. Demirezen, D, "Seasonal changes of metal accumulation and distribution in shining pondweed (Potamogeton lucens)," Chemosphere, vol. 65(11), pp.2145-2151, 2006.
[19] J.R. Caicedo, N.P. Van der Steen, O. Arce and H.J. Gijzen, "Effect of total ammonia nitrogen concentration and pH on growth rates of duckweed (Spirodela polyrrhiza)," Water research, vol. 34(15), pp. 3829-3835, 2000.
[20] S. Körner, S.K. Das, S. Veenstra and J.E. Vermaat, "The effect of pH variation at the ammonium/ammonia equilibrium in wastewater and its toxicity to Lemna gibba," Aquatic botany, vol. 71(1), pp.71-78, 2001.
[21] S.O. Ojoawo, O.A. Agbede and A.Y. Sangodoyin,"Characterization of Dumpsite Leachate: Case Study of Ogbomosoland, South-Western Nigeria," Open Journal of Civil Engineering, vol. 2(01), pp. 33, 2012.
[22] J.E. Vermaat and K.M. Hanif, "Performance of common duckweed species (Lemnaceae) and the water fern Azolla on different types of waste water," Water Research, vol. 32(9), pp. 2576, 1998.
[23] APHA, "Standard Methods for the Examination of Water and Wastewater, 21st Edition," American Water Works Association/Environment Federation, Washington, 2005.
[24] EPA, "Methods for Chemical Analysis of Water and Waste," Environmental Protection Agency, Cincinnati, Ohio, USA.1983.
[25] M.M. Mufarrege, G.A. Di Luca, H.R. Hadad, and M.A. Maine, "Adaptability of Typha domingensis to high pH andsalinity," Ecotoxicology, vol. 20 (2), pp. 457-465, 2011.
[26] F. Al-Nozaily, G. Alaerts and S. Veenstra, " Performance of duckweed-covered sewage lagoons—II. Nitrogen and phosphorus balance and plant productivity," Water Research, vol. 34(10), pp. 2734-2741, 2000.
[27] E. Landolt and R. Kandeler, "Biosystematic investigations in the family of duckweeds (Lemnaceae), Vol. 4: The family of Lemnaceae-a monographic study, Vol. 2 1987.

IJHS