Research Journal of Chemical and Environmental Sciences
Res J. Chem. Environ. Sci. Vol 3 [2] April 2015: 15-21
Online ISSN 2321-1040
CODEN: RJCEA2 [USA]

Website: www.aelsindia.com/rjces.htm

RJCES

ORIGINAL ARTICLE

Aquatic Treatment Process Coupling Waste Stabilization Ponds with Duckweed (*Lemna Minor*) and Water Hyacinth (*Eichhornia Crassipes*) In the Sahel

AMADOU Haoua*[1], LAOUALI Mahaman Sani[1], MANZOLA Abdou Salam[1], Martin SEIDL[2]
[1] Laboratoire de Chimie de l'eau, Faculté des sciences et Techniques Université Abdou Moumouni de Niamey, Bp 10662 Niamey-NIGER.
[2] Université Paris-Est, Cereve ENPC, UMR-MA102 -AgroParisTech, 6-8 ave B.Pascal, F77455 Marne la Vallée cedex 2, France.
*Corresponding Author: Phone: +00-227-96547254;
E-mail: haoua_amadou2000@yahoo.fr

ABSTRACT
The aim of the study was to verify if waste water could be satisfactorily treated in a pond system with continuous macrophyte harvesting. Two local aquatic plants, duckweed (Lemna minor) and water hyacinth (Eichhornia crassipes) were tested in a system of ponds using different hydraulic and BOD loadings. The results show a significant contribution of the water plants to the treatment process. At a production rate of 200 T-d.s./ha/year for water hyacinth and 20 T-d.s./ha/year for duckweed, a removal efficiency of more than 70% was achieved for S.S, COD and TNK. The hyacinth contributes already at low residence time (4 days) to suspended solid removal (80%), being almost two times more effective than classical ponds. Duckweed contributes better to the treatment when placed at the head rather than at the end of the treatment file. On the other hand only 20% of TNK can be removed with the biomass, 4times more for hyacinth than for duckweed. The contribution to the nitrogen removal is far more important in the open ponds. The same can be established for the pathogens, where the removal is far (100 fold) better in open ponds than in the duckweed ponds, most likely due to better light penetration. A good treatment efficiency and satisfactory level of biomass production can be better achieved if different subsystems are combined. The application of water plants in ponds is only useful if the produced biomass is harvested.
Keywords: *Waste water, treatment, stabilization ponds, nutrient reuse, duckweed, water hyacinth.*

Received 22.01.2015 Accepted 10.03.2015

INTRODUCTION

Waste stabilization ponds (WSPs) are widely used as natural treatment systems because of their low cost and simplicity of construction, operation, and maintenance. However, the major operational problem encountered in WSPs is the excessive discharge of particles in the effluent caused by algal activity especially during the summer season. Therefore, it is essential to polish the effluent from the WSPs by removing over-discharged suspended solids (SS), biochemical oxygen demand (BOD), and nutrients. An effective method to separate algae and other particles from the effluent of WSPs is the use of water hyacinth ponds (WHPs). The WHPs can remove particles through sedimentation and filtration (due to the dense root system of the water hyacinths). Their leaves and stems help control algal growth by preventing sunlight from reaching the water surface **[1].**

Beyond their ability to remove suspended matter from the wastewater stream, several researchers, in their studies, have recognized the WSPs' role as an additional treatment step reducing organic matter and nutrients from an effluent stream **[2- 4].**

Water hyacinths (*Eichhornia crassipes)* has been selected as one important kind of water plant cultured in the experimental area for improving water quality, since it can grow quickly and take up a lot of nutrients from water, such as phosphorus, nitrogen **[5-9].** It is a kind of free-floating water plant whose leaves are above the water surface. It reproduces rapidly by budding. Water hyacinths in the water surface can minimize light penetration to the water column below and therefore phytoplankton is outcompeted. This is a favorable situation from the point of ecological management as the nutrients are concentrated in water hyacinths instead of in phytoplankton, because water hyacinths can be more easily harvested with nets or forks and used as feed for pigs and fish. Besides taking up nutrients, water hyacinths have also been reported to take up heavy metal ions [**10]** from the water and to metabolize organic substances such as phenol **[6 -7]**.

Other common water plant is duckweed (*Lemna minor*), studied for its ability to withdraw nutrients and heavy metals. The major advantages of duckweeds are their small size and their natural presence in almost all water ecosystems, while their major disadvantages have been their shallow root systems and wind sensitivity. Duckweed was successfully used as animal feed in poultry farming and aquaculture [11].

The purposes of this study were: 1) to test the capacity of water hyacinth (E. crassipes) to purify domestic sewage under arid climate of the city of Niamey (Niger) and 2) to compare the performance of duckweed in two different position in the treatment process and to find the related range of organic loads in which duckweed may grow.

MATERIALS AND METHODS

Pilot plant

The treatment plant of the Abdou Moumouni University Faculty of Sciences in Niamey (Figure 1) treats the University main campus and restaurant wastewater. This plant is composed of 3 lines of treatment, each composed of 6 trapezoid basins with an area of 14 m^2, one meter depth and an approximate volume of 7 m^3.

Analysis

Classical parameters of water quality like, conductivity, DBO, DCO, N, P and Coliforms were estimated according to the French standards (AFNOR) and the standards of AWWA for the raw waste water and the effluent of each pond, where by total and dissolved fractions were measured. The dissolved fraction was obtained by gentle vacuum filtration through Whatman GF/F glass fibre filter. The effluents of each pond were sampled once a week during a period of six month.

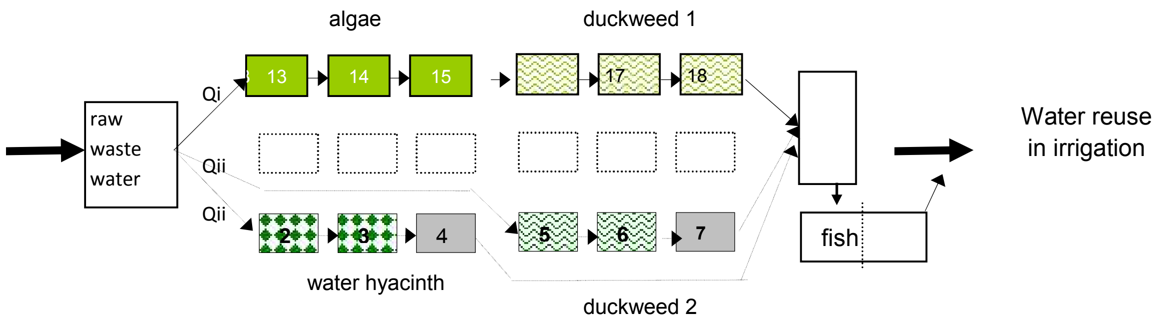

Figure 1: The overall set-up of the experimental treatment plant

The treatment efficiency was studied from February to June, in three series of ponds (figure 1):

- ✓ The first serie (N° 13 -18) was composed of 3 ponds with algae followed by 3 ponds covered with duckweed.
- ✓ The second serie (N° 2-4) was a set of 2 ponds covered by water hyacinth terminated with a polishing step.
- ✓ The third serie (N° 5-7) was a set of 2 ponds covered (again) with duckweed terminated with a polishing pond.

The pilot (Figure 1) was fed during the day by raw waste water from the university campus. The flow was controlled by a pump filling a storage tank five times a day from 7 AM to 7 PM. 3 diverters were calibrated to give the combined treatment line (n° 13-18) about 3.5 m^3/day and the two other lines each about 1.5 m^3/day.

Duckweed (*Lemna minor*) and water hyacinth (*Eichornia crassipes*) were collected from water ponds near the Niger River, where they grow naturally. The duckweed production was estimated 3 times a week. The harvested biomass was weighed to obtain the wet weight; a small part was used for the estimation of standard parameters like solids, N, P and pathogen contents. The determination of N-content was done after drying at 60°C by the method of Kjeldahl nitrogen. The average standing crop was maintained for all duckweed basins at 200 gram fresh weight a square meter.

RESULTS

Over the whole experimental period the treatment efficiency for solids was significantly better for the ponds using macrophytes (Figure 2). The efficiency was not only better but the effluent levels were also more constant. The algae or not cover ponds were more sensible to temperature and load fluctuations. The algae pond showed high oscillations due to periods with "bulking" and phytoplankton bloom. From the composition of organic matter (Figure 3) we can see that the biodegradability (expressed as BOD/COD) of the waste water passing through the hyacinth pond is not significantly modified, about 60 % remains rapidly biodegradable (expressed as BOD5).

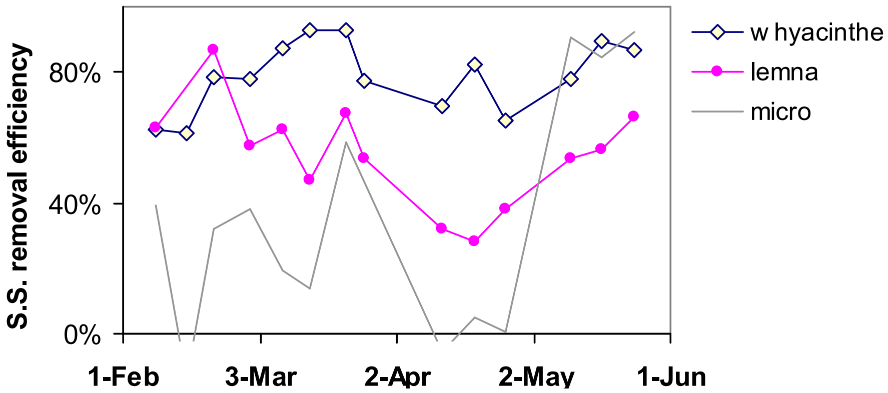

Figure 2: Evolution of the suspended solid removal efficiency for macrophytes (pond1) and algae (ponds2) corresponding to approximate residence time of 4 days.

The high level of solid removal indicates that an important fraction of particulate pollution will be removed most probably by settling. Indeed 90% of the particulate COD is removed against only 30% of the dissolved. The elimination of solids seems to be more in the mineral fraction than in the organic, which seems to be confirmed by the degradability of the solids expressed as pBOD/SS which is 57% at the entrance of the hyacinth pond and only 41% at the exit. The main difference between duckweed and hyacinth was less efficient in solid removal most probably due to the more developed hyacinth root zone. On other hand, the duckweed effluent shows very low levels of particulate biodegradable matter, suggesting its degradation.
Though the residence time for the algae pond was 25% shorter than for the macrophyte ponds, the treatment efficiency is appreciable and even better than that of duckweed (Figure 3). Compared to the macrophyte ponds, the particulate BOD5 in the algae pond remains high, probably due to presence of algae.

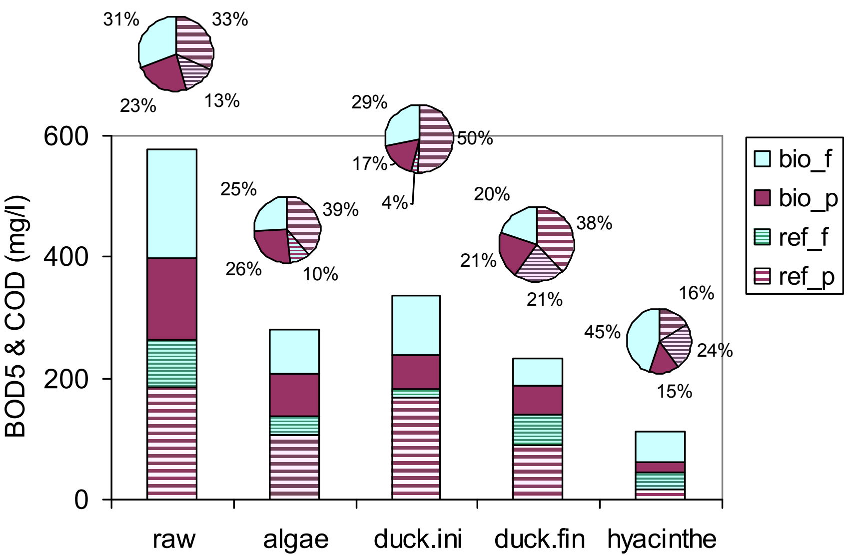

Figure 3: Composition of organic matter for raw waste water and after five (5) days of different treatments using average concentrations of COD and BOD. It's supposed that the level of COD (total) depends principally of organic matter, that the particulate fraction (p) is the difference between total and dissolved fraction (f) and that the refractory fraction (ref) is the difference between total and

biodegradable (bio) fraction measured as BOD5: bio_f=BOD5 filtered, bio_p=BOD5 particulate, ref_f=COD filtered - BOD5 filtered, ref_p=COD particulate - BOD5 particulate.

The lower efficiency was mostly due to lower residence time. If we look on the relation between residence time and the removal efficiency (Figure 4), we can see that for macrophyte covered ponds there was no improvement with longer residence time, while a significant improvement can be observed for ponds without macrophytes. Figure 4 shows average efficiencies calculated as mean from weekly in- and effluent data for each basin. To compare the efficiencies for the same residence time, linear regression was used to recalculate a theoretical efficiency for a residence time of 12 days, being the maximum residence time of each treatment line. The utilization of BOD5 is not 100% pertinent to compare the efficiencies between the different treatments because the composition of BOD5 is not constant through the algae line. The influent BOD5 corresponds to the organic matter issued from waste water, while the effluent BOD5 in was composed (principally) from algae or algae organic matter. For this reason aside BOD5 also COD and the particulate and dissolved fractions, were considered.

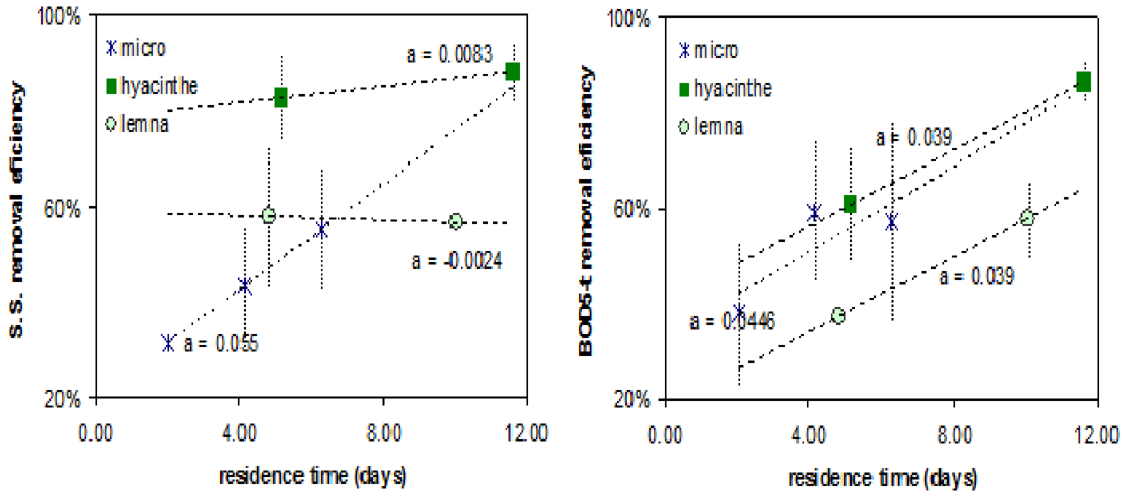

Figure 4: Mean of efficiencies observed during the experiment (7< n<15). The standard deviation (68% of observed values) is indicated by a vertical dash. The slope "a" gives a fraction of removal a day of residence time. A difference of less than 10% over the whole period (-0.008<a<0.008) was considered as not significant change for the experimental conditions used.

For suspended solids and COD-t the slope was significantly different for algae compared to macrophytes. For the efficiency of suspended solids removal an increase from 5 to 10 days of residence time does not have any effect contrary to algae. A hyacinth pond with 5 days detention time removes the same as algae ponds with 10 days of detention time (table 1). The removal efficiency for BOD, COD and TNK evolutes in the same manner for hyacinth and duckweed, though duckweed is less efficient. This tendency is the same for the dissolved fraction, though the efficiencies were slightly lower for the dissolved than the total concentration.

Table 1: Theoretical efficiency for a series of ponds with a residence time of 12 days calculated with linear regression from average removal efficiencies as showed in figure 3.Slope is given in % of removal a day.

C(mg/l)	**hyacinth**	std%	slope	**duckweed**	std%	slope	**algae**	std%	slope
SS	*88.3%*	*7.4*	<1	*56.4%*	*14.7*	<1	84.6%	19.5	5.5
BOD5-t	87.7%	7.7	3.9	65.6%	9.8	3.9	86.6%	16.9	4.6
COD-t	89.1%	4.6	2.8	56.6%	8.6	1.9	99.5%	12.2	7.4
TNK-N	71.1%	7.5	4.0	56.3%	7.7	3.2	70.1%	11.7	4.3

Position of the macrophyte in the treatment line

Another interesting aspect to evaluate is whether a macrophyte contributes in the same/ manner to the treatment exposed to raw or to pre-treated waste water. In figure 5 we can see the evolution of carbon (as COD) and nitrogen (as TNK) through a treatment file containing 3 ponds with algae followed by 3 pond containing duckweed (Figure 1). In figure 5, we observed that the dissolved COD remains the same after the second algae pond and does not change any more through the file. The contribution of duckweed is only significant in the nitrogen removal. Though the strongest nitrogen removal occurs in the algae ponds, the TNK concentration continues to fall down through the duckweed pond. If we look at the pathogen removal (Fecal coliforms), the tendency is comparable, about 3 log units in the algae ponds and only 1 log unit in the duckweed pond. This might be explained by less light penetration in the non-covered ponds.

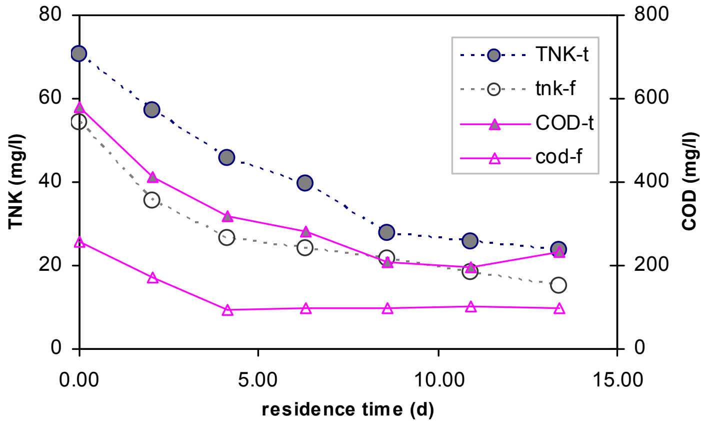

Figure 5: Evolution of the COD and TNK through a combined treatment file, 3 algae ponds followed by 3 duckweed ponds.

Table 2 gives a detailed comparison between the duckweed treatment efficiencies if used as initial or as a final treatment step. Though the residence time is higher for the experiment with duckweed in the "final" position, we remark that COD removal is almost insignificant contrary to the "initial" position. As stated before (figure 4a), in the "initial" position duckweed contributes to COD removal through improved sedimentation and through degradation of the dissolved "BOD5" fraction. After 6 days of pre-treatment this fraction is not any more present in the waste water.

Table 2: Concentration in mg/l of dissolved and particulate COD and TKN, and the removal efficiencies, for 2 different positions of duckweed within a line of waste water treatment by stabilization ponds. "Std"indicates the standard deviation, "t_R"stands for residence time in days.

duckweed treatment	fraction	COD (n=14) C_{IN}	C_{OUT}	R%	std	TKN (n=8) C_{IN}	C_{OUT}	R%	std
initial	filtered	258	108	63.4%		19.3	12.8	36.0%	
t_R =5.1d	particulate	359	227	45.8%		51.5	27.2	52.1%	
	total	617	335	**53.6%**	9.0%	70.8	40.0	**50.1%**	7.7%
	F/T	0.42	**0.32**			0.27	**0.32**		
final	filtered	100	96	16.0%		26.8	15.0	51.9%	
t_R =7.1d	particulate	174	138	25.4%		14.9	8.98	32.3%	
	total	280	234	**20.8%**	19%	41.8	23.5	**47.6%**	15%
	F/T	0.36	**0.41**			0.64	**0.64**		

If we look at the nitrogen we realize that the removal efficiencies are the same, though in the final position the TKN is mostly present in dissolved form as NH4, contrary in the initial position where the majority of TKN is in the particulate form. In the primary position duckweed contributes to the TKN removal through sedimentation like DCO and in both positions duckweed eliminates TKN through assimilation.

Figure 6 resumes the nitrogen transformations for all systems studied. Algae are the most performing, like the macrophytes, though in 40% less of time. The contribution of aquatic plants in the whole N cycle is less important than that of bacteria.

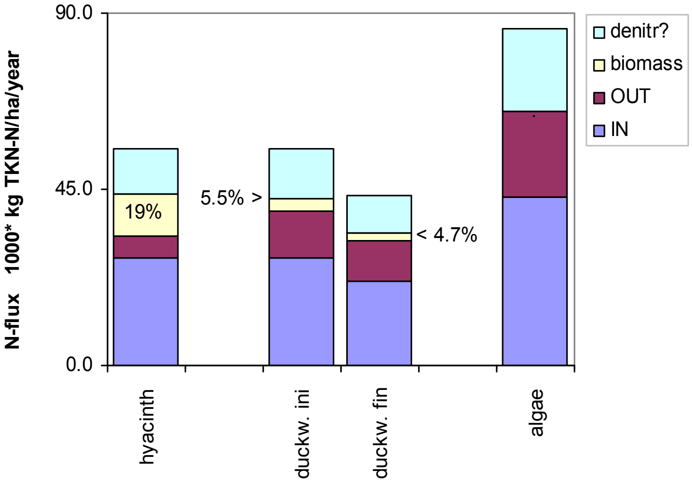

Figure 6: The Nitrogen fluxes from the different treatment lines related to the total treatment surface of each. The residence times were hyacinth 11.6 day, duckweed 10 day, duckweed final 7.5 day and algae 6.3 days.

DISCUSSIONS

Our results showed the feasibility of the wastewater treatment combined with aquatic plant production. The systems used, attains biomass production rates removal efficiencies for BOD and COD comparable to other aquatic plant systems in the literature [12- 14]. Only 3 to 4 m^2 were needed to treat an equivalent of habitant. The results show a significant contribution of the water plants to the treatment process. A removal efficiency of more than 80% was achieved for S.S, COD for water hyacinth and about 60% for the duckweed. A classical pond with algae needs a residence time almost two times higher to achieve the same removal. The solid removal in macrophyte ponds does not improve with increased residence time, an effect already observed for other plants in similar conditions **[15].** The main difference between duckweed and hyacinth is less efficient in solid removal most probably due to the more developed hyacinth root zone. On other hand, the duckweed effluent shows very low levels of particulate biodegradable matter, suggesting its degradation. The duckweed is 10 times less productive (20 T-d.s./ha/year) than the hyacinth, and converts 4 times less nitrogen in biomass. Though its advantages are multiple, it's easier to harvest, its biomass which contains 2 times more nitrogen, the plant can be used directly as fodder and is not invasive in natural environment **[16- 17].** In the primary position duckweed contributes to SS, DCO and TKN removal through sedimentation. In final position duckweed contributes only to TKN (NH4) elimination through assimilation. On the other hand the nitrogen removal is more important in the open ponds probably due to better nitrification/denitrification showing the preponderance of microbial transformations. The same can be established for the pathogens in open ponds, as their removal is far (100 fold) better in algae ponds than in the duckweed ponds.

The aquatic plants improve the treatment and if used it should be used at the head of treatment to enhance the pollutant removal by sedimentation. To remove also efficiently pathogen the macrophyte pond should be followed by algae ponds or a filter.

CONCLUSION

The concept of treating wastewater in water hyacinth ponds is receiving increased attention in warm climatic zones in various parts of the world. The efficiency of water hyacinth in wastewater treatment has been demonstrated in this study and Compared to water hyacinth, duckweed plays a less direct role in the treatment process because of its small size. Duckweed can be used in primary treatment of wastewater characterized by a low organic load. As with any other lagoon system, most of the biological activity in a duckweed system is caused by the microbial and other flora suspended in the water column.

The quality of the effluent from water hyacinth-based systems should be classified within category B according to WHO guidelines for crop irrigation. However, under the arid climatic conditions of Niamey, wastewater purification by the water hyacinth process is faced with two major problems in the summer period: water loss by evapotranspiration reaching 60%, and mosquito breeding.

REFERENCES

1. Kim, Y. and W. Kim, 2000. Roles of water hyacinths and their roots for reducing algal concentrations in the effluent from waste stabilization ponds. Water Res. 34 (1), 3285–3294.

2. Polprasert, C. and N.R. Khatiwada, 1998. An integrated kinetic model for water hyacinth ponds used for wastewater treatment. Water Res. 32 (1), 179–185.
3. Kim, Y. and D.L. Giokas, 2003. Design of the water hyacinth ponds for removing algal particles from waste stabilization ponds. Water Sci. Technol. 48 (11/12), 115–123.
4. Kim, Y. Giokas, D.L. Lee, J.W. and P.A. Paraskevas, 2006a. Potential of natural treatment systems for the reclamation of domestic sewage in irrigated agriculture. Desalination 189, 229–242.
5. Yan, J.S. 1986. The main principles and types of ecological engineering for the conversion of waste water into resource. Rural Eco-Environ. 4, 19–23.
6. Wu, Zh.-B. Qiu, Ch.-Q. Xia, Y.-Ch. and D.M. Wang, 1987a. A study on the purifying the Yanshan petroleum chemical industry waster water by using *Eichhornia crassipes* (Mart.) Solms, I. Dynamic simulation experiment. Acta Hydrobiol. Sinica 11 (2), 139–150.
7. Wu, Zh.-B. Qiu, Ch.-Q. Xia, Y.-Ch. and D.M. Wang, 1987b. A study on the purifying the Yanshan petroleum chemical industry waster water by using *Eichhornia crassipes* (Mart.) Solms, II. Stable purifying experiment. Acta Hydrobiol. Sinica 11 (4),299–308.
8. Zhang, Y.-Q. 1989. Effect of the carrying capacity of *Eichhornia crassipes* on its utilization and purification function. Rural Eco-Environ. 1, 40–43.
9. Dou, H.S. Pu, P.M. Zh, Sh.Zh. Hu, W.P. and Y. Pang, 1995. An experimental study on culture of *Eichhornia crassipes* (Mart.) Solms on open area of Taihu Lake. J. Plant Resources Environ. 4 (1), 54–60.
10. Dai, Q. Chen, Y. and Yu. Pi, 1991. Study on the accumulation amount of silver in waster water and its utilization by water hyacinth. Chin. J. Appl. Ecol. 2 (2), 159–167.
11. Seidl, M. Sani, L. Tahar, I. and J.M. Mouchel. 2003. Duckweed - Tilapia system : a possible way of ecological sanitation for developing countries. Proceedings of AGUA 2003: Multiple uses of water for life & sustainable development 29 septembre - 3 octobre 2003, Cartagena de Indias, Colombia.
12. Alaerts, G. J. Rahman, M. P. and P. Kelderman, 1996. Performance analysis of a full-scale duckweed-covered sewage lagoon water research: 1996, vol. 30, no 4, pp. 843 – 852.
13. Vermaat, J. E. and H.M. Khalid, 1998. Performance of common duckweed species (Lemnaceae) and the waterfern Azolla Filiculoides on different types of waste water Water research : 1998, vol. 32, no 9, pp. 2569 – 2576.
14. Steen, P. Brenner, A. and G. Oron, 1998. An integrated duckweed and algae pond system for nitrogen removal and renovation. Water.Sci. Tech. (38):335-343.
15. Koné, D. Seignez, C. and C. Holliger, 2002. Natural wastewater treatment by water lettuce for irrigation water reuse in Burkina Faso. In: 5th International IWA Specialist Group Conference on Waste Stabilization Ponds, Pond Technology for the new millennium, Auckland. IWA, NZWWA.2/2: 733-734.
16. Iqbal, S. 2001. Duckweed Aquaculture Potentials, Possibilities and Limitations for Combined Wastewater and Animal Feed Production in Developing Countries EAWAG SANDEC (http://www.sandec.ch/files/duckweed.pdf).
17. Oron, G. Porath, D. and H. Jansen, 1987. Performance of the duckweed speciaes Lemna gibba on municipal wastewater for effluent renovation and protein production Biotech.Bioeng 1987(29):258-267.

CITE THIS ARTICLE

AMADOU H, LAOUALI M S, MANZOLA A S, Martin S. Aquatic Treatment Process Coupling Waste Stabilization Ponds with Duckweed (*Lemna Minor*) and Water Hyacinth (*Eichhornia Crassipes*) In the Sahel. Res. J. Chem. Env. Sci. Vol 3 [2] April 2015. 15-21