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Integrated Management of Wastewater through Sewage Fed Aquaculture for Resource Recovery and Reuse of Treated Effluent: A Case Study

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Abstract

India has 18% of the world's population, 1.15 billion people, but access to only 4% of world's fresh water resources. In the recent past, the dependency of Indian agriculture on ground water resources has increased upto an enormous extent due to several factors including increased demand of food, erratic behavior of monsoon, developmental pressure of various allied sectors *etc*. Currently, the available 70% of water resources in India being used to fulfill the water demand for agriculture and the 80% of domestic water supplies come from groundwater which led to rapidly declining groundwater tables in most of the states in India and has found no longer sustainable. Present study has primarily highlights the need of the Indian conditions for treatment and reuse of wastewater which happens to be the main cause for pollution of water resources in India. In this study efforts were made for assessment the potential of model sewage fed aquaculture system of capacity 8 MLD in Karnal, India for wastewater treatment, reuse and resource recovery during the treatment process. The in-depth evaluation study were conducted for integrated assessment of STP in association with health, environment, society, and institutions aspects as well as quality of treated effluent subjected for reuse in irrigation. The Economic analysis of the model sewage-fed aquaculture system shows that there was an annual profit of INR 8-10 lakhs through selling of fish in local market as well as ample amount of revenue generated through selling of treated effluent to the farmers. Also, the irrigation with treated wastewater able to save the fertilizer upto 50kg of Urea and 50kg of diammonium phosphate during cultivation of one acre of crop annually. The system was found good for removal of physic-chemical pollutants and also found very effective in removal of bacteriological pollutants. The reported removals for total coliform, fecal coliform and fecal streptococci were found 99.988, 99.965 and 99.9567, respectively.

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1. Introduction

A large volume of wastewater continues to be discharged into natural watercourses leading to pollution of the coastal zones and drinking water reservoirs in India [1]. Disposal of partially treated and mostly untreated effluents into rivers and lakes and runoff from urban and agricultural areas are the two main reasons responsible for deterioration of drinking water resources [4]. In addition, the excessive withdrawal of water for agricultural and municipal utilities as well as use of rivers and lakes for religious and social practices, and perpetual droughts limits the capacity of river for dilution of wastes [2, 5]. On one hand the available water resources are rapidly depleted due to increased domestic water demands whereas the available water is getting deteriorated due to disposal of domestic and industrial effluents, on other hand. Although, the number of sewage treatment plants (STPs) have increased over the years in urban India, this increase is not adequate to keep pace with escalating generation of wastewater which results in a large volume of untreated or partially treated wastewater continues to be discharged into natural watercourses leading to pollution of the coastal zones and drinking water reservoirs in India [1, 3].

The conventional mechanised wastewater treatment systems turn out to be rather expensive in terms of both, the installation as well as O&M costs and hardly gave any resource out of the treatment process, whereas the NTSs provide opportunity to produce useful byproducts during the course of treatment. It is argued here that the newer solutions should be such that the peri-urban and small communities should be able to own and operate their wastewater treatment systems [4]. Interestingly, in the recent past, communities seem to accept the natural treatment systems (NTSs) that are capable of providing adequate treatment to wastewaters in conjunction with supplementing fish and nutrition to the food baskets of the fishing communities engaged in managing the systems as well as generating adequate water for irrigation of farms and agro-forests [3]. Also, the engineered NTSs blend well with the agricultural, peri-urban, and rural ecosystems.

There are different types of NTSs practiced in India and the most experienced include, Waste Stabilization Ponds (WSP), Sewage fed Aquaculture, Constructed Wetlands, Polishing Ponds, Duckweed Ponds, and Karnal Technolgy [5]. Sewage Fed Aquaculture system in conjunction with pisciculture is one such technology which has the potential of offering effective wastewater treatment besides providing economic returns as well as generating employment opportunities in the rural areas. The traditional practices of recycling effluent through agriculture, horticulture and aquaculture have been in used in several developed and developing countries in the world [6, 9]. The practices of using waste as a resource for the sustainable rural and urban development is not only help in treating the wastewater but also make the system long-lasting. Moreover, the practices of using wastewater for resources recovery not only reduces the pollution load into the natural water bodies but also make a continuous system of food production irrespective of any environmental disparity such as rainfall or drought.

In the present study efforts have been made for in-depth evaluation of selected sewage fed aquaculture plant of capacity 8 MLD operated in Karnal, India. During in-depth evaluation study the integrated assessment of STP Karnal, India was carried out in association with health, environment, society, and institutions aspects as well as quality of treated effluent subjected for reuse in irrigation.

2. Materials and Methods

To treat the wastewater of Karnal city, the WSP of capacity 8 MLD was established in year 1999 under

Yamuna Action Plan at a cost of INR 1.06 crore. Initially, the WSP units were not being utilized for aquaculture but latter on the facultative and maturations ponds of the STP were decided for production of pisciculture. For the integrated assessment, the data related with technical, physical, geographical as well as social aspects were collected by interviewing operating staff of the STPs as well as by utilizing their literature, log books, and progress reports. Interviews with farmers were also conducted in order to evaluate the satisfactoriness of treated effluent, any adverse health impacts detected throughout the course of handing of wastewater for irrigation as well as the associated cost-economic benefits in comparison with using bore-well water for irrigation. To evaluate the quality of treated effluent during the course of wastewater treatment and resource recovery in the form of fishes, wastewater samples were collected from inlet and outlet of each treatment unit. Care was taken during collection and preservation of wastewater samples that truly represents the existing condition in such a way that it does not deteriorate or become contaminated before it reaches to the laboratory [7]. The collected samples were subjected for analysis of physico-chemical and bacteriological parameters at IIT Bombay laboratory in Mumbai. The all kinds of analysis of collected samples were carried according to APHA, 2005 [8]. Characteristics of raw and treated sewage samples obtained from STP Karnal are shown in table 3.1.

3. Results and Discussions

The wastewater treatment system was found performing satisfactorily in achieving the standards prescribed by CPCB, New Delhi [10] for discharge of treated effluent into the natural water body (as depicted in Table 3.1). Besides the adequate performance for the removal of physico-chemical pollutants, the system was also found effective in removal of total coliform, fecal coliform and fecal streptococci. The overall percentage removal of the system for the total coliform, fecal coliform and fecal streptococci were found 99.988, 99.965 and 99.9567, respectively. This high removal may be achieved by virtue of the presence of high number of protozoan in facultative and maturation ponds which has found responsible for direct killing of bacteria [3]. The plant operator reported that the fish species namely Katla which was currently being cultivated has been found the maximum survival potential among commonly used fish species in tolerating higher organic pollution. During the course of treatment, the density of fish was found to be increased during the course of treatment which gives the direct indication of improved quality of treated effluent.

The treated wastewater is being well accepted by the farmers as it gives additional benefit in consuming lesser fertilizers during cultivation of crops. In wastewater irrigated fields, different types of crops are being cultivated. The most cultivated crops include rice, wheat, maize, millet, barley, jute, cotton, sugarcane and oil seeds *etc*. During the O&M of treatment plant, two types of health risk have been observed, first the health risk associated with handling of effluent during the course of treatment as well as during irrigation field's crops. The second type of health risk associated with sewage fed aquaculture observed in use of process product (fish) which may be found infected with pathogenic bacteria, virus and heavy metals. The persons dealing the operational activities at treatment plant were found well trained and their main tasks were to observe the appropriate flow pattern of wastewater in the treatment units as well as any nuisance in the fishponds (facultative and maturation pond). It was observed that only low skilled manpower may also be found suitable for O&M activities and hence the local community people can own and operate the treatment plant successfully. During day-to-day O&M activities of 8 MLD STP, three persons (2 operators and 1 sweeper) were appointed – who are successfully managing the system.

During treatment of wastewater, the main source of revenue comes from selling of fishes. It was reported that the amount of annual fishes cultivated during wastewater treatment was around 12000 kg to 16,000 kg which gives benefit of INR 6 – 8 Lakhs (fish rate in local market is around INR 50 per kg). The second benefits occurred for selling of treated effluent to the farmers – which cost around 10 – 15 Lakhs per year. It was also found that the farmers using the treated water was able to save the fertilizers upto 50 kg Urea and 50 kg diammonium phosphate – which gives benefit of around INR 1700 during cultivation of one acre of crop during one year of cycle. The practices of using wastewater as the resource for fish cultivation are playing two important roles in the selected area, first recycling of nutrients from wastewater to reduce eutrophication and second the production and continuous supply of fish for community. The treatment plant is giving directly benefits for creating employment to nearby community as well as provides the low-cost fish for poor peoples. The one more benefit from the treatment plant was observed to get better quality of treated wastewater as compared to conventional treatment process because aquaculture significantly contributes in betterment of overall quality of the effluent.

Table 3.1. Performance evaluation of different treatment units of sewage fed aquaculture

Parameter	Units	Raw Sewage	Outlet of Pond 1	Outlet of Pond 2	Outlet of Pond 3	Outlet of Pond 4	Overall % Removal
*p*H	--	7.04	6.4	7.2	7.4	7.8	-10.8
EC	µS	890	980	960	955	965	-8.4
TDS	mg/L	445	440	480	476	483	-8.5
DO	mg/L	0.6	0	2.2	2.8	4.2	-600.0
COD	mg/L	460	266.8	202.8	158.2	129.7	71.8
BOD_5	mg/L	224	138.9	81.9	51.6	31.0	86.2
NH_3-N	mg/L	5.5	4.4	3.3	2.1	1.5	73.1
TKN	mg/L	14.6	12.2	10.4	8.1	6.2	57.7
PO_4^{3-}	mg/L	3.6	3.3	3.1	2.8	2.6	27.6
TP	mg/L	6.54	6.2	5.7	5.3	4.9	24.4
TC	MPN/100mL	1.6×10^7	0.89×10^6	1.4×10^5	0.2×10^4	1.9×10^3	99.9881
FC	MPN/100mL	2.8×10^6	0.2×10^6	1.4×10^4	2.8×10^3	9.8×10^2	99.9650
FS	MPN/100mL	3.0×10^5	8.0×10^4	1.0×10^4	3.0×10^3	1.3×10^2	99.9567

Pond 1 = Anaerobic Pond; Pond 2 = Facultative Pond 1; Pond 3 = Facultative Pond 2; Pond 4 = Maturation Pond; EC = Electrical Conductivity; TDS = Total Dissolved Salt; DO = Dissolved Oxygen; COD = Chemical Oxygen Demand; TKN = Total Kjehldahl Nitrogen; TP = Total Phosphorus; TC = Total Coliform Count; FC = Faecal Coliform Count; FS = Faecal Streptococci

4. Conclusions

The overall performance of the treatment systems was found compliance according to the guidelines prescribed by CPCB, New Delhi for disposal of treated effluent into the natural water bodies. During day-today O&M activities, the treatment system does require any high skilled manpower. This is due to that the sewage fed aquaculture is type of NTSs which does not require any sophisticated instrumentations. For successful day-today O&M activities of 8 MLD, only three persons (two operators and one sweeper) were found adequate. Apart from the adequate performance for the removal of physico-chemical pollutants, the system was performing well in removal of total coliform, fecal coliform and fecal streptococci. The system was found socially relevant to the communities residing in the nearby area as it is giving several direct benefits including continuous supply of fishes at low cost, availability of treated wastewater to the farmers, employment generation during treatment of wastewater, fish cultivations and its selling *etc*. There was certain type of health always remains during the O&M activities related with sewage fed aquaculture – which can be minimized if proper precautions being taken place. The system are generating ample amount of revenue through selling of fishes in the market as well as treated effluent to farmers.

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