Fishery Technology 60 (2023) : 8 - 14

Augmenting Aquaculture Production in Sewage-Fed Village Ponds through Regulated Growth of Water Hyacinth, *Eichhornia crassipes* (Mart.) Solms

Ajit Chaudhari*, Chandra Kanta Misra, Sunil Kumar S Ail, Rathindra Nath Mandal
ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar, Odisha, India

Abstract

The freshwater aquaculture activities in Gujarat State, India are mostly carried out in the village ponds leased to the fish farmers through the Village Pond Fisheries policy, 2003. Domestic sewage from households is continuously fed to the village ponds resulting in excessive growth of aquatic weeds. This study describes the effect of aquatic macrophyte, *Eichhornia crassipes* (Water hyacinth) management in sewage-fed aquaculture ponds in three districts of Gujarat namely Vadodara, Anand, and Kheda. Advanced fingerlings (yearlings) of Indian Major Carps and exotic carps (100-150 g) were stocked @ 5000 no./ha. *E. crassipes* was maintained at an extent of 5-10 % water area of the pond. Monitoring of water quality, growth, and health of fish were recorded bimonthly from three locations viz., the inlet of sewage entering to pond (L1), mid location of pond (L2), and the farthest location of pond (L3). The analysis of data showed that the water pH and dissolved oxygen showed an increasing trend at L2 and L3 locations when compared with L1 while other parameters such as total alkalinity, total hardness, total ammoniacal nitrogen, nitrite, nitrate, phosphate, BOD, COD, and TDS decreased. Fish production was estimated to be 3.1±0.17 MT/ha over a period of 8 months. This research will aid in the management of water quality in aquaculture ponds fed by sewage.

Keywords: Rural aquaculture, village pond, sewage-fed fisheries, water hyacinth

Received March 26, 2022; Revised 16 January 2023; Accepted 17 January 2023

**Email: chaudhari77@yahoo.com*

Introduction

Aquaculture production in inland water bodies is increasing day by day with increasing demand for animal protein. The share of freshwater aquaculture in the inland fisheries in India has increased to 80 % (DAHDF, 2017). In order to maximize production, more efficient use of unused and degraded water bodies is needed. Sewage-fed aquaculture is well developed in the outskirts of Kolkata city, which is a great success as a sustainable farming model. Several authors have worked on sewage-fed aquaculture and its role in crop farming, sustainable production, and combating environment pollution (Jana, 1998; Dasgupta et al., 2008; Adhikari et al., 2009; Azanu et al., 2016; Jana et al., 2018; Mandal et al., 2021). Kumar et al. (2015) emphasized the operation and management aspects of sewage-fed aquaculture in Sewage Treatment Plants (STPs). Jena et al. (2010) studied the water quality parameters by biological sewage treatment through duckweed cum fish culture. Although this technique of sewage-fed aquaculture is well practised in Kolkata, it has yet to be spread to other parts of India (Nandesha, 2002).

Gujarat has vast resources of Village ponds covering an area of 0.22 lakh ha (6860 no.), which holds immense potential for rural development through freshwater aquaculture. These ponds are leased to fish farmers through the Village Pond Fisheries Policy, 2003 for ten years (Ail et al., 2021). The productivity of these village ponds was one MT/ha (DAHDF, 2018). However, it is far below the actual potential due to their poor management. Domestic sewage generated in rural areas is released into most of the village ponds in Gujarat, which are used for bathing livestock, domestic purpose, and aquaculture. The release of domestic waste from the village households (including sewage, kitchen waste, and detergents) into ponds has negative effects on the water quality and productivity of ponds.

Aquatic weeds are classified into four life forms: emergent, submerged, rooted floating, and free-floating (Sculthorpe, 1967). All these aquatic plants are considered as weeds when they proliferate aggressively and thus infest any water body rendering itunsuitable for aquaculture (Mandal et al., 2021). Controlling aquatic weeds is difficult, especially when they proliferate in an ideal habitat. The more favourable the environment, the more rapidly aquatic weeds will spread. Excessive accumulation of organic waste leads to the eutrophication of any water body that, in turn, facilitates the growth of aquatic weeds. Even in sewage-fed aquaculture, the excess amounts of nutrients, which are deposited in the water body facilitate algal bloom making it unsuitable for fish culture (Mandal et al., 2018).

Despite all the drawbacks, aquatic plants also can play a role in converting water body back into a useful one in a controlled manner. *E. crassipes* was previously proven to capture a substantial amount of nutrients from sewage-fed ponds in a regulated manner (Mandal et al., 2015a; Mandal et al., 2015b). Sewage-fed ponds are made usable for aquaculture by using different aquatic plants by means of bio-remediation. This study was carried out with the objective of improving aquaculture production through management of *E. crassipes* in the domestic sewage-fed village ponds of Gujarat.

Material and Methods

The study was carried out in three districts of Gujarat state, India; Anand, Kheda, and Vadodara, where great potential exists for aquaculture in sewage-fed village ponds. Eight non-drainable sewage-fed village ponds were selected from each district. Domestic sewage from households was fed continuously into these village ponds. Pre-stocking operations included partial removal and/or growing of water hyacinth, *E. crassipes* covering up to 5 % of the water spread area of the pond at the inlet of sewage water into the pond, liming @ 200 kg/ha and stabilizing the pond for 15 days. Advanced fingerlings or yearlings of size 100-150 g were then stocked @ 5000/ha and were grown for eight months (October 2018 to June 2019). These sewage-fed fish ponds were stocked with Catla (*Gibelion catla*), Rohu (*Labeo rohita*), Mrigal (*Cirrhinus mrigala*), Silver carp (*Hypophthalmichthys molitrix*) and Grass carp (*Ctenopharyngodon idella*) in equal proportion. Post-stocking operations included partial removal of water hyacinth at a fortnightly interval to maintain the extent of coverage up to 5 % water area of the pond, bimonthly monitoring of water quality, and regular boating to remove excess aquatic weeds from the pond and netting operations. For analysis of water quality parameters such as Total Dissolved Solids (TDS), pH and temperature, the multi-parameter kit (Make: Thermo Scientific, USA, EC-PCTestr 35) was used. For other water quality parameters such as dissolved oxygen, total alkalinity, total hardness, total ammonia nitrogen (TAN), nitrite-N, nitrate-N, phosphate-P, BOD, COD, etc. standard methods of APHA (1998) were followed. Water samples from each sewage-fed pond were collected on each occasion from three locations viz., inlet of sewage into the pond (L1), middle of the pond, (L2) and the farthest location from the sewage inlet (L3). The final harvest of fish was recorded from the ponds after eight months of culture period and assessed for production attributes. The data generated were statistically analysed in SPSS version 16.0.

Results and Discussion

The ponds in most of the village areas of Gujarat act as natural sinks of domestic sewage generated daily from households. Household generate most wastewater fed to ponds in villages of Gujarat since there are no major industrial activities around the study areas. These household wastes or domestic sewage are rich in nutrients that act as a sustainable resource for supporting aquaculture. Aquaculture operations were already successfully demonstrated in the ponds fed with raw sewage in Munich, Germany and the Bheries of West Bengal in India (Edwards, 1992; Jana & Dutta, 1996; Jana, 1998). Nevertheless, these models are not widely adopted in other parts of India (Nandesha, 2002), including Gujarat. Pre-stocking pond preparations were undertaken during September-October, during which advanced fingerlings or yearlings were adequately available in the nearby fish seed farms. During pre-stocking preparation, water hyacinth was introduced into the pond up to the extent of 5 % of the water spread area of the pond at the inlet location of sewage water into the pond, which usually is doubled within two weeks. Aquatic macrophytes are known to have a high capacity for the biological purification of wastewater (Gersberg et al., 1986; Mann & Bavor, 1993). Conversion of ammonia present in household wastewater or domestic sewage into proteins of plants in ponds is a relatively energy-efficient process, when compared with other alternative methods (Oron et al., 1987; Zirschky & Reed, 1988).

The selection of fish species is a key factor in the success of sewage-fed aquaculture. The fish species occupying lower trophic levels in the food chain and compatible to occupy all the niches of pond and bottom grazing ability were selected for polyculture in sewage-fed ponds (Jana, 1998). Thus, five species combinations of *G. catla, L. rohita, C. mrigala, H. molitrix* and *C. idella* were selected for polyculture in the pond at a stocking density of 5000 numbers of advanced fingerlings or yearlings per ha of the pond area. Five species combinations of carps in equal ratios were also poly-cultured in sewage-fed ponds biologically treated by duckweeds (Jena et al., 2010). During the pre-stocking preparation of the pond, lime was applied @ 200 kg/ha. During post-stocking operations also, lime was applied depending on water quality. There was a heterogeneous rate of growth of *E. crassipes* in different ponds under the study, which could be due to the variable nature and volume of sewage wastewater entering the ponds under study. Two plants of *E. crassipes* can produce 300 offspring within 23 days under a suitable environment, and ten plants can multiply 6.0 lakh numbers to cover a one-acre area within eight months (Sharma & Solomon, 2005). Hence, during post-stocking aquaculture operations, partial removal of *E. crassipes* was undertaken at fortnight intervals so that the growth of aquatic macrophytes near the sewage inlet covered only up to 5 % of the water area of the pond. No supplementary feeding and fertilization were done in any of the ponds. It was assumed that the nutrients available in the sewage wastewater will contribute to the natural food of fish species under aquaculture. No aeration devices were provided during aquaculture operations except fortnightly boating and netting operations during the evening to improve the dissolved oxygen level in ponds, as reported by Jana (1998).

The efficiency of the management system was assessed through bi-monthly monitoring of important chemical parameters of water collected from three locations such as inlet of sewage entering the pond (L1), the centre of the pond (L2), and the farthest location of sewage inlet (L3). The water temperatures of the selected ponds were influenced by seasonal changes, with a lower mean value of 23.0 ^{o}C in December to the highest mean value of 28.5 ^{o}C in June in the selected ponds of three districts (Fig. 1). Although the atmospheric temperature influences the variations in the record of monthly temperatures, the source, volume and concentration of sewage wastewater also might have influenced the water temperature.

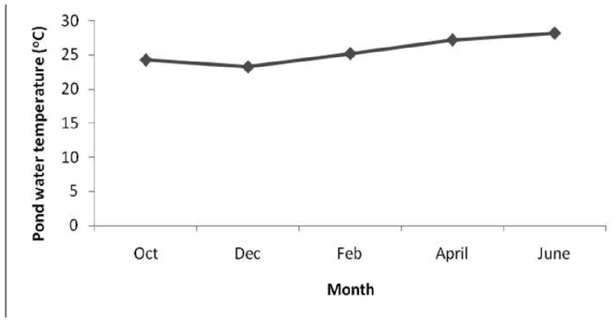

Fig. 1. Mean Water Temperature (^{o}C) of selected ponds in different months during the study

The pH, total alkalinity, and total hardness of pond water were observed to be within the desired range (Table 1) for successful aquaculture operations throughout the study (Jena et al., 2002). There was a gradual increase of dissolved oxygen level in the pond water from the inlet location of sewage water into the pond to the farthest location of sewage entry (Fig. 2). Dissolved oxygen was very low at the initial location of sewage entry due to heavy organic load in sewage whereas, the dissolved oxygen level improved drastically towards the locations away from the inlet of sewage entering into the pond. The improvement in dissolved oxygen level towards the farthest point of sewage entry can be attributed to the oxygen generated by the photosynthetic activity of phytoplanktons in the pond using the nutrients available in the sewage wastewater, which is an indication of better management by regulated growth of aquatic macrophytes and phytoplankton in the pond (Jena et al., 2010).

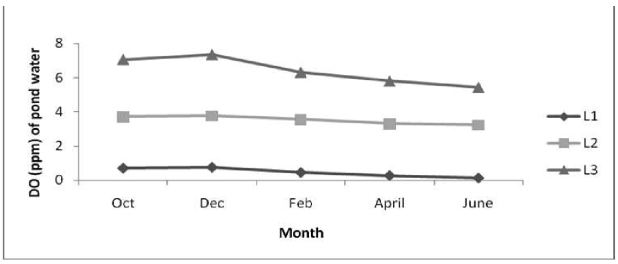

Fig. 2. DO (ppm) of pond water at different locations of selected ponds in different months during the study

Table 1. Water quality parameters at different locations of selected ponds during the study

Parameter	L1	L2	% Change (L1 to L2)	L3	% Change (L1 to L3)
pH	7.1-8.4	7.3-8.9	(↑) 5.34	7.8-9.1	(↑) 9.88
Total alkalinity (mg/l)	193.53±23.95	155±25.43	(↓) 20.27	149.99±244.74	(↓) 22.86
Total hardness (mg/l)	258.13±20.86	224.58±10.75	(↓) 12.75	211.18±17.62	(↓) 18.18
Dissolved Oxygen (mg/l)	0.45±0.24	3.51±0.22	(↑) 1889.74	6.38±0.73	(↑) 3117.51
Total Ammoniacal Nitrogen (mg/l)	5.85±0.44	0.86±0.65	(↓) 85.62	0.22±0.10	(↓) 96.16
Nitrite Nitrogen (mg/l)	0.78±0.02	0.27±0.05	(↓) 64.94	0.14±0.03	(↓) 82.21
Nitrate Nitrogen (mg/l)	1.77±0.38	0.96±0.20	(↓) 45.35	0.74±0.14	(↓) 58.03
Phosphate Phosphorus (mg/l)	2.24±0.36	0.96±0.10	(↓) 56.56	0.61±0.60	(↓) 72.10
BOD (mg/l)	121.73±5.89	68.87±6.05	(↓) 43.52	30.10±3.76	(↓) 75.35
COD (mg/l)	222.44±13.50	89.18±9.63	(↓) 60.02	35.15±8.55	(↓) 84.37
TDS (PPT)	2.78±0.33	2.02±0.14	(↓) 26.64	1.13±0.21	(↓) 59.71

The values are represented as mean of 24 samplings at bimonthly intervals ± SD.
L1: Inlet location of sewage entering to pond; L2: Mid location of pond;
L3: Farthest location of sewage entering to pond; ↑: Increase; ↓: Reduction

Excessive nutrients such as nitrogen and phosphorus in the sewage wastewater entering ponds must be removed with suitable methods. In this study, different forms of nitrogen, such as total ammonia nitrogen (TAN), nitrite-N and nitrate-N, were removed to the extent of 96 %, 82 %, and 58 %, respectively, from the sewage entry point (L1) to the farthest point of sewage entry (L3) by allowing the regulated growth of aquatic macrophytes in the ponds (Fig. 3-5 & Table 1). Similar observations of the removal of nitrogen were also reported by several researchers (Alaerts et al., 1996; Körner & Vermaat, 1998; Rose, 2000; Jena et al., 2010). Even excess levels of phosphate at the entry of sewage into the pond (L1) were reduced to the extent of 72 % (Fig. 6 & Table 1) at the farthest point from the sewage entry in the pond (L3), which indicated better efficiency of regulated growth of aquatic macrophytes in the removal of excess nutrients from the water medium, thereby improving the water quality of the pond. Phosphate removal was comparatively higher than nitrate removal, indicating better efficiency of the regulated growth of aquatic macrophytes and further phosphorus utilization by phytoplankton (Patil, 1985).

BOD and COD levels in the pond water were also reduced in L3 than L1 to the extent of 75 % and 85 %, respectively (Table 1). The trend of BOD and COD levels in the pond water (Fig. 7 & 8) might be due to the mineralization of organic load in sewage wastewater and temperature fluctuations during different months. The BOD and COD removal

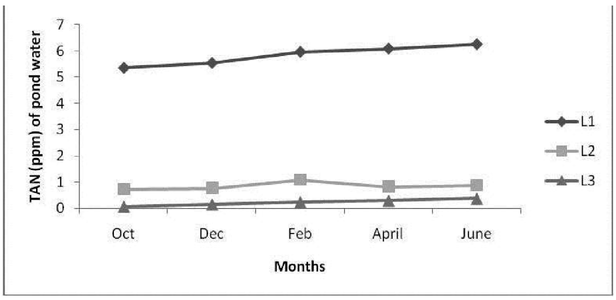

Fig. 3. TAN (ppm) of pond water at different locations of selected ponds recorded in different months during the study

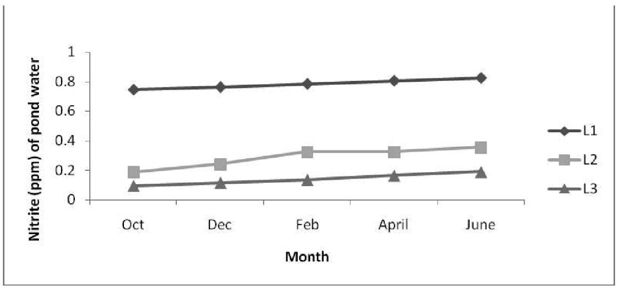

Fig. 4. Nitrite (ppm) of pond water at different locations of selected ponds recorded in different months during the study

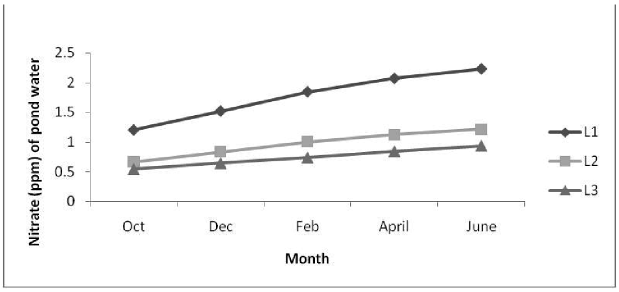

Fig. 5. Nitrate (ppm) of pond water at different locations of selected ponds recorded in different months during the study

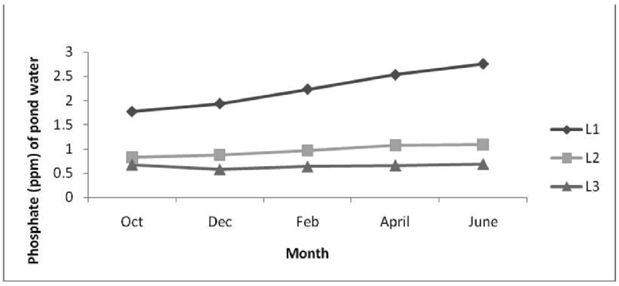

Fig. 6. Phosphate (ppm) of pond water at different locations of selected ponds recorded in different months during the study

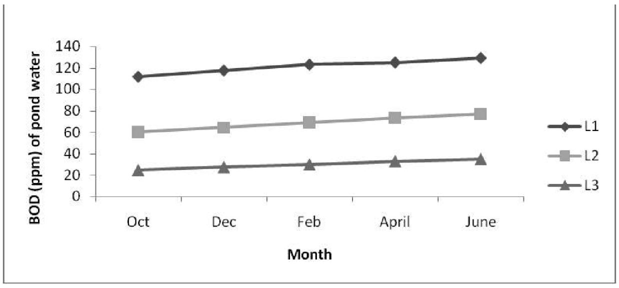

Fig. 7. BOD (ppm) of pond water at different locations of selected ponds recorded in different months during the study

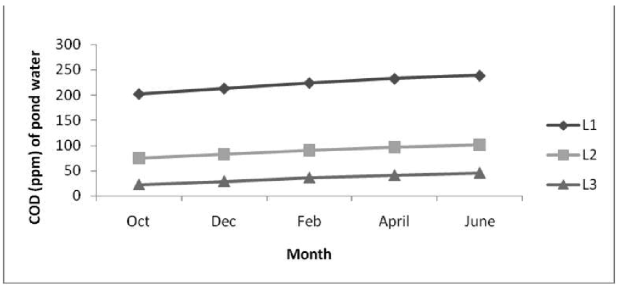

Fig. 8. COD (ppm) of pond water at different locations of selected ponds recorded in different months during the study

efficiency of the regulated growth of water hyacinth in pond water were also similar to several previous studies (Alaerts et al., 1996; Korner et al., 2003; Jena et al., 2010). Total dissolved solids in the ponds were also reduced to the extent of 60 % (Fig. 9 and Table 1) at the farthest location of sewage entry (L3) as compared to the point of entry of sewage into the pond (L1), probably due to absorption of dissolved solids by the regulated growth of *E. crassipes*.

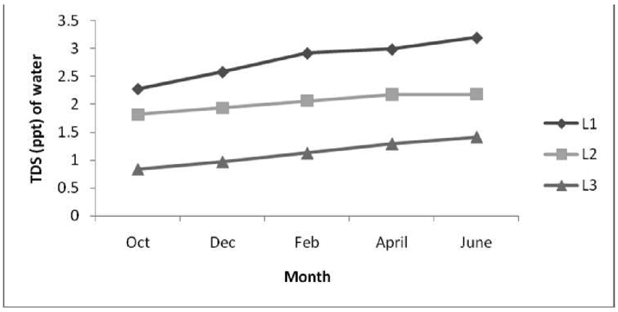

Fig. 9. TDS (ppm) of pond water at different locations of selected ponds recorded in different months during the study

Sewage wastewater fertilized ponds resulted in higher fish production due to the abundance of natural fish food organisms (Jena et al., 2010) utilizing the nutrients available in the sewage entering to pond. This study revealed fish production to the tune of 3.093±0.162 MT/ha in eight months. Earlier, Ayyappan et al. (2002) also reported more than 4 MT/ha production in 14 months. In the present study, the increased fish production could be due to an adequate abundance of natural fish food organisms as the desired range of available nutrients in sewage water was maintained by regulated *E. crassipes* in the ponds.

From our results, it is evident that the sewage-fed village ponds leased by the farmers can be well managed by regulating the growth of *E. crassipes* to the extent of 5-10 % water area of the pond, not only by removing the excess nutrients from the source of water but also by helping to maintain the desired range of natural fish food organisms in the pond. Further, the periodic release of wastewater with low BOD from households in rural areas of Gujarat might have contributed to the increased productivity of the ponds, which was also reported by Jana (1998).

Fish production in sewage-fed ponds is dependent on the nature, volume, and management of sewage. The chemical characterization of domestic sewage entering fish ponds from its inlet location revealed higher values than those in the farthest part of the pond. However, the efficiency of this system to improve the fish production in sewage-fed village ponds using regulated growth of water hyacinth, *E. crassipes* is dependent on the nature of sewage entering the pond, which needs the development of location-specific technological methods. The use of water hyacinth, *E. crassipes* is beneficial in sewage–fed aquaculture or nutrient-laden ponds for removing excess nutrients to make the water body usable, subject to maintenance of suitable biomass of water hyacinth through continuous monitoring.

Acknowledgements

The authors are thankful to all the farmers included under the study for sharing useful data. Authors are also thankful to the Director, ICAR-CIFA, Bhubaneswar for his constant support and all others who have directly and indirectly co-operated for the success of the study.

References

Adhikari, S., Ghosh, L., Rai S.P. and Ayyappan, S. (2009) Metal Concentrations in Water, sediment, and fish from sewage-fed aquaculture ponds of Kolkata, India. Environ. Monit. Assess. 159(1-4): 217-230

Ail, S.K.S., Devadas, D., Sudhan, C., Misra, C.K., Chaudhari, A.K., Landge, A., Dube, K., Nayak, B.B. and Shenoy, L. (2021) Plankton diversity and dominance in three undrainable village pond aquaculture systems. Proc. Natl. Acad. Sci. India SectB. Biol. Sci. 91(2): 391-396

Alaerts, G.J., Mahbubar, M.D.R. and Kelderman, P. (1996) Performance analysis of a full-scale duckweed covered sewage lagoon. Water Res. 30: 843-852

APHA. (1998) Standard Methods for the Examination of Water and Wastewater, 20th edn. American Public Health Association, Washington, USA

Ayyappan, S., Purushothaman, C.S., Aravindakshan, P.K., Jena, J.K., Patri Priyambada, Mishra, B., Behera, P.K. and Prasad, J. (2002) Scope for utilising secondary treated domestic sewage for aquaculture. The Fifth Indian Fisheries Forum Proceedings, AFSIB, 53-56 p, Mangalore and AoA, Bhubaneswar, India

Azanu, D., Jørgensen, S.E., Darko, G. and Styrishave, B. (2016) Simple metal model for predicting uptake and chemical processes in sewage-fed aquaculture ecosystem. Eco. Modell. 319: 130-136

DAHDF. (2017) Annual Report 2016-17, Department of Animal Husbandry, Dairying and Fisheries, New Delhi, India

DAHDF. (2018) Annual Report 2017-18, Department of Animal Husbandry, Dairying and Fisheries, New Delhi, India

Dasgupta, S., Pandey, B.K., Sarangi, N. and Mukhopadhyay, P.K. (2008) Evaluation of water productivity and fish yield in sewage-fed vis-à-vis fertilized based carp culture. Bioresour. Technol. 99(9): 3499-3506

Edwards, P. (1992) Reuse of human wastes in aquaculture: A technical review. Ecol. 7(7): 1-8

Gersberg, R.M., Elkins, B.V., Lyon, S.R. and Goldman, C.R. (1986) Role of aquatic plants in wastewater treatment by artificial wetlands. Water Res. 20: 363-368

Jana, B.B. (1998) Sewage-fed Aquaculture: The Calcutta Model. Ecol. Eng. 11(1-4): 73-85

Jana, B.B. and Datta, S. (1996) Nutrient variability of six sewage-fed tropical fish ponds. In Proceedings of the international conference on ecological engineering for wastewater treatment, Switzerland. Environ. Res. Forum. 5-6: 379-382

Jana, B.B., Mandal, R.N. and Jayasankar, P. (2018) Wastewater management through aquaculture, p 335, Springer Nature Singapore Pvt. Ltd., Singapore

Jena, J.K., Ayyappan, S. and Aravindakshan, P.K. (2002) Comparative evaluation of production performance in varied cropping patterns of carp polyculture systems. Aquacul. 207: 49-64

Jena, J.K., Patro, B., Patri, P., Khuntia, C.P., Tripathy, N.K., Sinh, S. and Sarangi, N. (2010) Biological treatment of domestic sewage through duckweed-cum-fish culture: A pilot-scale Study. Ind. J. Fish. 57(4): 45-52

Körner, S. and Vermaat, J.E. (1998) The relative importance of *Lemna gibba* (*L.*), bacteria and algae for the nitrogen and phosphorus removal in duckweed covered domestic wastewater. Water Res. 32: 3651-3661

Körner, S., Vermaat, J.E. and Veenstra, S. (2003) The capacity of duckweed to treat wastewater: Ecological considerations for a sound design. J. Environ. Qual. 32: 1583-1590

Kumar, D., Chaturvedi, M.K.M., Sharma, S.K. and Asolekar, S.R. (2015) Sewage-Fed Aquaculture: A sustainable approach for wastewater treatment and reuse. Environ. Monit. Assess. 187(10): 1-10

Mandal, R.N., Das, A., Chattopadhyay, D.N., Hussan, A., Adhikari, S., Paul, B.N., Hoque F., Chakrabarti, P.P. and Pillai, B.R. (2021) Use of sewage in split doses to enhance water productivity for fish culture. Aquacul. Fish. 6: 609-619

Mandal, R.N., Chakrabarti, P.P., Paul, B.N., Chattopadhyay, D.N., Das, A., Hussan, A. and Jayasankar, P. (2018)

Recycling of sewage in aquaculture: decadal technical advancement. In: Jana, B.B., Mandal, R.N. and Jayasankar, P., (Eds.), pp 95-118, Wastewater Management Through Aquaculture. Springer Nature Singapore Pte Ltd., Singapore

Mandal, R.N., Chattopadhyay, D.N., Chakrabarti, P.P., Pandey, B.K., and Jayasankar, P. (2015a) Bio-remediation of domestic sewage recycled in aquaculture: A central Institute of freshwater Aquaculture model. Aquacul. Asia, 20(3): 14-19

Mandal, R.N., Chakrabarti, P.P. and Jayasankar, P. (2015b) Sewage fed aquaculture: A viable proposition for fish production through nutrients recovery and water conservation, in Effect of Abating Water Pollution. In: Singh, R.P. and Sarkar, A., (Eds), pp 93-113, Waste management. Nova Scientific Publication, USA

Mann, R.A. and Bavor, H.J. (1993) Phosphorus removal in constructed wetlands using gravel and industrial waste substrata. Water Sci. Technol. 27: 107-113

Nandesha, M.C. (2002) Sewage fed aquaculture systems of Kolkata a century-old innovation of farmers. Aquacul. Asia. 7(2): 28-32

Oron, G., Porath, D. and Jansen, H. (1987) Performance of duckweed species *Lemna gibba* on municipal wastewater for effluent renovation and protein production. Biotechnol. Bioeng. 29: 258-268

Patil, H.S. (1985) Studies on the physico-chemical and biological characteristics of sewage stabilization ponds. J. Environ. Biol. 6: 93-102

Rose, A.E.S. (2000) Studies on wastewater treatment by *Lemna minor*. J. Environ. Biol. 21(1): 43-46

Sculthrope, C.D. (1967) The Biology of Aquatic Vascular Plants, p 610, Edward Arnold Ltd., London

Sharma, l.L. and Solomon I.J. (2005) Weed menace in Udaipur lakes and option for control: a limnological perspective. In: Aquatic Weeds-Problems, Control, and Management. Mathur, S.M., Trivedi, R.K., Bhat, Y.C. and Mohonot, P., (Eds.), pp 155-171, Himanshu Publication, Delhi

Zirschky, J. and Reed S.C. (1988) The use of duckweed for wastewater treatment. J. Water Pollut. Control. Fed. 60: 1253-1261