IS THE WORKING PRINCIPLE OF ECOLOGICAL ENGINEERING BEING FOLLOWED IN WASTEWATER FED AQUACULTURE?

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ABSTRACT
There has been a paradigm shift towards reclamation of wastewater from high cost to low cost effective technology for treatment of sewage and resource utilization for economy driven activities. Under appropriate conditions, sewage fed fisheries would reduce the cost of fish production by utilizing the sewage induced natural plankton and become cost effective because of savings through chemical fertilizer and supplementary feed. It is conceived that concept of ecological engineering is followed by the way of design and development of sustainable ecosystem for reclamation cum fish culture practices in waste stabilization pond systems. Living machines are also employed as tool for reclamation enhancement in wastewater pond system. However, further research are necessary to critically assess the pathogenic load of the fish grown in sewage fed ponds vis-a-vis, mode of transmission of bacteria and other parasites to fish farmers and the health risk of the fish-consumers who use them after proper cooking process.

Key Words: Wastewater, aquaculture, sewage, ecological engineering.

INTRODUCTION
There has been much concern about the quality and quantity deterioration of freshwater as it is finite in quantity and tangible in nature and is being depleted. The demand for water for human use has almost tripled in the last 50 years and is projected to increase by 70% of the surface water by 2025. As a consequence, there has been much depletion of climate change aggravated inland water resources and its implications on human and ecological receptors. Therefore, it necessitates protecting and conserving 20-60% of fresh surface water supplies to maintain ecosystem functions and to ensure sustainability of the natural resources.

Rapid industrialization during the post war period has caused major changes in ecological footprint resulting in environmental pollution at the subtle level and consequent health hazards through food chain and bio-magnification. Consequently, many water bodies have been turned into perturbed, eutrophic or derelict and remain unutilized for economic activities. This warrants appropriate strategies for water conservation and integrated water resource management through rational use of water and reuse of wastewater, rainwater harvesting, reclamation of eutrophic water bodies and their use for economy driven activities that are necessary for poverty alleviation in the tropical developing countries.

There are different ways by which water conservation and rehabilitation of perturbed aquatic ecosystems can effectively be made. Water conservation strategy may start from individual to community and institutional level in an interlinked manner. A vast number of contaminated or polluted water bodies can be reclaimed or rehabilitated using some low cost, energy saving, nature based green eco-technologies. The terms eco-restoration, bio-

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remediation, rehabilitation, reclamation, biomanipulation are almost synonym with each other having the main focus to restore the perturbed system and bring it back to its original state by way of removal of toxic elements or recover the excess amount of precious nutrient elements which is undesirable causing eutrophication of the system and the ecological process helps converting it into an usable form which would provide valuable ecosystem service to the society.

Emerged in late eighty’s, ecological engineering is the design of sustainable ecosystems that integrates society with its natural environment for the benefit of both. The fundamental principles of ecological engineering are holism, harmony, self-resiliency, regeneration, circulation, multilayer and multiuse system. The ecosystem components are interconnected, interdependent causing multiple interactions among themselves. Ecosystems are rich in information nets, comprising the physical and chemical communication flows that connect all parts, and steer or regulate the system as a whole. Thus, ecosystems are considered cybernetic in nature, but control functions are internal and diffuse involving interaction between primary and secondary subsystems.

One of the important properties of ecosystem is the self-resiliency which indicates the ability to recover when systems are disturbed by perturbation from outside. Self-resiliency includes self-regulation, self-organization, self-regeneration, self-reproduction, self-purification, and so on. This dynamic homeostasis can promote sustainable development and evolution of an ecosystem. The beautiful integration and excellent coordination among different subsystems of ecosystem through chemical messengers have led to develop sustainable ecosystem that may provide service to the society. The collective efforts are greater than the sum total of the components that comprised the ecosystem. This signifies the holistic effects of the ecosystem.

Right selection of species from nature’s library, traditional knowledge, wise planning, innovative application, and patience to natural functioning of ecosystem are the main attributes of the begin-of-the-pipe approach. Since ecosystem perturbations in tropical waters are more pronounced because of high temperature dependent intense metabolism leading to high recycling rates, turnover and complex food web, high biodiversity and high biomass production. As this approach involves integration of traditional knowledge of nature’s biodiversity, it would become a unique tool towards solving much of the environmental problems related with industrial development in the tropical developing countries.

THE AQUATIC ECOSYSTEM

Aquatic ecosystem is a complex system regulated by functional forces of several biotic and abiotic factors which interact with each other towards maintaining ecological equilibrium. Though, ecosystems are capable of accommodating mild, high frequency, external forces including human exploitation and management, diverse communities within the system with a stable behaviour is very sensitive to such high degree of manipulations resulting in decrease in efficiency of ecosystem functioning. Therefore, human engineered sustainable ecosystem has certain advantage to solve the problem and promote the economic growth of the society and ecological development in a sustainable way (Jana et al., 2000).

CHARACTERISTICS OF MUNICIPAL WASTEWATER

Municipal or domestic sewage containing 250-400 ppm organic carbon, 80-120 ppm nitrogen, (C:N=3:1), 300-1200 ppm solid particle, 100-400 ppm BOD, 20-96 ppm CO₂ and pH ranging from 6.9-7.3 is not suitable for direct use in fish farming. However, it becomes most useful after proper treatment and suitable dilution. In most countries, the waste disposal practice is based on the philosophy
that the ‘solution to pollution is dilution’. As a rule, organic and bacterial loads are substantially reduced in the sewage treatment systems for effective use of aquaculture. Industrial sewage comes from industries and contains unhygienic water, obnoxious gases like $\text{H}_2\text{S}$, $\text{NH}_3$, and iron and other minerals. It has a higher C:N ratio than domestic sewage and hence, generally not suitable for direct use in fish farming (Jana et al., 2000). Likewise, the nutrient potentials of sewage sludge are equally prudent. Experiences in China revealed that one ton of pond humus is equivalent to 6 kg of ammonium sulphate. Intensively cultured pond produces about 52.5 tons of humus and silt/ha/yr which is equivalent to 225 kg of urea.

The waste stabilization ponds

Though various methods have been employed all over the world for wastewater treatment and management, waste stabilization ponds have proved to be most trustworthy and useful especially in developing countries due to low capital investment and low operational cost for functioning. As a result, waste stabilization ponds have been strongly recommended for sewage treatment which has been assessed to be not only cheap and safe but would also provide ecosystem service to the society for the production of fish biomass and vegetable crops.

The break down process

Basically, sewage containing dissolved organics undergoes decomposition process in which microorganisms participate in two ways: (a) hydrolytic breakdown of the organic high polymers which constitute the major parts of plants and animal tissues into compounds of low molecular weight, and (b) non-hydrolytic breakdown of the resulting small organic molecules, generally accompanied by the consumption of oxygen. Through this mineralization process, organic molecules are converted into inorganic compounds (Fig 1). In this process, excreta, night soil or organic rich wastewater is decomposed and mineralized into inorganic minerals that induce the production of natural fishfood organisms.

![Fig. 1. Decomposition and mineralization process in pond environment.](image-url)
Nutrients are available to the producer through microbial dependent biogeochemical cycle of organic wastes. The producers in their turn produce oxygen that keeps the ecosystem healthy and wealthy. The oxygen required by the pond bacteria to oxidize the organic load of wastewater is provided by the micro-algae that grow profusely in response to nutrient enrichment (Fig. 2). It is ensured, that the partly reclaimed water in maturation ponds is further improved by the solar energy driven algal-microbial mutualism in aquaculture ponds and then achieve the standard water quality before being discharged into the natural waters. Further, partial decontamination of wastewater is achieved by the microalgae dependent oxygenated conditions that are helpful in killing most of the anaerobic bacterial pathogens present in the wastewater environment.

**SYSTEM**

Sewage fed aquaculture is a unique system for biological production using the 5 R policies of cleaner production. It is an integrated bio-system with at least two subsystems, the wastes from the first subsystem is used by the next subsystem to produce value added cash crops (Edwards, 2000). Wastewater aquaculture ponds provide an economically viable source of high protein through recycling of organic residues in the eco-friendly balanced system, and thus maximizing waste recycling and converting wastes into wealth. In the concept of wastewater aquaculture, the organic wastes are recycled into fish biomass since fish is the cheapest animal product when grown on wastewater. In tropical countries, fish grows rapidly on wastewater or organic wastes, and thus replace the need for expensive supplementary diet and conventional chemical fertilizers. Because of self-resilience of the ecosystem, the wastewater gets cleaned and usable while the sewage effluent passes through the series of constructed ponds from anaerobic to the last maturation pond. The self-purification processes are also added by human engineered intervention using living machines that enhances the reclamation process of the wastewater. The reclaimed is used for multidisciplinary economy driven activities such as aquaculture, hydroponics and source of fertilizer, irrigation in agriculture, horticulture crops landscape development, and so on. This activity helps not only in water conservation but also boosts the rural economy since the water at the end of pipe are used for industries such as cooling processes in power plants, fire protection, road cleaning and many others.

In order to reduce the toxic effects of some heavy metals like cadmium, chromium, lead and nickel, the fish farmers allow the growth of water hyacinth (Saha & Jana, 2003) in the canal, or around the pond margins. The constructed wetland systems in Kalyani (West Bengal, India) have been observed

![Fig.2. Algal–bacterial mutualism in facultative and maturation ponds](image)
to reduce more than 30% of the cadmium load from inflow water (Rana et al., 2011). Introduction of Lamellidens into the cadmium containing wastewater systems resulted in significant reduction of cadmium by tissue mediated uptake of several living machines (Das & Jana, 1999, 2003, 2004). Presence of algal bloom in water bodies was also controlled by the introduction of herbivorous fish silver carp (Dutta & Jana, 1998).

The sludge is used as a source of organic manure in crop production. All these integrated multidisciplinary economy driven holistic approaches help poverty alleviation and conserve water and wetlands, reclaim wastewater, combat environmental pollution in a more definitive balanced way that create a benign environment necessary for sustainable development.

The culture practices

Raw sewage is harmful to fish life and hence should not be directly used in fish farming. After safe dilution with freshwater (1:1 to 1:4) or proper loading of diluted sewage, city sewage provides congenial environment and aerobic condition necessary for fish culture. As a rule, organic and bacterial loads are substantially reduced in the sewage treatment systems for effective use in fish culture. Considerable reduction of organic and BOD loads of sewage is a prerequisite before its transfer to aquaculture facilities. Generally, the BOD load of raw domestic sewage ranging between 120 and 400 mg l^{-1} and primary treatment by sedimentation is likely to reduce it by 33%. It is suggested, that a BOD_{5} level of 10-20 mg l^{-1} of pond water should be continuously maintained for better fish growth (Jana, 1998). Because of presence of certain obnoxious gases like, unionized ammonia, carbon dioxide and hydrogen sulfide in the treated effluents even after reduction of BOD load, the treated effluent remain anaerobic and is not suitable for direct use.

In Kalyani sewage-fed fish farms, partially treated sewage effluents are also flown along a gradient through a series of anaerobic, facultative and fish growing ponds, and finally effluents are discharged into the river canal. In practice, domestic sewage is carried by underground drains or sometimes by surface channels to the fish growing ponds. The wastewater aquaculture system network at Cuttack (Odissa, India) comprises 18 duckweed culture ponds, two fish culture ponds and two marketing reservoirs for the depuration before marketing of fish. An average retention time of 5 days was maintained throughout (Ayyappan, 2000).

Selection of fish species

Judicious selection of fish species is another key factor for effective utilization of sewage in fish culture. Omnivorous and bottom grazing fishes consume directly the organic detritus of sewage fed ponds and thereby help to eliminate obnoxious gases from ponds bottom and to keep the pond aerobic through bio-turbation activity. The species those are suitable for wastewater aquaculture are: Indian carp, Israeli carp, silver carp, bighead carp, grass carp, common carp, hybrid buffalo, catfish, largemouth bass, tilapia, freshwater prawn and so on. Tilapia has been considered an ideal species for rearing because it can tolerate relatively low oxygen, wide range of salinity, high level of ammonia and other adverse ecological factors. Likewise, air breathing catfishes like, Clarias batrachus are also considered suitable in most situations. Carps which are often more sensitive to low dissolved oxygen and high level of ammonia need larger water area for growth. In some sewage fed fish ponds of West Bengal, freshwater giant prawn culture is quite successful.

Fish Growth

In general, fish yields from wastewater fed ponds are 2-4 times higher than those from ordinary fish culture practices. The growth rates of different
species of carp were as follows: big head carp > rohu > grass carp > mrigel. The mortality was maximal in mrigel and least in common carp, suggesting that the latter was more tolerant to sewage fed aquaculture than the former. Recycling of domestic sewage in Kolkata wetlands yielded 7000 kg ha\(^{-1}\) yr\(^{-1}\) of carp and 9350 kg of tilapia. It is estimated that the return over investment is 28%, the profit to turnover is 22%, and return over fixed capital cost is 7%. At Cuttack city with duck weed based wastewater aquaculture system, the per cent survival of common carp was found to be less than other species reared.

**Nutrient removal efficiency**

It is fairly established that waste water aquaculture systems are highly effective in the reclamation of sewage effluents. There was a distinct gradient of COD, ammonium, nitrite, nitrate and total nitrogen, exhibiting the highest values at the source of effluent and lowest at the final discharge points, suggesting a clear cut microbial degradation and improved water quality along the effluent gradient. The COD values at the source were reduced as much as 20-30% and attained the values of mg l\(^{-1}\) in the last fish growing pond.

**Microbiological considerations**

Usual load of bacteria in raw sewage ranges between \(10^8\) to \(10^9\) MPN 100 ml\(^{-1}\) or above. Some non-pathogenic bacteria present in domestic sewage are largely involved in biogeochemical cycle of the wastewater system.

It has been demonstrated that the ponding system not only reduces the nutrient and organic loads to 50-90%, the bacterial loads are also reduced by 2-3 log units at 100 kg COD ha\(^{-1}\)day\(^{-1}\). The fecal coliform concentrations were reduced by 4 log units within 24 hours of retention. Researches have shown that the values of fecal coliform were relatively less than total coliforms, and a downward trend in the values of fecal coliform was noticed (Patra et al., 2010, 2012). In fact, the water quality of sewage effluents at the maturation ponds achieved the water quality criteria required for fish farming and that criteria is safe as per WHO (2006) recommendations.

**CONCLUSION**

The wastewater aquaculture is highly imperative because of its immense benefits for conservation of water resources, aquatic biodiversity, production of zero or no wastes from industries and cost effective aqua-based production. However, much study are required to critically assess the pathogenic load of the fish grown in sewage fed ponds vis-a-vis, mode of transmission of bacteria and other parasites to fish farmers and the health risk of the fish-consumers who use them after proper cooking process. However, maintenance of fish in isolation pond for 2-3 weeks prior to marketing is considered to be a safe measure for decontamination or minimizing the pathogenic load of the fishes.

In many cases, fish farmers do not consider the public health aspects because they are not aware of its relevance. Therefore, basic training program should be undertaken to include lectures and demonstrations encompassing the topics on wastewater as a reservoir of human pathogens, the route of infection of various pathogenic organisms present in wastewater and in the fish ponds, wastewater treatments prior to use in the fish ponds and basic environmental hygiene and sanitation rules. Other efforts are to increase public awareness and education, to provide information to individuals on how they can contribute to solving lake and reservoir problems.
REFERENCES


