Dual Purpose of Domestic Waste-Water Reuse: Fish Production and Eutrophication Abatement

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ABSTRACT
Recycling waste water is an alternative to the gradual degradation of natural water resources. In the present study, domestic sewage effluent was used for the removal of nutrients via poly fish culture. Carps were stocked in primary and secondary oxidation ponds and their growth rate was measured every 3 months for a period of one year and was compared with freshwater control pond. Major nutrients present in the sewage secondary oxidation ponds were found to be significantly removed and utilized by the fishes grown in these ponds. The fish growth rate in one year was as follows: *C. carpio* 1780 gms, *L. rohita* 1300 gms and *C. mrigala* 1100 gms. These were 3 to 4 times higher than the same species of fishes grown in freshwater control pond. It is concluded that the fishes grew very fast in the secondary oxidation ponds without any supplementary feeding, attenuating the eutrophication of water by consuming the excessive amount of nutrients via the natural food chain, which was available in plenty in the tropical ponds. It was also found that the concentration of nitrogen and phosphorus was much higher in oxidation ponds, where there was no fish culture.

Keywords: Reclamation, Removal of nutrients, Sewage oxidation ponds, Carp fish culture.

Introduction

In the last century environmental scientists, civil engineers, and water conservation authorities are looking at the treatment of wastewater sewage waters from different points of view (Abdel-Raouf et al., 2012, Wollman et al., 2019). Waste-water or domestic sewage is highly loaded with nutrients, suspended solids, organic and inorganic matter, plankton and microorganisms. The reuse of municipal domestic sewage has become an attractive option to culture fishes in it, (Khan & Ali, 1992, Ambakisya, 2006, Castine et al., 2013, Jana et al., 2018, Fauzi et al., 2021, Wang et al., 2022).
Fish farming using domestic sewage water has been experimented for years by many countries across the world, (WHO, 1989, Jana et al., 2018). It is one of the best alternative ways to treat domestic waste for the fish culture. It also involves one of the cheapest and eco-friendly processes to remove excessive nutrients like phosphorous and nitrogen to maintain a balanced food cycle of the ecosystem, (An et al., 2003; Wang et al., 2013; Manea & Ardelean, 2016; Yang et al., 2019, Ali et al., 2020; Li et al., 2021).

The present paper has used the concept of nutrient recovery by the culture of fishes in domestic sewage oxidation ponds which not increases the growth of fishes but also attenuates eutrophication. We have comparatively analyzed the culture and growth pattern of four species of fishes such as *C. carpio L.rohita, C.mrigala,* and *C.catla* in different tropical sewage oxidation ponds along with a freshwater control pond, to buttress the fact that fish culture in domestic sewage oxidation ponds serves a dual purpose of protein reclamation, as well as the removal of nutrients, attenuating eutrophication.

Material and Methods

The experimental work was carried out in Shahpura sewage oxidation ponds, located at 10km South-East of Bhopal city $25^{0}17^{1}$, constructed in two services of primary and secondary oxidation ponds as per specifications of National Environmental Engineering Research Institute (NEERI), Nagpur India. Each pond had an area of 0.4 hectares and was designed to treat biologically 3 million gallons of domestic sewage per day. The sewage was collected by pumped to oxidation ponds where it is detained for a period of about 15 to 20 days for microbial transformation. The raw sewage enters the primary pond through 3 inlets, and after the detention period, the biologically treated effluent goes out of the secondary pond through the outlet.

In the present study out of 8 ponds, as above mentioned, four were selected for nutrient removal and fish culture. Two are primary, designated as IA and IB, and two as secondary called IIIA and IIIB. The particulars of the pond: Length-100.65 mts, breadth-50.32 mts, average depth-1.20 mts, retention period-20 days, and the capacity of the pond treating 3 million gallons of sewage per day.

Nutrients: Nitrogen and phosphorous were estimated from the sewage pond water as per the procedure of the American Public Health Association (APHA, 1985), and the values are expressed in mg/L. The presence of nutrients was calculated in both the primary and secondary ponds and the date was correlated with fish growth in the ponds.

Culture of fishes: Fingerlings of *Cyprinus Carpio*, *Labeo rohita*, *Cirrhinus mrigala*, and *Catla catla* were purchased from M.P. Fisheries Corporation Bhopal, M.P. and stocked as per the standard norms (Jhingran, 1983). For monitoring the growth, fifty fishes were caught at random once every 3 months, and length & weight were recorded. The experiments were conducted for a period of one year.

Ethical Statements: The Ethical Committee for Animal Experimentation and Research, Saifia College of Science, Bhopal, India certified the use of animals (approval number SSC/06-06-22/, dated October 26, 2006).

Results

Nutrient studies and Fish growth particulars: Nutrients like nitrogen and phosphorous were estimated from the primary and secondary domestic sewage oxidation ponds and compared with freshwater control ponds. To know the percentage recovery or removal of nutrients from the sewage secondary oxidation ponds, four species of fishes were stocked in them and their growth rate particulars were recorded (4 times in a year) and compared with the fishes grown in control freshwater ponds along with physicochemical parameters such as light penetration, pH, temperature and DO. The comparative Physico-chemical parameter analysis is well supported by the data of fish culture experiments, whereas it has been observed that in the ponds IA & IB, no fishes survived after 24 hours of stocking of fingerlings of the selected species of fishes. Because of the IA & IB oxidation ponds experienced poor light transparency throughout the year due to high algal growth, solids, and other undesirable materials present in domestic sewage (Table 1B). On the other hand, *C.carpio, L. rohita, C. mrigala,* and *C.catla* did not show any post-stocking mortality in ponds, IIIA & IIIB (Table 2). The fishes in IIIA & IIIB sewage oxidation ponds exhibited tremendous weight gradually from the initial period.

Table No: 1A: Showing the average seasonal nutrient values of Phosphorous & Nitrogen of Primary and Secondary Sewage oxidation ponds along with a fresh water control pond

Seasons	Ponds	Light Penetration (cm)	Temperature (^{0}C)	pH	Dissolved oxygen (mg/L)	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)
Winter	IA	17.60 - 20.40	17.70 - 22.10	7.20 - 9.50	2.05 - 7.72	4.90 - 7.86	28.25- 29.86
	IIIA	16.40 - 25.80	18.30 - 23.80	9.10 - 10.00	5.30 - 13.30	4.68 - 6.88	25.60 - 28.62
	IB	18.70 - 21.80	18.60 - 21.90	7.80 - 8.70	3.60 - 9.60	3.50 - 6.00	22.50 - 24.00
	IIIB	15.60 - 26.30	18.10 - 23.90	9.40 - 10.20	5.10 - 10.40	2.94 - 4.13	18.90 - 22.55
	CP	35.60 - 41.30	18.50 - 24.10	7.80 - 8.40	5.40 - 7.20	0.21 - 0.30	01.66 - 01.96
Summer	IA	09.20 - 15.30	29.40 - 34.00	9.10 - 10.30	1.00 - 12.00	6.30 - 7.963	26.15 - 30.08
	IIIA	12.60 - 14.80	29.00 - 34.70	8.70 - 9.90	3.00 - 17.30	6.00 - 7.05	24.73 - 29.38
	IB	12.70 - 15.70	30.00 - 36.10	8.80 - 10.00	1.50 - 12.10	2.88 - 6.11	19.77 - 24.43
	IIIB	9.20 - 11.60	32.00 - 36.20	8.60 - 9.90	3.80 - 10.50	1.03 -4.26	16.27 - 22.85
	CP	39.30 - 77.00	32.34 - 36.50	8.20 - 9.00	4.50 - 7.20	0.20 - 0.38	0.95 - 1.80
Rainy	IA	11.00 - 14.90	23.60 - 27.70	8.50 - 9.7	2.80 - 11.90	0.69 - 6.78	12.00 - 27.60
	IIIA	11.00 - 12.90	24.30 - 28.10	9.20 - 10.20	3.60 - 12.80	0.53 - 7.00	10.32 - 26.90
	IB	12.20 - 23.10	22.90 - 27.60	8.10 - 9.60	3.10 - 12.20	0.72 - 5.53	8.18 - 20.77
	IIIB	11.00 - 13.10	23.60 - 27.70	9.60 - 10.00	4.30 - 16.90	0.73 - 2.52	9.80 - 19.64
	CP	26.60 - 30.30	24.50 - 28.30	7.80 - 8.60	5.20 - 8.40	0.21 - 0.76	1.36 - 2.30

IA, IIIA - Primary oxidation ponds: IB, IIIB - Secondary oxidation ponds: CP - Fresh Water control pond.

Table No: 2: Showing the weight (gms) of control and sewage cultured fishes in the sewage oxidation and control ponds

Species	At the time of Stocking		3 Months		6 Months		9 Months		12 Months	
	C	S	C	S	C	S	C	S	C	S
C. carpio	2.0	2.0	140	275	210	450	300	1090	500	1780
L. rohita	5.0	5.0	100	200	186	300	260	845	450	1300
C. mrigala	2.5	2.5	94	220	120	265	200	600	300	1100
C. catla	4.0	4.0	70	110	160	FNS	180	FNS	250	FNS

C = Control (freshwater fishes. Stocking density = 10000 fingerlings per hectare per year
S = Sewage cultured fishes. *C. carpio, L. rohita, C. mrigala & C. catla* = 3:1: 1: 1
* Weight of the fishes are +/- 0.5 gms to 10.0 gms. 50 fishes were caught randomly.
FNS = Fish not survived

Nutrients: Nitrogen and phosphorous ranged between 29.38 mg/L to 22.85 and 7.05 mg/L to 4.26 in ponds IIIA & IIIB during the summer, where fish culture was carried. These values were 10 to 20 times higher than the freshwater control ponds (Table No:1A). The nutrients present in sewage secondary oxidation ponds (IIIA & IIIB) were removed and utilized by the fishes grown in that ponds. The nutrients present in the primary oxidation ponds were not utilized by the fish where the untreated primary sewage contains high algal bloom and the unfavorable conditions present there the nutrients precipitate at the surface forming a dry algal blanket and avoiding the sunlight into the pond.

Fish growth studies: After every 3 months about 50 fishes were caught at random from the secondary oxidation ponds (IIIA & IIIB) and the weight particulars were recorded. Out of the four species *C. carpio,* a voracious feeder was found to grow maximally, (1700 gms) followed by *L. rohita* (1300g), *C. mirigala* (1100 gms) in a period of one year. The control pond fishes exhibited *C.carpio* 500, *L.rohita* 450 & *C.mrigala* 300 grams respectively. The fish growth data particulars are shown in (Table 2).

Wide fluctuations in temperature ranges, depending on the season have been observed in summer ranging from 34.7 to 36.2^{0}C (Table No:1A) even in a single pond due to continuous streaming of plankton as well as mixing of the influent. The pH also showed extreme fluctuations season-wise, in secondary sewage oxidation ponds maximum being (10) in the winter and the minimum (9.90) being in summers. High pH values are highly alkaline due to as the ponds are with algal dominance (Table No:1A). DO values were found to change considerably in the study period. The minimum DO was observed during pre-dawn (1.0 mg/L to 1.50) in ponds IA & IB and maximum DO was recorded at 17.30 mg/L to 10.50 in ponds IIIA & IIIB where fish culture was carried (Table No:1A). The results of our study were supported by the Physico-chemical conditions and tremendous fish growth which are the reasons for to complete removal of nutrients such as nitrogen & phosphorous present in the sewage secondary oxidation ponds.

Discussion

Physicochemical parameters are an important controlling factor of biological productivity and the trophic status of aquatic bodies. Their evaluation becomes necessary although several studies on the physicochemical analysis of freshwater oxidation ponds are few. It has been observed that the knowledge of physicochemical parameters such as light penetration, temperature, pH, dissolved oxygen, BOD and nutrients to eutrophication abatement.

Light penetration was found in primary sewage oxidation ponds IA and IB in a very low range than IIIA and IIIB, it was observed that the transparency was three times less than the freshwater control pond due to high organic matter, total solids, nutrients, and algal density.

These results are in full agreement with the findings of Ali et al. (2021) and Wang et al. (2022) who have reported that algal density inhibits light penetration in oxidation ponds. As the initial or primary oxidation ponds are more atrophic loaded with excessive nutrients, they have high algal proliferation rates thus transparency followed an indirect relationship with that of nutrients and algal biomass. It was found to be greatly affected by the algal density and the seasonal fluctuation in light penetration was minimum in the rainy season and maximum in summer. Ponds IA and IB had maximum algal biomass and minimum transparency whereas ponds IIIA and IIIB had maximum transparency and minimum algal biomass.

The result of the present investigation indicates the importance of algae which are photolithographs and their extensive role in phosphorus removal in tropical oxidation ponds where high temperature and pH are common features. The present high range of temperature during summer when the phosphorus removal rates were maximum adequately stimulated the photosynthetic activity of algae, which resulted in rapid depletion of CO2 and increase pH value. Thus, due to increased algal biomass, the high pH value was responsible for the precipitation of phosphate which brings about its reduction. The data of the recent study where high pH temperature and light intensity induced phosphate reduction due to coagulation and adsorption are in full collaboration with the finding of Yang et al. (2019). In contradiction Bogam et al. (1960), Bush et al. (1961), Lin et al. (1974) have reported that 96% of phosphorus removal can take place with increased algal growth at low pH (7.0-8.5).

The data of the present investigation do not support the findings of the above two workers as pH is directly proportional to that of phosphorus removal. Because of the lacuna in this area, some importance is given to the reduction and per cent removal of phosphorus and nitrogen in different oxidation ponds i.e., Primary, secondary and data have been compared with freshwater control ponds. In the present investigation high percentage of phosphorus removal has taken place from the raw sewage in various oxidation ponds, the maximum annual average reduction occurred in secondary oxidation ponds followed by primary oxidation ponds.

The massive amounts of nutrients such as nitrogen and phosphorus in sewage function as perfect fertilizers for plankton and algae to flourish and enhance the productivity of the aquatic ecosystem, which is a valuable food source for fish and other aquatic organisms (Garcia et al., 2000, Al-ghais, 2013, Wang et al., 2013, Sayara et al., 2021, Ali et al., 2021).

The data of the current study indicated that the nutrients such as N and P were higher in sewage secondary oxidation ponds as compared to freshwater control ponds (Table 1), it was found that maximum phosphorus reduction took place in summer when pH minimum (9.90) and maximum in winter (10) and Temperature (32.00 - 36.20) was observed. The minimum reduction occurred during the rainy season when all the above physicochemical parameters were observed at their lower ranges. The high fish growth rate was recorded in the secondary oxidation ponds, supporting the fact that there is abundant nutrient content in the oxidation pond where the cultured fishes utilized these nutrients and recorded tremendous growth.

Thus, nitrogen was recorded at 2-3-fold higher levels as compared to phosphorous, the urine and faecal matter present in domestic sewage ponds break down into organic and inorganic molecules, which change into ammonia and finally into nitrogen. This nitrogen is used by aquatic organisms like plankton and fishes on which they grow. If the nutrients grow abundantly and are not consumed by fish, the nutrient load and the algae present in the sewage pond form rapid algal blooms at the surface of the pond, causing excessive eutrophication. So the growth of the fish, particularly in our experiments, showed that the carps utilized these nutrients and algae content from the ponds (particularly in the secondary ones) and exhibited tremendous growth as compared to fish cultured in control freshwater ponds.

Due to high nutrient loads and unsuitable ecological conditions, the fish could not survive in the primary oxidation ponds and as well as due to the high number of suspended solids, nutrients and algae (Ganapati & Chacko, 1950; Khan & Ali, 1992; Shafel et al., 2007, Vollenweider 1968, Oswald, 1995, Yang et al., 2019, Ali et al., 2020, Ali et al., 2021, Wang et al., 2022) in the primary oxidation ponds caused mortality and unfavourable conditions for the culturing of fishes.

In our study, the presence of phosphorous in sewage ponds was found to be in a lower amount as compared to nitrogen. It was observed that more nitrogen comes from faecal and organic matter coming from sewage oxidation ponds than phosphorous. It was found that nutrient removal also was done by fish culture in sewage oxidation ponds when nutrients are present abundantly Ali (1991, 1992), Khan & Ali (1992), Bogan (1961), Ambakisye, (2006), Water Resources, 2019; Sayara et al., 2021).

Our results are the same as these findings. Thus, it was observed that the presence of high algal matter and favourable physicochemical parameters like temperature, pH, and dissolved oxygen will favor the removal of nitrogen and phosphorus. The data of physico-chemical and limnological studies clearly suggest that a part form cascading trophic interactions takes place in the oxidation ponds thereby producing the rich food web of plankton, there is every possibility that the smaller particles of the organic wastes in the oxidation ponds provide a direct source of food to zooplankton and fishes like *C. carpio*. This process is not light limited as is the production of organic matter by phytoplankton. In the present studies ponds, nitrogen and phosphorus along with trace elements also stimulated phytoplankton production in the same manner as inorganic fertilizers.

The tremendous simulation of plankton by the nutrients was one of the factors of the high growth rate of the fishes. It is reported that increased growth of minnows and food of fish in a pond is related to the application of inorganic phosphate and nitrogen to increase the production of plankton which acts directly or indirectly as fish food. Therefore, in the present study, the classical growth of fishes was due to the increased primary productivity. These observations are supported by the earlier findings of (Munero, 1961) and (Naumann, 1964), Rawat, 2016, Yang et al., (2019), Ali et al., (2020), Ali et al., (2021), Fauzi et al., (2021).

The physicochemical parameters and the organic and inorganic water, algae and plankton are the reasons for the high occurrence of nutrients like nitrogen and phosphorus in the domestic sewage oxidation ponds. Due to favorable physicochemical and biological conditions in the sewage secondary oxidation ponds, then the fishes were adjusted to that environment and utilized the nutrients, algae, and planktons as food and recorded tremendous growth as compared to the freshwater control oxidation ponds.

Conclusion

It was concluded that the nutrients present in the secondary oxidation ponds such as nitrogen, and phosphorus, were removed by fishes and culture effectively and completely. Fish culture has been done without any feeding in that environment. Because of those nutrients, if the removal of nutrients is not done in a proper way, eutrophication occurs and algal blooms form at the surface of the pond, which causes the pond to die. As a result, high fish mortality may happen. Finally, nutrient removal serves a dual purpose in fish culture and the prevention of eutrophication in sewage ponds.

Declaration

Ethical approval and consent to participate: The Ethical Committee for Animal Experimentation and Research, Saifia College of Science, Bhopal, India certified the use of animals (approval number SSC/06-06-22/, dated October 26, 2006).

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Dr. Sharique A. Ali: Visualization, Conceptualization, Writing - Original Draft, Final Corrections, Supervision, Project administration, **Hanumanth H Raju**: Methodology, Formal analysis, **Gulafsha Kassab:** Writing – Statistical Analysis, Review & Editing

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