Public Health Issues
of Wastewater-fed Aquaculture

Farming fish in ponds fertilised with urban wastewater or sewage is not widespread although it does benefit millions of people, particularly in China, India and Vietnam. It provides food and employment, particularly for the poor, and more general environmental benefits such as low-cost wastewater treatment, stormwater drainage and provision of green areas or "lungs" which improve the health and well-being of urban residents.

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Harvesting fish from a wastewater-fed pond in Calcutta.

It is important to note that most wastewater-fed aquaculture systems, although often large and covering areas of tens to hundreds of hectares or more, are traditional in the sense that they have been developed mainly by farmers and local communities. Pond complexes have been developed in the past in water-logged, low-lying areas such as lakes, marshes and wetlands mainly in periurban areas where settlement and alternative uses of land have been impeded. The availability of large volumes of nutrient-rich wastewater pouring out of the city at little to no cost, led to its re-use by farmers as a fertiliser for fish culture. They gave scant attention to either waste treatment or to public health.

Fish is mainly purchased by less well-off consumers

First impressions invariably are that fish farmed in such systems are not safe to eat because of likely infection from disease-causing organisms contained in domestic wastewater. In contrast, anecdotal evidence and a growing body of scientific evidence indicate that such fish pose relatively low risks to public health -even though wastewater is increasingly contaminated with toxic-laden industrial wastewater- contributing in particular to increased welfare of the urban and periurban poor.

Public health aspects of wastewater-fed aquaculture are discussed here with reference to Calcutta. Calcutta is the largest and best documented system in the world, but in contrast to most other areas, the benefits derived from these experiences are leading to the development of newly-designed systems elsewhere in the Calcutta Metropolitan Area (CMA) and West Bengal.

THE CALCUTTA SYSTEM

The wastewater-fed fish ponds cover about 2,500 ha and are located in a government-designated recycling region for the city which also includes cultivation of vegetables on wastewater, garbage and rice in paddy fields irrigated with fish pond effluent (Ghosh 1990). Since about 1930, when a landowner discovered how to farm fish by releasing wastewater by gravity from the sewage channel leading to the estuary, the area of fish ponds expanded rapidly to a peak of about 8,000 ha in the 1950s, after which it declined markedly to about 2,000 ha today, due to urban expansion. Major cultured species are rohu, silver carp and tilapia, which produce relatively high yields of 3-8 tonnes/ha/year because of multiple stocking and harvesting of fish in fertile pond water. Currently, the wastewater-fed ponds provide employment for about 17,000 poor fishermen and produce 20 tonnes of fish daily for urban and periurban markets in Calcutta. Fish is mainly purchased by less well-off consumers.

Calcutta is located in West Bengal where a cultural preference exists for fish as compared to meat. Large- and small-sized fish appear to be purchased by different socio-economic groups of city dwellers, by the better-off and poorer consumers, respectively (Morrice et al. 1998). Moreover, larger carps, which dominate freshwater fish on the market, are mainly imported on ice from other states in the country by rail, with most of the smaller-sized fish raised locally in wastewater-fed ponds. Small fish (< 250 g) dominate sales in city retail markets. Producers either transport fish to city markets themselves, or sell them to poor traders who transport small fish in

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open bowls and get higher prices if the fish remain alive.

In the Calcutta system as well as in most other wastewater-fed pond systems, the wastewater has already undergone partial treatment as it takes several hours to flow from city outfalls along open channels to the ponds. As it flows into the ponds, it is rapidly diluted with pond water. Nutrients in the wastewater stimulate aquatic food webs comprising phytoplankton and zooplankton in the water column and organisms such as midge larvae and tubifex worms in the pond sediments, which provide natural food for fish.

The colour of well-managed, wastewater-fed fish ponds is green due to the dominance of phytoplankton in the water. Besides providing the main source of food for the three major filter-feeding species of fish farmed in the ponds, the phytoplankton have a major influence on the quality of the water in the ponds. Intense photosynthesis by phytoplankton in "green water" ponds raises the pH during the daylight hours, which helps to remove both microbial and chemical contaminants that would otherwise threaten public health.

HEALTH RISKS

The major health risks in wastewater-fed aquaculture are both biological hazards from potential disease-causing organisms in human excreta in domestic wastewater, and chemical hazards from industrial effluents (see table 1). In Calcutta, there is an unregulated discharge of effluents from thousands of small-scale factories; also 600 tanneries discharge 150 kg of the heavy metal chromium daily into an urban wastewater channel that drains into fish ponds.

Biological hazards

Research has shown that there is a rapid dying-off of enteric bacteria and viruses in well-managed, wastewater-fed fish ponds (WHO 1999). This is due in part to phytoplankton raising the pH in "green water" ponds. Despite this, pathogenic enterobacteria (from the human digestive tract) have been occasionally found in fish guts although not in fish muscle. Consumption of wastewater-fed fish would thus not be a hazard to consumer health if they are gutted, washed and cooked well. Risk from enteric viral disease is considered to be lower than for bacterial diseases based on epidemiological evidence (WHO 1999).

Food-borne trematodes (Chinese liver fluke, *Clonorchis sinensis;* the live fluke, *Opisthorchis viverrini)* cause diseases in some parts of the world. The cause of infection is ingestion of raw, poorly-cooked or minimally-processed fish that contains viable trematode cysts. Another trematode, *Schistosoma* spp, which causes Schistosomiasis or Bilharziasis, infects humans by larvae penetrating the skin and is thus a potential occupational disease for pond workers.

Unlike microbes, trematode worms are distributed locally. None of the major species occurs in Calcutta: *Clonorchis sinensis* is endemic to China and N. Vietnam; *Opisthorchis viverrini* to Laos and Thailand; and *Schistosoma* spp. mainly to parts of Africa and Latin America. The relative contributions of aquaculture and wild fish to food-borne trematode disease are unknown.

Consumers face a greater (although still relatively low) risk to their health than producers or fish farm workers. With the exception of Bilharziasis, most diseases occur through consumption of contaminated fish. Bilharziasis can be controlled by integrated approaches involving health education, snail control and selective population chemotherapy in areas where it occurs (McCullough 1990).

Chemical hazards

Urban wastewater is likely to contain a high concentration of chemicals such as heavy metals and chlorinated hydrocarbons if it is mixed with industrial wastewater. The chemistry and fates of such chemicals in the aquatic environment are complex. However, concentrations of heavy metals in fish do not exceed regulatory or recommended levels, even when the fish have been harvested from water with high metal concentrations (WHO 1999, Eisler 2000). Heavy metals are precipitated as insoluble sulphides or hydrated oxides under anaerobic (or oxygen-free) conditions as occur in raw sewage, and levels are reduced further in the alkaline water of wastewater-fed ponds as the solubility of metals decreases with increasing pH.
In addition, metals also tend to precipitate into anaerobic pond sediments rich in organic compounds. Furthermore, although fish absorb metals through the gills and from food in the gut, they regulate the concentrations of inorganic metal compounds in muscle tissue. An exception is mercury, which is poorly regulated by fish in its organic form, methyl mercury. However, this is primarily a concern in older and larger carnivorous fish, which

Table 1: Relative importance of various health risks in wastewater-fed aquaculture

Health risk	Relative importance: low risk	Relative importance: higher risk
Biological hazards		
Microbes		
Bacteria	●	
Viruses	●	
Trematode worms		
Clonorchis		●[1]
Opisthorchis	●[1]	
Schistosoma		●[1]
Chemical hazards		
Heavy metals	●	
Chlorinated hydrocarbons		●

[1] local importance

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Poor traders transporting fish from wastewater-fed ponds to market in Calcutta.

Several new wastewater-fed aquaculture systems have recently been constructed in India. These include pre-treatment since wastewater re-use has been accepted by local governments as being superior to conventional mechanical treatment plants in terms of cost, benefit and reliability (Ghosh 1998). Three systems have been constructed within the CMA under the Ganga Action Plan to reduce the adverse environmental impact of municipal wastewater on the river Ganges, and another system has been constructed in Kalyani township in West Bengal (Jana, 1998). A system at Mudialy in the CMA that receives a high amount of industrial wastewater has recently been upgraded also by introducing anaerobic ponds and water hyacinth-filled canals. Furthermore, an improved fish pond design has been published for India (Mara 1997) based on a concept of maximum production of fish safe for human consumption from wastewater (Mara et al. 1993).

are at the end of long food webs because of bioaccumulation, rather than in fish cultured in wastewater-fed ponds (which feed low down in the food web and are harvested when relatively small and young).

Although they were well within recommended safety levels, residues of three heavy metals (cadmium, chromium and lead) in three commonly raised species (the Indian major carps *mrigal* and *rohu*; and tilapia) were much higher in fish from wastewater-fed ponds purchased at seven markets in the CMA, than from a rural market (Biswas & Santa 2000). City vegetables also had higher heavy metal content than those from the rural market. Although the risk of unsafe levels of heavy metals in fish raised in wastewater-fed ponds is very low, there is a need to consider the total daily intake of metals from all sources. This is especially so if there is daily consumption of fish and vegetables contaminated with heavy metals, which are staple foods in Calcutta.

Fish raised in contaminated water show only low tissue levels of organic pollutants such as chlorinated hydrocarbons. However, it is recommended that these should be considered as a risk because of the limited amount of available data (WHO 1999).

TOWARDS INCREASED PUBLIC HEALTH

Although the risk to public health from wastewater-fed aquaculture appears to be low, safety may be further improved by various means (Edwards 2001):

Introduction of more realistic guidelines

The current, tentative guidelines of WHO (1989) are "unduly restrictive" and have constrained the development of more widespread wastewater-fed aquaculture. The high recommended degree of treatment of wastewater to 1 x 10^3 faecal coliforms / 100 ml before it is introduced into a fish pond may require a series of ponds, which leads to minimal fish production because of nutrient removal before the wastewater stream enters the fish pond. The WHO recognised this and called for epidemiological guidelines based on actual risk rather than the current guidelines based on potential risk (see page 25). The WHO (1989) also recommended that guidelines, which are currently being revised, should follow a more integrated approach involving control of wastewater application, exposure control and promotion of hygiene as well as wastewater treatment.

Wastewater should never be used raw

Primary treatment in particular is required, with a minimum of 8-10 days to remove trematode worms which are considered to be one of the major threats to public health (WHO 1989), at least in some areas. Primary treatment would also increase the removal of toxic chemicals because it has anaerobic conditions.

Reduction of the level of industrial effluents in urban wastewater

This may be difficult to achieve in rapidly industrialising developing countries. Even if fish do not contain hazardous levels of toxic chemicals, it may prove increasingly difficult to market fish contaminated with industrial wastewater as they are tainted (smell and taste) with petroleum and phenolic compounds as has happened in China (Edwards 2000).

Control of wastewater application

This should be introduced by suspension of wastewater loading for 2 weeks prior to fish harvest and holding fish for a few hours to facilitate the evacuation of their gut contents.

Production of good hygiene

This includes handling and processing of wastewater-fed fish, including gutting, washing, avoidance of cross-contamination with other food in the kitchen, and cooking or processing well

Hazard Analysis and Critical Control Point (HACCP)

Introduction of the principles of the HACCP system could be a general strategy to control specific hazards, thereby reducing the need for costly routine end-product testing (Reilly & Käferstein 1997). As there is no conclusive evidence for passive transfer of pathogenic bacteria and viruses from wastewater-fed fish to humans, and contamination of fish with toxic chemicals is usually within regulatory limits, the major critical point may be to achieve the total elimination of helminth or worm eggs. This is feasible within the recommended guidelines for the minimal treatment of wastewater prior to its use in aquaculture (Mara et al. 1993, Mara 1997) although it would be superfluous for Calcutta and West Bengal.

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