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Literature review

Renewable natural resource-use in livelihoods at the Calcutta peri-urban interface

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DFID Natural Resources Systems Programme

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1. Introduction

Major land-water interface (LWI) production systems in peri-urban Calcutta have been described by a number of authors. Strategies employed include horticulture, wastewater aquaculture and irrigated rice production (Olah, Sharangi and Datta 1986; Ghosh and Sen, 1987; Ghosh, 1990; Ghosh, 1991; Kundu, 1994; Jana, 1998). Horticulture practices have evolved to use nutrient enriched wastewater from the city for irrigation, and to exploit organic residues, separated from solid waste collected in Calcutta, as a nutrient source and soil conditioner. Ponds managed for wastewater aquaculture have been established in wetland areas close to sewerage canals draining away from the city; rice paddies further from the urban fringe are also irrigated with wastewater from these drainage canals. In conjunction, these practices have evolved to produce dynamic, interdependent farming systems at the LWI in peri-urban Calcutta. This review summarises previous development initiatives related to production systems at the Calcutta peri-urban interface, describes the major production systems, constraints facing operators, benefits that may be contributing to the continued operation of these systems and finally identifies some key knowledge gaps that require further investigation.

From the review it is evident that although much is known regarding the management and operation of the large-scale aquaculture and horticulture enterprises in the region, little work has been done on assessing the role of employment and products from these systems in the livelihoods of poor people. Consequently, specific knowledge gaps relating to the role of these farming practices in the livelihoods of poor people are proposed for further investigation. The contribution of income derived from employment in peri-urban production systems and associated support activities to the livelihoods of those employed should be evaluated, and the relative wealth of these individuals assessed. Furthermore, despite the proposition that these peri-urban production systems supply affordable vegetables, fish and livestock to urban markets it is not known whether poor households have access to this produce, therefore, it is suggested that this issue requires further investigation. However, in addition to examining the role of these production systems in the livelihoods of poor people, it is proposed that further investigation on the constraints reviewed here will assist in the identification of development opportunities and researchable constraints, that when addressed may lead to improved prospects for livelihoods enhancement. Finally, it is proposed that knowledge generated on the constraints and opportunities for livelihoods enhancement through the proposed study will prove valuable in developing peri-urban natural resource management strategies that benefit the poor.

2. Previous development initiatives

Wastewater aquaculture production systems at the Calcutta peri-urban interface have attracted much international attention as a model system for the productive reuse of waste resources. Contributions to the UNDP-ESCAP-World Bank sponsored workshop highlighted aspects of wastewater reuse practices for aquaculture, including a series of recommendations for further research on the design and operation of culture systems, public health aspects and technology transfer and dissemination (Edwards and Pullin, 1990). Following this conference, it was widely acknowledged that the East Calcutta Wetlands system should be investigated further to elucidate the complexity of the inter-relationships within wastewater aquaculture systems (Edwards, pers. comm.).

Subsequently, ODA commissioned a project identification mission (Asian Institute of Technology, 1991) and following this initial review, ODA commissioned Lagoon Technology International Limited to conduct a pre-appraisal mission to develop a research proposal for a two phase project, the first focusing on the operation and performance of existing wastewater aquaculture practices and the second facilitating the implementation of findings and recommendations (Lagoon Technology International, 1993). Despite a comprehensive description of the physical nature, health risks, social aspects, environmental considerations and future prospects, a detailed project proposal and an assessment of local institutional capacity, ODA requested a follow-up mission prior to commissioning the full project (Muir, Goodwin and Walker, 1994). The purpose of this study was to develop a more integrated approach considering the relative merits of alternative sewage treatment and wastewater aquaculture, and also identified potential clients for research outputs. The authors concluded that a major research and development project was difficult to justify, and that a more modest study would be appropriate. This could review existing information, provide initial technical and economic data to waste managers and assist in creating a focus for further development, including support for local actors and stakeholders involved in integrated waste reuse.

Following this recommendation, the management of the DFID Aquaculture Research Programme commissioned a programme development exercise, entitled 'Constraints and opportunities for wastewater aquaculture: identifying directions and mechanisms for change'. This short project focused explicitly on institutional issues, policies, structures and processes that influence the operation of ponds managed for wastewater aquaculture at the peri-urban interface. A preliminary review compiled at the outset of the project identified a range of issues that were considered relevant to the current status and future prospects of wastewater aquaculture. Through a series of field visits to case-study sites i.e. Calcutta, Dhaka, Saidpur and Bangkok it was possible to place these issues in context, assessing their importance with respect to specific situations and ultimately developing a framework suitable for evaluating the potential of wastewater aquaculture.

Calcutta was identified as an important study site due to the existence of traditional wastewater aquaculture practiced in an extensive area of wetland to the east of the city. However, reports by Mukherjee (1996), Kundu (1994) and Muir et al. (1994) have described a number of factors that appear to threaten the sustainability of the system. During the field visit a range of stakeholders e.g. farmers, international development agencies, researchers, donors, non-government organisations, government departments and local authorities, were identified. The perceptions of these various groups regarding wastewater aquaculture were ascertained through interviews employing open questioning. Using information obtained during the study it was possible to classify the various issues that influence the development and sustainability of wastewater aquaculture in general groups of systems features e.g. organisational considerations, economic implications, public health issues or ecological interactions. The processes at work within these various fields act at a variety of scales ranging from the individual or micro scale through to the global or geo-environment; placing wastewater aquaculture in this context enabled the development of a systems perspective of a major LWI production system at the Calcutta peri-urban interface. The following section describes the main features of this system and considers its relationship with horticulture, rice production and livestock farming.

3. LWI production systems at the Calcutta peri-urban interface

Kundu (1994) describes in detail the origins and current status of the major peri-urban LWI production systems in the wetlands immediately to the east of Calcutta, the major production systems i.e. wastewater aquaculture and horticulture are discussed in more detail in the following sections. Rice production in paddy fields at the Calcutta peri-urban interface has also been described and this aspect of the agro-ecosystem is reviewed below. However, having reviewed the literature, it appears that little work has been undertaken regarding the importance of livestock in the LWI production systems at the Calcutta peri-urban interface.

3.1. Wastewater aquaculture

Wastewater aquaculture in the context of this study is the culture of aquatic organisms carried out in water that, having fulfilled its primary function, is discharged from the 'blue water' based societal system (Falkenmark, 1997) into systems incorporating aquaculture. Two distinct categories of aquaculture utilising wastewater can be identified. The first is the formal development of wastewater aquaculture, making deliberate use of wastewater as a nutrient source. The second is the development of aquaculture in waterways 'contaminated' or indirectly enriched through wastewater discharges; this can be considered an informal approach to wastewater aquaculture. In the majority of cases wastewater aquaculture, whether formal or informal, is synonymous with aquaculture in peri-urban settings.

Edwards (1992) presented a comprehensive review of wastewater aquaculture systems from 21 countries. Systems described in the various countries were classified according to the delivery system used to introduce the faecal material into the aquaculture system i.e. overhung latrines, cartage of urban nightsoil to the fishponds, faecally polluted surface water and sewage water. This study is primarily concerned with the use of faecally polluted surface water and sewage water in wastewater aquaculture systems. Informal wastewater aquaculture systems receiving faecally polluted surface water were described in five Asia countries i.e. Indonesia, Japan, China, Sri Lanka and Taiwan (Edwards, 1992). Faecally polluted surface water containing human waste is commonly used in Indonesia to culture fish (Edwards, pers. comm.). In Bogor, Indonesia, faecally polluted surface water was used to culture red tilapia; the majority of the wastewater was grey water, but excreta was also being discharged to this particular drainage system (Edwards, 1992). Indonesian aquaculturists have also developed a system of culturing common carp (*Cyprinus carpio*) in bamboo cages positioned in canals containing faecally polluted surface water. In the traditional system, carp were cultured without the use of supplementary feeds and the fish would feed on benthic organisms e.g. chironomids; this system has now been modified and supplementary feeds are being provided to enhance fish production.

In addition to informal wastewater aquaculture systems in Asia that received faecally polluted surface water, Edwards (1992) noted four Asian countries (India, Indonesia, Israel and China) producing fish in formal wastewater aquaculture facilities utilising sewage water. This author also reported that formal systems had been developed in four European countries (Czechoslovakia, Poland, Russia and Germany) and four African countries (Kenya, Malawi, South Africa and Zimbabwe). With the exception of Germany, recent accounts of the formal wastewater aquaculture systems in these countries are limited. Of the numerous wastewater aquaculture systems developed in Germany during the past century (Prien, 1990; Prien, 1996), only the Birkenhof wastewater aquaculture system situated to the north of Munich remains operational (Prein and Edwards, 1989). The Munich wastewater aquaculture system was originally used for secondary treatment; river water was mixed with the effluent from the primary treatment system in a ratio of six to one. Currently the Munich wastewater aquaculture system functions as a tertiary treatment system, secondary treatment being performed by an activated sludge plant.

Wastewater aquaculture is extensively practiced in the Thanh Tri District of Vietnam; during the 1960s a central canal system was constructed to transport wastewater away from the urban areas. Ponds were subsequently constructed adjacent to this canal, wastewater was then pumped from the canal into the fishponds. The reticulated nature of the canal system means that although fishponds situated further from the urban area were not receiving nutrient rich wastewater, the water they were receiving was rich in biota e.g. phytoplankton assemblages. The management of some wetland areas receiving wastewater included the cultivation of rice in addition to fish cultivation. Fish yields in the wastewater aquaculture system ranged from between 4.7 t ha^{-1} in rice-fish culture systems to 5.6 t ha^{-1} in fish-only culture systems during the ten month growing season; in 1992 the system produced 3,900 t of fish (Hoan, 1996).

The origins and current status of the extensive wastewater aquaculture system in the wetlands immediately to the east of Calcutta, India are described in detail by Kundu (1994) and an economic appraisal of the system is presented by Mukherjee (1996). This peri-urban aquaculture system, widely referred to as the east Calcutta wetlands, consists of approximately 154 fisheries or *bheries* that cover an area of some 3,000 hectares. The wastewater aquaculture system receives 550,000 m^3 of untreated wastewater per day (Edwards and Pullin, 1990); wastewater from Calcutta is pumped into a series of secondary canals that convey the wastewater to the extensive wetland that, in addition to facilitating wastewater aquaculture, supports an area of wastewater agriculture. It is currently possible to achieve yields of approximately 7 t ha^{-1} in ponds receiving wastewater; total annual production from the system has been estimated at approximately 13,000 t of mainly Indian major carp and tilapia. Fish produced in this system is sold at nearby markets in Calcutta and represents ~16% of total fish sales in the municipality.

In the past, various actors, including farmers, local authorities, researchers and international donors, have developed wastewater aquaculture systems in a wide range of geographic and socio-political situations. However, with the exception of the system in Munich, formal wastewater reuse systems have been implemented by fishermen and agriculturists i.e. farmers have been the main agents of development. Institutional actors have largely been responsible for developing experimental and pilot-scale systems for wastewater aquaculture (Edwards, pers. comm.).

3.2. Horticulture

Horticulture practices exploiting solid waste and wastewater resources as production enhancing inputs were established around Calcutta during the 1880s, at this time ~260 ha of land was being used for garbage dumping and farming, by the 1980s the area being used for vegetable production had increased to ~320 ha (Ghosh and Sen, 1987). According to a survey by the Institute of Wetland Management and Ecological Design (1986), cultivation of this land constituted the main occupation of people form nine local villages. Garbage dumping in the wetland area has been planned to produce a mixed landscape of fishponds and agricultural land, the reason being that vegetable growers depend on water from the fishponds for irrigation; Kundu (1994) found that 60% of growers surveyed relied on this water source for irrigation. The production of vegetables from farming systems based on waste reuse has been estimated at 370 t ha y^{-1} (Ghosh and Sen, 1987) with producers routinely cultivating more than eight types of vegetable on their land (Kundu, 1994). However, recent trends in demand have lead to producers cultivating more salad vegetables and herbs (Giri, 1995; cited in Furedy, Maclaren and Whitney, 1997). Although solid waste from Calcutta has been used traditionally in these systems, recent problems with the supply have resulted in some producers being forced to use chemical fertilisers. The range of problems and benefits associated with horticulture at the Calcutta peri-urban interface are discussed in subsequent sections.

3.3. Irrigated rice production

In common with vegetable producers, rice farmers exploit water from fishponds to irrigate paddy fields at the Calcutta peri-urban interface. However, it appears that recent accounts regarding the extent of land used for rice cultivation and irrigated with wastewater from peri-urban fishponds are absent from the literature. Ghosh and Sen (1987) report that during the 1960s around 2,400 ha of fishponds were converted for rice cultivation due to problems of land tenure, and that rice was cultivated on 400 ha of the dry bed of the Bidyadhari River; in both instance water from neighbouring fishponds was used for irrigation. Ghosh and Sen (1987) note that two rice crops may be grown annually, *aman* during the rainy season and *boro* during the winter season, yields for *aman* and *boro* rice have been reported at 2.3 and 2 t ha, respectively, however, over half of the area used to cultivate *aman* rice is not suitable for cultivating *boro* crops. This literature review also suggests that knowledge regarding the number and status of those engaged in rice cultivation at the Calcutta peri-urban interface has not been communicated widely.

3.4. Summary

From this review it is evident that peri-urban aquaculture, horticulture and rice production have a mutual dependence on wastewater from Calcutta, however, the nature of agreements and strategies for sharing the wastewater resource have not been widely reported, nor the constraints associated with this mutual dependence. The general extent of these farming practices have been described and mean levels of productivity have been extrapolated, however, knowledge on the range of productivity and the relationship this has with access to resources, input levels and management strategies has not been reported. Furthermore, the apparent lack of studies regarding livestock farming around Calcutta may be a significant oversight as it has been shown the livestock production at the peri-urban interface of other cities plays several important roles in the livelihoods of poor people (Richardson and Whitney, 1995; Brook and Davila, 2000; Nunan, 2000). With respect to Hubli-Dharwad, India, Nunana (2000) noted that urban dairies contribute to household nutrition and income generation, manure inputs are important in maintaining soil fertility and livestock provide draught power for other peri-urban agricultural activities. The following section presents a review of possible constraints to the continued operation of the major production systems outlined above.

4. Constraints to continued operation

Furedy (1990) reported that wastewater aquaculture was in decline in several countries i.e. Japan, Malaysia and Taiwan, and that in China, aquaculture using human excreta was due to be phased out. Furthermore, Muir et al. (1994) report that a general fall in productivity has been observed in the peri-urban fishponds to the east of Calcutta, a production system that has been regarded widely as a model for wastewater aquaculture. With respect to traditional peri-urban production practices a number of factors threaten their continued operation and constrain the development of more refined management strategies for this potentially highly productive system. Indicators, such as the area managed for peri-urban production, the number of people employed and the levels of production, show a general decline (Kundu, 1994; Muir et al., 1994; Mukherjee, 1996). Several diverse factors have impinged upon this established and potentially highly productive system (Kundu, 1994). The following sections outline the main factors implicated in this decline and discuss their origins and nature.

4.1. Urbanisation

Institutional issues associated with the decline of the wetland systems of East Calcutta are many and varied. The partition of India and East Pakistan in 1947 initiated a mass migration of people into the urban areas of India (Kundu, 1994). This trend of urban migration continues not only in India but many other developing countries, with people from rural areas migrating to towns and cities in search of employment. In addition to urban migration other forces contribute to the process of urbanization; industrial development on land at the urban fringe represents a stimulus to the development of settlements for employees, furthermore, increased access to the urban fringe, associated with new roads and improved public transport, increases the attractiveness of land at the edge of towns and cities to industry and commuters. Urban migration, industrial development and improved access represent important factors that contribute to development pressure at the peri-urban interface, and as a result of this increased pressure, traditional extensive waste treatment systems are often seen as archaic and redundant, especially when alternative technologies requiring less land area exist (Khupe, 1996).

This conflict was made explicit by the proposed scheme to abandon 52 ha of oxidation ponds on the outskirts of Gaborone, Botswana in favour of an activated sludge wastewater-treatment system (Khupe, 1996). The oxidation ponds at the Gaborone peri-urban interface received ~25,000 $m^3\ d^{-1}$ of wastewater from the city and achieved a reasonably high level of treatment; the final effluent was used to irrigate vegetables, a golf course and hotel gardens, water livestock, meet the demand of construction activities and was discharged to Gaborone Game reserve to rehabilitate swamps and marshes. Furthermore, treatment employing oxidation ponds required no machinery or energy. However, the land area required for additional ponds to service the needs of the growing urban population was considered by Gaborone City Council to be unacceptable (Khupe, 1996). This technocentric approach to development is not necessarily an answer in itself, the more intensive technological wastewater treatment systems merely concentrate the waste flow, which ultimately still requires disposal (Gunther, 1997). Concomitantly, the water produced by these systems may be less desirable for subsequent uses e.g. irrigation, due to the reduction in its nutrient status.

Urban development encroaching into peri-urban areas affects the physical nature of the environment and leads to more subtle changes in social interactions. In the recent past the Indian government imposed compulsory acquisition on peri-urban areas used for horticulture and wastewater aquaculture; this had both a direct impact on those people displaced and generated feelings of insecurity within the more general community. The largely unregulated sprawl of the urban fringe is seen as an irresistible force, once again generating feelings of insecurity. Feelings of insecurity manifest themselves in what have been termed 'law and order' problems (Kundu, 1994); it would appear that disgruntled labourers, confused as to the legal basis of ownership, dewater the ponds and poach the fish prior to the seemingly inevitable cessation in operations.

Poaching has been described as a key constraint to the sustained operation of ponds managed for aquaculture at the Calcutta peri-urban interface, and this sentiment has been confirmed through key informant interviews. The transient nature of many poor peri-urban communities may act against the establishment of a community spirit and this has been proposed as one factor resulting in individuals and groups poaching fish from local ponds, reducing the financial return to the managers and operators of the system. However, Harrison, Stewart, Stirrat and Muir (1994) considered poaching of fish from ponds in Africa in a different light i.e. as a means to redistribute the benefits derived from aquaculture to the poorer sectors of the community, as opposed to the benefits being retained solely by the better off and more socially and politically active members of the community. This could be considered true of poaching in certain situations, however, in peri-urban Calcutta poaching is often an orchestrated and frequently violent affair (Kundu, 1994), and it is doubtful that the poorest sectors of the community benefit. In the majority of cases anti-social behaviours such as poaching, theft and vandalism represent a serious constraint to investment in infrastructure and improved management strategies in peri-urban production systems.

The distribution of benefits derived from aquaculture to a wider section of the community can occur through the presentation of fish to family and friends in the form of gifts; this custom was reportedly widespread in Saidpur, Bangladesh. In addition, it was found that through the distribution of some fish at harvest time to community members residing closest to the ponds, it was possible to reduce the proportion of unaccounted for fish. This was attributed to either a reduction in poaching carried out by the recipients or greater vigilance on behalf of these neighbours, reducing the incidence of both poaching and predation (Bunting, Edwards and Muir, 1999).

In contrast to the scenario presented above, the demand for land and potential benefit from selling this asset may encourage some owners to limit access to their property; from the perspective of the owner, restricting access may prevent others from laying claim to rights over the property and reduce the potential for conflict that could delay or disrupt the sale. Mechanisms employed to restrict access may include the termination of leases or actively discouraging the continued operation of production practices. Feelings of insecurity engendered through the common practice of issuing only short-term leases have been cited as stifling innovation and constraining investment in the maintenance of the existing infrastructure supporting peri-urban production.

4.2. Labour migration

Many studies suggest that migration of household members from rural to urban areas is prompted by a number of 'push' and 'pull' factors e.g. limited livelihood options in rural areas or opportunities for livelihoods enhancement in urban areas, respectively. However, in many cases rural-urban migration reflects traditional patterns of labour movement determined by social and cultural institutions, and societal strategies to obtain livelihoods (de Haan, 1999). Describing the status of those families involved in horticulture and aquaculture in peri-urban Calcutta, Kundu (1989) noted that a significant number of those sub-letting vegetable plots and employed by operators of ponds managed for wastewater aquaculture were migrants from other States. Furthermore, informal tenure arrangements described by the author indicate that tenants commonly sub-let vegetable plots to their relatives, suggesting that access to land may be restricted through family patronage. Tenure over land resources in peri-urban areas is frequently governed by a number of structures and processes that may conflict with traditional and less formal tenure agreements, consequently, the author noted that during the interview process participants were generally reluctant to discuss the issue of tenure.

The migration of people within rural areas and from rural to urban areas has been documented in a number of settings. In contrast, studies focusing on micro-scale migration of individuals from peri-urban to urban livelihoods appear largely absent from the literature. The reasons for this are not clear, and it may be that this type of migration is not considered significant, or that the difficulty in assessing if and where it is occurring has constrained detailed assessment. However, following an investigation of problems affecting the operators of production systems at the Calcutta peri-urban interface, Kundu (1994) noted that the loss of labour to more highly paid employment represented a constraint to continued operation. Experiences from other regions also demonstrate that the opportunity cost of labour is important in determining the livelihoods adopted by household members. For example, Edwards, Demaine, Innes-Taylor and Turongruang (1996) report that low-input aquaculture, based largely on buffalo manure and some off-farm inputs, is declining. This is because it contributes less than 10% to the income of small-scale farmer households in north-east Thailand, with much of the household income being derived from off-farm employment.

Enhancing the benefits derived by the poor from peri-urban production systems and support services though increased wages and more secure employment arrangements may contribute to the retention of skilled employees in these activities. However, where such arrangements are difficult to implement it may be necessary to explore the various options for transferring skills more effectively to new employees. Although not reported in the literature it could be inferred that if dynamic labour markets exist in peri-urban areas with the frequent movement of individuals away from peri-urban activities to more attractive urban employment, then this creates opportunities for underemployed community members and recent migrants to capitalise on these vacancies, permitting them to consolidate their asset base and in turn gain access to better employment opportunities in urban activities. However, despite apparent benefits attributable to this process of livelihoods enhancement for the individual involved, reviewing the literature suggests that broader issues such as access to information regarding opportunities, transaction costs, lowered labour-intensity in rural areas, remittances and expectation of returns through inheritance or continued access to rural income generating activities, will strongly influence the potential benefit derived by the individual, household and community. This will influence the decision of whether or not an individual should migrate (see de Haan, 1999).

4.3. Competition with other producers

When threatened by development during the 1950s, a key argument for retaining the network of ponds, paddy fields and horticultural plots in the Salt Lake area to the northeast of Calcutta was its ideal location from which to supply fresh produce to urban markets (Kundu, 1994). With the advent of new roads and increased access to transportation, these markets have become easily accessible to more distant producers. Following a survey of selected fish markets in Calcutta, Morrice, Chowdhury and Little (1998) noted that the majority of large Indian major carp on sale at wholesale markets had been imported from other Sates, by truck from Uttar Pradesh and train from Madras, Orissa, Gudjarat and Punjab. However, these larger fish are usually cut into steaks and subsequently sold in middle-class retail markets, only being found rarely in markets serving poorer communities.

Observations by Morrice et al. (1998) provide valuable information on the changing demand for fish with respect to size, species and freshness depending on the wealth of the community served. Furthermore, the article suggests reasons why operators of ponds managed for wastewater aquaculture tend to produce small fish, highlighting the diversity of motivations for peri-urban producers and providing an insight to risk management in this dynamic setting. Investigating the diversity and price of fish for sale in suburban markets serving the poor, Morrice et al. (1998) observed the dominance of small freshwater fish, harvested from local ponds managed for wastewater aquaculture. Despite the higher price per unit weight for larger fish, managers of these systems continue to harvest their fish at a small size to reduce the risks posed by flooding, poaching and poisoning, both intentionally and through the contamination of wastewater inputs (Morrice et al., 1998). Management strategies including multiple stocking, partial harvesting and the sale of live fish, which command a premium, have been adopted to optimise small fish production and compensate for the price differential between large and small fish. In one market, the authors observed that small (100g) live tilapia commanded a higher price than equivalently sized Indian major carp, furthermore, it was noted that wild fish e.g. *Clarias batrachus*, *Channa striata*, *Anabas testudineus* and *Hereoneustes fossilis* attracted the highest prices in both urban and suburban markets.

4.4. Uncertain waste resource supplies

Surprisingly, following a survey of the distribution and management of peri-urban farming practices around Calcutta, Kundu (1994) noted that 'neither garbage nor sewage seems to be directly linked to the ongoing production activities in East Calcutta'. Results from this survey indicated that only 15% of respondents perceived the inadequacy of the sewage supply as a limiting factor and it was suggested that this was due to the fact that the majority of *bheries* in operation today are not dependent on municipal wastewater (Kundu, 1994). However, this situation of non-reliance on the wastewater resource could have evolved due to poor management of the wastewater supply system. It may have been in the interests of operators to purchase alternative, more manageable nutrient sources e.g. inorganic fertiliser, as opposed to relying on an unpredictable supply of free wastewater from the city. The inadequate supply of wastewater was only one of a number of technical factors identified during interviews with key informants that could potentially be threatening the sustainability of the existing wastewater aquaculture system.

The Calcutta Meteropolitan Corporation (CMC) and Department of Irrigation and Waterways (DIW) are responsible for the distribution of the wastewater to the wetlands to the east of Calcutta; however, these departments are under no obligation to supply the needs of the aquaculturists in the area. Individuals involved in aquaculture have no say in the control of the water level in the supply channels and consequently the supply of sewage is largely unpredictable. It has been suggested that the wastewater aquaculturists find themselves in this position as no payment is made for the waste resource (Muir et al., 1994). Other factors also constrain the equitable distribution of wastewater resources amongst users. Siltation of the urban drainage systems has been implicated in limiting the degree of control that the urban authorities have over the levels of wastewater in the canals used to supply fishponds; problems with the maintenance of pumping stations and regulating the operation of sluice gates have also been implicated in hampering the delivery of wastewater (Kundu, 1994). A further factor to consider is that of competition between those groups exploiting the wastewater resource (Kundu, 1994). Introducing a pricing system for the waste resource may be one approach to optimising the use of the waste resource, although, such a strategy would probably disadvantage the poor. The potential of developing markets for waste resources in stimulating improved supply channels has been further highlighted by Furedy et al. (1997); these authors suggested that where traditional solid waste reuse practices have declined, establishing markets for organic waste may promote separation and collection, increasing the value of this resource to farmers and providing income for those involved in waste processing.

4.5. Contamination

The contamination of solid and liquid waste resources discharged from Calcutta represents a potential constraint to the sustainability of traditional irrigation and aquaculture practices that have evolved at the peri-urban interface. Ponds managed for wastewater aquaculture are frequently subject to contamination with industrial pollutants and Edwards (pers. comm.) observed fishponds being filled with industrial wastewater that appeared orange due to the high concentration of chromium. When the chromium had settled out of suspension and the water had lost its distinctive orange appearance fish were stocked into the pond in the belief that the water had been purified. Amongst stakeholders, there is concern that products from aquaculture practices are being contaminated with heavy metals from tanneries found at the eastern edge of the city. Anecdotal evidence suggests that the problem of contamination with tannery wastewater is a cause for concern, although, due to an absence of a formal monitoring programme it is impossible to assess the extent of this problem.

Studies examining the heavy metal content of fish and vegetables purchased from urban and suburban markets in Calcutta have demonstrated that these products had relatively higher concentrations than similar products purchased from rural markets (Biswas and Santra, 1998). Furthermore, during a study of the bioaccumulation of metals cultured in fishponds receiving a high proportion of industrial effluents, Deb and Santra (1997) demonstrated that fish cultured in these ponds had accumulated higher levels of copper, lead, zinc and chromium than fish from neighbouring ponds; accumulation was found to vary between fish species and between tissue types. However, focusing on the dynamics of mercury in fishponds receiving wastewater from Calcutta, Sadhukhan, Ghosh, Ghosh, Chaudhuri and Mandal (1996) found that fish from these ponds did not contain mercury levels above the permissible level. The authors do report, however, that the highest mercury levels observed were recorded in sediment dwelling fish species and this may have implications for stocking and management practices. Cage culture, which has been practiced successfully in ponds receiving wastewater in South Africa (Gaigher and Krause, 1983; Gaigher and Toerien, 1985), and represents a management practice with the potential to reduce the risk of fish being exposed to contaminated sediments.

Studying the impact of using wastewater to irrigate vegetables at the Calcutta peri-urban interface, Adhikari, Mitra and Gupta (1992) found that soils irrigated with wastewater for several years showed elevated levels of iron, copper, zinc, manganese, lead, cadmium, cobalt and nickel. Furthermore, concentrations of iron, copper, zinc and lead in vegetables such as gourd, mustard, spinach, cauliflower and radish were considered exceptionally high, and commonly exceeded critical levels. Irrigation employing untreated wastewater has also been implicated in contaminating local groundwater resources. Mitra and Gupta (1997) found elevated levels of calcium, magnesium, sodium, chloride, phenolic compounds, heavy metals and faecal coliforms in groundwater samples taken along the dry weather flow canal draining wastewater away from Calcutta. In addition to irrigation water, sediments in sewage feeder canals were identified as possible sources of contamination. As a result, the authors proposed that the use of untreated wastewater for irrigation should be restricted and that settled sludge should be removed from the feeder canals.

Referring to the extensive wastewater aquaculture system situated in the Thanh Tri district, Vietnam, Edwards (1997) described how water from the Set River is now the main source of wastewater for the system, as the To Lich River is not used due to industrial pollution. The entire wastewater reuse system in the Thanh Tri district is now apparently in decline, the canal system has fallen into disrepair and rubbish being dumped in the channel is compounding the problem. The inadequacies of the wastewater supply system have resulted in the fish producers purchasing inputs of fertiliser and by-products from the local brewery industry. The reduced usage of wastewater in these production systems has resulted in an increased discharge of untreated wastewater to the local river. Problems of contamination have also been encountered in the Chinese wastewater aquaculture systems in the Han Kou region. There are reports of fish produced in these systems smelling and tasting of phenols; now the grow-out system has been converted to a nursery system, removing problems with consumer acceptability of the product (Edwards, pers. comm.).

Considering wastewater aquaculture at the Calcutta peri-urban interface, the risk posed by contaminants demands careful assessment and a monitoring programme may be required to establish the suitability of the wastewater flow for reuse. With respect to large-scale systems an appropriate programme may require the composition of wastewater entering the system to be monitored, this is desirable as it becomes increasingly difficult to monitor individual sources of pollution as the size of the catchment from which wastewater is collected increases. In small-scale systems it may be sufficient to conduct a general survey of the area from which the wastewater is collected; local knowledge may be invaluable in this situation, permitting the identification of small-scale industries that could potentially pollute wastewater derived largely from domestic sources. Bartone and Benavides (1997) identified a range of small-scale and cottage industries associated with hazardous waste problems in developing countries; these include tanneries, textile dyeing plants, dye producers, metal working and electroplating shops, foundries, automobile repair shops and petrol stations. At the household scale, exploitation of solid or liquid waste in homestead production systems may require a change in the activities and behaviour of household members, and the use of substances that could potentially affect the quality of the waste resource e.g. bleach, may need to be curtailed.

In addition to possible contamination associated with the waste resource, other sources of pollution require consideration. The indiscriminant dumping of solid waste and refuse may cause serious problems for operators of peri-urban farming systems. The physical filling of waterways with rubbish may interfere with drainage and the supply of wastewater and dumping of toxic or hazardous chemicals may contaminate water supplies or waste resources. These impacts are in evidence at the Calcutta peri-urban interface where a large land area has been designated to receive the majority of solid waste collected by the municipal authorities (Kundu, 1994). The drift or leaching of agrochemicals from neighbouring agro-ecosystems represents a further constraint to production in peri-urban farming systems, especially aquaculture, where the effect of pesticides and herbicides applied in terrestrial farming may impact severely on the aquatic environment and possibly contaminate plants and animals being cultured. Consequently, the management of agricultural land close to peri-urban areas e.g. paddy fields, may require modification to prevent contamination of ponds managed for wastewater aquaculture (Mukherjee, pers. comm.). Practical steps to safeguard against the contamination of peri-urban LWI production systems from agrochemicals may include the establishment of buffer zones between aquatic and terrestrial farming systems, or the development of guidelines for those engaged in the application of these chemicals. Buffer zones between landfill sites and production systems would also assist in preventing contamination, however, the management of leachate from the site may require prior planning to facilitate collection and treatment to prevent this potentially diffuse pollution source from contaminating neighbouring production systems, surface-water and groundwater resources.

A further threat of contamination, especially in wastewater reuse systems is the indiscriminant defecation of local residents and operators within the system, possibly resulting in pathogen loads in inappropriate places. Mara and Cairncross (1989) noted that where water supply and sanitation are not adequate, local residents are likely to use ponds managed for wastewater aquaculture for bathing and defecation. Therefore, these authors propose that water supply and sanitation for local communities is important for human exposure control. However, imposing modified defecation practices on target groups to establish centralised wastewater collection systems is reportedly an ineffective means of achieving sustainable behavioural change (Jahan, pers. comm.; cited in Bunting et al., 1999). The key feature in achieving long-term behavioural change is the participation of the target group in the decision process leading to the proposed behavioural change. The success of this methodology ultimately depends on the perspective of the target group, although perceptions of these groups are open to external influences such as education and peer pressure. Consequently, it may be possible to increase the proportion of the target group who adopt the proposed modified system by beginning the project with a period of community education or, where appropriate, demonstration or pilot projects.

4.6. Public health concerns

A number of authors have described the possible health hazards associated with wastewater aquaculture wastewater irrigation, garbage-fed horticulture and peri-urban livestock farming (Mara and Cairncross, 1989; Cooper, 1991; Strauss, 1991; Edwards, 1992; Gaspard, Wiart and Schwartzbrod, 1997; Birley and Lock, 1999). Although these reports make the hazards associated with each farming strategy explicit, it is much harder to quantify the associated level of risk. The risk associated with products grown using waste resources varies, depending on the characteristics of the waste resource, degree of treatment prior to use, nature of the culture system, husbandry and processing practices, subsequent handling and preparation and susceptibility of the consumer. Reviewing the health hazards posed by the use of wastewater and excreta in agriculture, Mara and Cairncross (1989) identified four groups of people at risk: field workers, crop handlers, local residents and consumers; the following sections discuss the hazards faced by these different groups, describe factors that influence the degree of risk and outline potential strategies for mitigation.

4.6.1. Field workers and crop handlers

Ensuring the health and safety of employees engaged in farming practices exploiting waste resources is an essential component in managing risks associated with these practices (Mara and Cairncross, 1989). Providing protective clothing and, where appropriate, regular treatment of the workers for intestinal helminths will limit the transmission and negative health impacts of parasites and bacteria. Mara and Cairncross (1989) suggest that the continuous use of appropriate footwear can reduce and even eliminate the infection of workers with hookworm, however, the authors note that persuading employees to follow this guideline may be difficult. As with encouraging modified defecation practices in local communities, the key to implementing these safeguards may be to encourage behavioural change through the education of employees. Furthermore, the need for education regarding the health risks posed by products cultured using waste-reuse practices extends to those involved with handling and processing. Although the risk to these individuals may be less than that posed to field workers, precautions such as wearing gloves and close attention to personal hygiene may be desirable; the prophylactic use of chemical control agents and the provision of adequate facilities to treat diarrhoeal disease are also recommended for highly exposed groups (Mara and Cairncross, 1989).

4.6.2. Local residents

A study by Amahmid and Bouhoum (1999) concerning the transmission of pathogenic protozoan infections as a result of wastewater reuse at the Marrakesh peri-urban interface highlights the possible negative impact of such practices on local communities. Stool samples were taken from two groups of children and analysis showed that those living in areas where wastewater spreading was used to irrigate agricultural land were more than twice as likely to be infected with protozoa when compared to a control group living in an area where surface water is used for irrigation. The authors conclude that exposure to wastewater used to irrigate agricultural land was the main causative agent of elevated protozoan infestations among children living in peri-urban areas. Providing local residents with information about waste reuse practices in the area, for example the location of all fields and ponds where human wastes are used, is recommended so that they may avoid these farms and prevent their children from entering these areas. Warning signs are also considered necessary, especially where fences are absent (Mara and Cairncross, 1989). Where sprinkler irrigation is employed, these authors suggest that a distance of 50-100 m should be maintained between the irrigated area and houses or roads.

4.6.3. Consumers

To assess the risk posed by the transfer of water borne diseases mediated through wastewater aquaculture, it is important to assess the prevalence of these diseases in the population served by the collection system (Mara and Cairncross, 1989). Having ascertained the possible level of pathogens in the waste resource it will be apparent what level of treatment is required to safeguard organisms being cultured in the system. Buras (1993) proposed that wastewater loadings should ensure pathogen numbers remain under a 'threshold concentration' i.e. the level above which the immune system of the culture organism is overwhelmed, leading to infection. Based on a review of epidemiological data, guidelines for the acceptable level of pathogens in wastewater for use in restricted and unrestricted irrigation and aquaculture have been developed (Mara and Cairncross, 1989). Furthermore, following a review of wastewater reuse practices, these authors propose that only systems incorporating pretreatment should be employed as they represent the most appropriate methodologies for safeguarding products from contamination. The problem of pathogens from inadequately treated waste contaminating products destined for human consumption is exemplified in the following account: Edwards (1992) reported that fish feeding directly on human faeces in the river Tjibunut, Bandung, had a large number of eggs from human helminths (*Ascaris lumbricoides*, *Ancylostoma duodenale* and *Trichocephalus dispar*) in their guts. Even in formal wastewater reuse systems, ubiquitous organisms e.g. *E. coli* and *Salmonella* spp. may represent a possible hazard, however, the level of risk may again be difficult to determine. Furthermore, where products are not prepared and stored in an appropriate manner the risk to consumers may be increased. Failing to prepare aquaculture products in clean water may allow pathogenic microbes to colonise the final product, while storing produce incorrectly e.g. on unhygienic market stalls, may permit poisonous bacteria to proliferate (Hatha, Paul and Rao, 1998). The level of risk will also vary depending on the mode and degree of exposure of the consumer and the resistance of the individual to infection.

With respect to risks posed by fish cultured in ponds managed for wastewater aquaculture at the Calcutta peri-urban interface, traditional food preparation methods i.e. cooking food for long periods or at high temperatures, provide a safeguard against the transfer of pathogens. In West Bengal and Bangladesh, fish is routinely cooked at very high temperatures before consumption, a culinary technique believed to minimise the incidence of pathogen transfer to the human population. However, it may not be prudent to suggest that the onus lies with the consumer to ensure that produce is prepared in such a way as to counter any public health risk posed by the primary product. Responsibility for safeguarding the quality of the product must lie primarily with the producer, although the consumer and others involved in processing and marketing do have a role to play in ensuring that produce is handled and prepared so as to minimise public health problems.

Depuration has been recommended as an essential component of wastewater aquaculture to ensure that products are safe for consumers (Little and Muir, 1987). The depuration period should be sufficient to allow the gut contents ingested in the wastewater aquaculture systems to be expelled, and in an ideal situation, a longer depuration period should be provided to reduce the population of bacteria and parasites that colonise both the external and internal structures of the culture organism. Studies have also shown that the concentration of persistent chemicals and heavy metals found in the tissues of organisms cultured in wastewater were lower following depuration (James, Sampath and Devakiamma, 1993). With respect to horticulture and agriculture, the cessation of wastewater irrigation prior to harvesting may reduce the risk posed by microbial agents and maintaining good standards of personal and food hygiene will further reduce the risk. However, in poorly educated communities and outside institutional settings health education campaigns to address such concerns may be relatively ineffective (Mara and Cairncross, 1989).

In addition to the possibility of contamination, other factors, for example, social restrictions on the direct use of wastewater and limited market demand for products from aquaculture may limit the potential benefits associated with using wastewater for aquaculture. However, culturing intermediate plant and animal products as feed inputs for other aquaculture enterprises or terrestrial agriculture systems represents a promising strategy, not only helping ensure that the product is safe, but in the mind of the consumer, dissociating the final product from the initial farming system exploiting the wastewater resource. Edwards, Polprasert and Wee (1987) present a simple schematic diagram summarising alternative pathways for wastewater reuse employing intermediate aquaculture production systems. Strategies proposed included the use of wastewater to culture either fish or duckweed to produce feed for carnivorous fish or livestock destined for human consumption. Investigations conducted in experimental ponds at AIT demonstrated the potential of using septage, collected in a vacuum truck from septic tanks in Bangkok, to fertilise fishponds used to culture tilapia. Findings from this work indicate that the most productive system for culturing tilapia is one predominated by small fish, and ideally, these small fish should be the product of a free breeding population. It was proposed that fish produced in this way could be processed into tilapia meal for use as an ingredient in feed for either cattle or carnivorous fish.

With respect to using aquatic macrophytes as intermediaries in farming systems that exploit wastewater resources, investigations conducted by Edwards, Hassan, Chao and Pacharaprakiti (1992) regarding the potential of duckweed culture in septage loaded ponds have resulted in extrapolated annual yields of *Spirodela polyrrhiza* and *Lemna perpusilla* of 20.4 t and 10.9 t ha^{-1}, respectively. Duckweed production may be inhibited as a result of fluctuating temperatures, competition from phytoplankton blooms for both nutrients and space and infestations with fly larvae, however, the major limiting factor in the system used in this study was the limited input of septage. Edwards (pers. comm.) suggests that flow-through duckweed culture systems such as that developed by the NGO, PRISM Bangladesh, may provide a solution to this problem.

The treatment system developed by PRISM Bangladesh receives wastewater from the resident population of 2,000-3,000 at Kumidini Hospital, Mirzapur, Bangladesh. The treatment system occupies an area of 2 ha and the duckweed-covered lagoon has a surface area of 0.6 ha. Alaerts, Rahman, Mahbubar and Kelderman (1996) described the operation of the system in detail and reported that on a weekly basis the lagoon receives ~2,000 m^3 of pre-settled wastewater from an anaerobic lagoon. Based on monitoring work undertake by these authors, production levels ranging from 21.2-38.3 t ha^{-1} can be estimated for the dry weight of duckweed harvested from the system annually. Duckweed produced is fed to fish in adjacent ponds and the local community readily accepts fish cultured in this manner. Commercial outlets also exist for duckweed at both local and regional markets e.g.

in Jessore, traders purchase duckweed to feed fingerlings in local hatcheries. Previously, duckweed would have been collected from the wild to supply these hatcheries, however, wild duckweed is increasingly difficult to find and, where it does occur, it is likely that exploitation already occurs either to feed fish or livestock. In Taiwan, duckweed produced using wastewater is fed to either grass carp or ducks and demand exists in local markets; in the mid 1980s, a region close to Chai Yi was converted from paddy fields to ponds suitable for duckweed culture. In Vietnam duckweed is in demand to feed golden snails being cultured for export; previously the snails were cultured in paddy fields, but their negative impact on rice production resulted in this system being abandoned (Edwards, pers. comm.).

An important initiative developed by PRISM Bangladesh is the cultivation of banana trees on the embankments of the duckweed-lagoon; in addition to the production of bananas, the sale of which contributes significantly to the economics of the system, planting tress on embankments provides environmental and social benefits. The physical effect of the trees on the boundary layer enhances the local microclimate, providing shade for the duckweed and reducing wind velocities over the lagoon. From a social perspective, management of the integrated production system provides employment for local workers, many of which are landless farmers or net-less fishermen.

Introducing intermediate production components to wastewater reuse system has the potential to help reduce both the real and perceived risks posed by the reuse of human excreta in the production of food. However, to adequately assess the benefit associated with the use of intermediaries a risk assessment framework is required that, in addition to considering the role of inputs, farming practice, the market chain and consumer behaviour, may be extended to include an analysis of all aspects of waste reuse that constitute a potential hazard. A recent innovation for improving food safety which is preventative in nature and focused on the consumer is the Hazard Analysis Critical Control Point (HACCP) framework (Ehiri, 1995; Lima dos Santos, 1995; Thompson, 1996; Reilly and Kaferstein, 1997) and the FAO Fish Utilization and Marketing Service (1997) outline a code of hygienic practice for the products of aquaculture, including recommendations for products cultured using wastewater. In summary, these recommendations state that only treated wastewater should be used and that the microbiological and chemical quality of products should be monitored and conform to WHO guidelines (see Mara and Cairncross, 1989). These guidelines also cover the use of wastewater in agriculture, although Blumenthal, Mara, Peasey, Ruiz-Palacios and Stott (2000) have recommended revisions to the WHO guidelines based on the type of delivery mechanism and whether children are exposed.

Despite the possible health hazards associated with the exploitation of waste resources in peri-urban farming systems, it should be noted that the adoption of formal waste reuse practices incorporating treatment components and procedures for monitoring the quality of products produced represents a significant improvement on unregulated informal waste reuse practices. Muir et al. (1994, pg. 3) state that 'a system of low and largely controlled risk with known and identifiable location and characteristics must be better than the lack of any system'. This sentiment is supported by the findings of Pal and Das-Gupta (1992) who demonstrated that water samples and organs from fish cultured in conventional rain-fed ponds contained certain pathogenic bacteria at concentrations two orders of magnitude greater than water samples and organs from fish cultured in ponds receiving sewage from Calcutta. The findings from this study suggest that fish cultured in ponds receiving water contaminated with human excrement can potentially represent a greater risk to the consumer than fish cultured in formal wastewater aquaculture systems. However, the risks of reusing wastewater should not be underestimated and those responsible for managing and regulating production systems should be provided with knowledge on limiting risks associated with reuse practices; schema for risk identifications and evaluation have been proposed by a number of authors (Blumenthal, Strauss, Mara and Cairncross, 1989; Mara and Cairncross, 1989; Strauss, 1991; Shuval, Lampert and Fattal, 1997), however, the development of appropriate materials for operators and local authorities may assist in implementing such measures.

4.7. Changing social expectations and perceptions

Waste reuse practices in peri-urban areas are in decline in several countries. Wastewater aquaculture in Japan, Malaysia and Taiwan has decreased dramatically, and in China, aquaculture using human excreta is due to be phased out (Furedy, 1990). Changing expectations and perceptions of operators, consumers and society may be responsible for the decline of once productive wastewater aquaculture systems. As mentioned previously, the migration of skilled and experienced employees from waste reuse practices at the Calcutta peri-urban interface represents a possible constraint to the continued operation of the traditional systems. However, it is important to acknowledge that the expectations of managers and employees are not limited to financial considerations; socio-cultural factors e.g. social status and conformity also require consideration. During interviews conducted in the field, key informants suggested that workers in Bangladesh who are engaged in activities associated with human excreta e.g. sweepers, are sometimes ostracized or victimised in society. In Zambia, Tanzania and Zimbabwe, levelling mechanisms, such as social pressure and obligation, have been identified as constraints to the adoption of aquaculture activities that have the potential to elevate individuals above their defined social role in a community (Sen, 1995). Education of society to raise the status of groups involved with resource recovery farming systems may represent one approach to avoiding the marginalisation of individuals within their own community.

Within households, adopting modified farming strategies that exploit waste resources or being employed to work in a large-scale production system may cause conflicts. Investing household resources, especially money and labour, in small-scale farming enterprises may divert these resources away from potentially more productive or rewarding livelihood strategies. The chance of conflict between household members is especially pronounced where the costs, benefits and risks associated with the farming practice are difficult to establish and resources, including labour, may be diverted away from more reliable or beneficial activities. Harrison et al. (1994) described how the adoption of aquaculture by households in Africa altered the distribution of labour leading to intra-household disputes.

Where tasks associated with managing homestead farming enterprises are undertaken by women, children or elderly relatives, this may account for a significant proportion of their workload and result in time and energy being diverted away from other important activities such as education, nurturing and socialising. The preparation of daily activity charts and seasonal calendars to assess activities and labour demand for household members could potentially highlight conflicts that may occur as a consequence of adopting household farming practices (Townsley, 1996). The loss of experienced workers to higher paid jobs has been cited as limiting investment and threatening the continued operation of traditional waste reuse practices at the Calcutta peri-urban interface. This suggests that the opportunity cost associated with the use of labour resources in peri-urban production systems must be considered when assessing the relative benefit associated with such activities. The investment of time, money or other resources in developing innovative or improved farming systems may also be limited by poorly defined or inequitable inheritance and divorce procedures within communities (Harrison et al., 1994). An inability to transfer established systems to future generations due to the absence of clearly defined inheritance mechanisms could limit the sustainability of the system in terms of intergenerational equity.

As consumers become more aware of the origins of the food they consume, the knowledge that products are derived from farming systems that exploit waste resources may influence the perception of the consumer, possibly restricting the acceptability of such products. The perception of farming systems that exploit waste resources may be more problematic where these practices contravene cultural restrictions, social taboos, religious edicts or local beliefs and operators of such enterprises become stigmatised. This not only restricts the markets open to the produce cultured by these individuals but may also affect social interactions, possibly resulting in persecution or ostracism. However, Edwards (1992) suggests that beliefs, values and customs regarding excreta reuse are not fixed but evolve, and that this evolution could potentially be induced by demonstrating that excreta reuse represents a low cost disposal option that benefits the population and does not represent a risk to public health. Ya'akov Zemach, advisor to Israel's Water Commissioner, stated that 'The Arab populace has a psychological and even religious aversion to using sewage water, but they are coming to realise that it is necessary and worthwhile' (Watzman, 1995). The mechanisms for this fundamental shift in attitude to using wastewater are not reported; however, the benefits of using wastewater have been demonstrated through irrigated crop production on the West Bank.

The perception of farming practices that exploit domestic solid waste and wastewater by key institutional actors may strongly influence the prospects for such practices. The authorities in certain countries may distance themselves from waste reuse farming practices to present a more acceptable image to foreign visitors and tourists. Tourism can make a significant contribution to the economies of less developed countries, however, to appeal to tourists, aspects of the local culture that could potentially offend visitors are removed from tourist routes or outlawed altogether by the authorities. The decline in several farming systems that exploited waste resources can be attributed to this phenomenon; abolition of these practices in less developed countries is sometimes seen as portraying a more developed image on the world stage. Until recently, wastewater aquaculture was widespread in southern Vietnam. Farmers stocked fish in cages and fed them with nightsoil from the city and overhung latrines were positioned over ponds stocked with common carp. However, the Governor of Can Tho province ordered that latrines over floating cages close to the market and one at the ferry landing should be removed as he was concerned about them being seen by tourists (Interim Committee for Coordination of Investigations of the Lower Mekong Basin, 1992).

Information disseminated by government agencies e.g. health departments, CBOs and NGOs, may result in the public receiving conflicting messages regarding the appropriate management of domestic waste. Where behavioural development programmes have highlighted the link between, for example, hand washing after defecation and the associated reduction in disease, then it may be difficult to promote or even sustain existing waste reuse practices. Although the health education message is not concerned directly with waste reuse practices, the message that disease is associated with faeces could mean that the target group has trouble understanding how waste reuse practices represent a safe reuse option. However, if agencies conducting health education programmes could be informed as to the potential role of formal waste reuse practices, in the safe and effective strategy for maximising the benefit derived from waste resource, this may represent an important channel for knowledge dissemination.

4.8. Management constraints

Constraints to peri-urban production presented above suggest that managers of such systems face a number of problems that are largely out of their control, but that have a significant influence on the type of management strategies employed. Insecurity of tenure has been cited as a key factor in constraining innovation and investment. Managers are unwilling to invest in new technologies as they wish to limit their exposure to financial risks, however, a lack of information and access to loans have also been cited as constraints to the introduction of improved management strategies (Kundu, 1994). A survey of sixty operators of ponds managed for wastewater aquaculture showed that 45% obtained loans to finance investment, 37% used their own savings and 18% took an advance; loans and advances came from various sources including moneylenders, seed-sellers, *aratdars* (wholesalers) and banks, however, the role of banks was considered of 'marginal importance' (Kundu, 1994). This author also found that operators of peri-urban vegetable production systems appeared more willing to obtain loans, with 53% of respondents having mortgaged their land. Where loans had been taken, repayment rates were considered exceptionally high; this was attributed to poorly defined tenure arrangements that permit moneylenders to exploit the situation. The problem is compounded further as operators are keen to introduce improved management strategies but are unable to access bank loans as they lack documentary evidence of ownership and cultivation rights.

Kundu (1994) found that a high percentage of vegetable growers interviewed (71%) had introduced improved technologies i.e. high yielding varieties, fertilisers and pesticides; however, with respect to operators of pond systems, limited access to information has been cited as limiting the introduction of improved management techniques. This suggests that informing operators of management strategies to reduce health risks associated with their farming systems may be restricted. The need for improved access to knowledge concerning constraints and opportunities for operators is further highlighted by reports that productivity in the per-urban production systems is declining. This decline has been attributed to disease problems, contamination, toxic algae blooms, poor seed quality and theft (Kundu, 1994; Muir et al., 1994; Srivastava and Mukherjee, 1994; Ghosh, pers. comm., cited in Bunting et al., 1999). Therefore, the development of improved dissemination pathways for information may be an important component in ensuring the continued operation of these farming systems.

Problems with acquiring loans and accessing information suggest that local institutions or private organisations may have a role to play in providing such services. However, to identify appropriate extension materials and pathways and to develop suitable credit arrangements may require further research and the development of capacity within local institutions. The following section presents some potential strategies for developing the capacity of local institutions to address the problems encountered by operators of peri-urban production systems.

4.9. Institutional considerations

The discussion in the previous sections pose the fundamental question of who is responsible for peri-urban production systems, providing support and technical advice, ensuring the safety of products and informing the consumer and other stakeholders about such activities? From a regional or local government perspective, it is likely that the responsibility for peri-urban production systems will be integrated into existing organisational structures. Where this is the case, it will be important to inform people of their responsibilities regarding the wastewater aquaculture sector. Establishing the position of peri-urban farming in a job description may not be as straightforward as it seems, especially when job descriptions are not formally implemented or documented (Spencer, 1996). Where basic building blocks of the organisation such as these are inadequate, a more fundamental approach of institutional development will be required.

Institutional development is concerned with the relationship the institution has with the external environment and with internal issues such as business objectives, technology, structure, systems, procedures and matters relating to employees e.g. job descriptions, skill levels and motivation. Where institutional structures are fairly well defined, it may be that the nature of the organisation's structure needs to be developed. Muir et al. (1994) described the local governments of West Bengal, Bihar and Uttar Pradesh in India as having 'hierarchical' structures. These systems may be able to function adequately, however, alternative organisational structures such as the 'matrix' model presented by Spencer (1996) may be better able to cope with the cross-sectorial demands of dealing with peri-urban production systems.

A primary responsibility for institutions dealing with peri-urban production systems exploiting waste resources will be to protect the health of consumers, and this may involve the implementation of standards, guidelines and regulatory safeguards. Where public perceptions of products cultured using waste resources are of concern, these measures may be instrumental in ensuring acceptance in the market place. Externally, products cultivated in peri-urban production systems exploiting waste resources may be indistinguishable from those grown in conventional farming systems. Therefore, monitoring programmes may need to be based on microbiological assays or chemical analysis, furthermore, any programme of sampling would also have to include processors and retailers. The implementation of such a programme, and the framework of legislation required for its support, may represent a significant cost to regional authorities, and in many situations more pressing issues may hold priority within institutions. However, if better defined, the benefits generated directly and indirectly by peri-urban production systems could potentially justify an increase in spending on behalf of local authorities. One such approach to achieving this objective would be to conduct a comprehensive cost-benefit analysis considering alternative waste disposal options. Haruvy (1997) undertook such an exercise for disposal options for wastewater from Ra'anana, Israel and demonstrated that local irrigation represented the most cost effective method of wastewater management. Where products are being supplied from conventional systems to export markets, the possible negative impacts of food scares associated with products grown using waste resources should also be considered. For example, during the first ten weeks of a cholera epidemic in Peru, the reduction in agricultural exports and tourism cost the country an estimated one billion dollars (World Bank, 1992). Including possible losses such as these in a cost-benefit analysis regarding the implementation of a monitoring programme may justify establishing such systems.

Implementing a monitoring programme for products from peri-urban production systems exploiting waste resources may make explicit the risk posed by such production strategies, which in turn, may lead to changes in consumer perception, reducing demand and causing a decline in product value. Furthermore, introduction of a monitoring programme may demand that informal approaches to waste reuse are brought within the regulatory framework, which may highlight the role of waste inputs in these farming systems, again leading to changes in product perception by consumers. As mentioned previously, the status of informal approaches to wastewater aquaculture has been described to a limited extent and a number of health risks and other negative impacts have been reported (Edwards, 1992). However, the possible impacts of such policy developments should not be underestimated; informal approaches to waste reuse, especially wastewater aquaculture, are widespread in many developing countries and changes in the acceptability and value of products from these systems may have a significant impact on the livelihoods of poor people managing such systems.

Although bringing informal and unregulated waste reuse practices into a regulatory framework may influence the perception of products cultured, in the long-term, safeguarding the health of workers and consumers should be a priority. Implementation of health and safety standards relating to such production systems, whether by a government agency or private sector body, would aim to reduce possible public health risks and increase the appeal of products in the market place. However, the process of informing consumers regarding newly introduced protection measures and associated implications for food safety may require further support from local authorities, and in many cases poorly developed pathways for communicating such issues to consumers may make such initiatives impractical and ineffective.

The continued operation of large-scale peri-urban production systems, like those at the Calcutta peri-urban interface, may also come into conflict with local and regional planning initiatives. Institutions may have preconceived development plans for a region, and consequently be reluctant or unwilling to support or promote any activity that could come into conflict with these. Reports from planning agencies in Calcutta have proposed that further expansion of Calcutta should proceed to the north of the city (Kundu, 1994; Roy, 1998), however, despite these recommendations, urbanisation continues towards the east, encroaching further into the low-lying wetlands, suggesting that policy decisions may be complicated by other considerations. Recent construction of the Eastern Metropolitan Bypass has improved access to areas to the east of Calcutta from both the city and airport. Furthermore, despite being considered a wetland area, the environment is not homogenous and selected areas represent attractive sites for development that require little investment in preparing the site. However, the impact of development on the periphery of the extensive wetland area may have profound effects, especially where local hydrological conditions are disrupted and pressure on the surrounding land resource increases as a result.

4.10. Summary

Having reviewed the literature it appears that major LWI production systems at the Calcutta peri-urban interface are under threat on a number of fronts. Encroachment of urban development leads to the physical loss of land previously available for peri-urban production systems, this physical loss also leads to the disruption of local communities and engenders feelings of insecurity. Uncertainty over the future of peri-urban production systems and the prospect of more rewarding employment has resulted in the loss of experienced workers. Improved access to urban markets for rural producers, through improved communications, has diminished the competitive advantages of peri-urban producers. The risk of contamination, leading to public health threats, and changing consumer perceptions may be further reducing the demand for products from such systems. Operators of peri-urban farming systems have to manage uncertain and variable waste resource inputs and contend with the limited availability to loans and information. In combination these factors have lead to a reluctance to innovate and invest in enhanced management approaches. Furthermore, contamination, disease problems, environmental degradation and risk-averse management strategies may have lead to the widely perceived decline in productivity within the peri-urban farming systems, reducing the competitiveness of these farming enterprises.

5. Factors contributing to continued operation

Despite numerous constraints outlined in the previous section, major production systems exploiting waste resources persist at the Calcutta peri-urban interface. The following sections review benefits associated with these systems and considers whether a greater knowledge of these benefits could contribute to a constructive dialogue amongst planners, key actors and stakeholders regarding the development of peri-urban natural resource management strategies that benefit the poor.

5.1. Employment and income

The operation of major peri-urban production systems creates a number of employment opportunities. The wastewater aquaculture system to the east of Calcutta provides direct employment for ~8,000 individuals (Kundu, 1994), these figures may not, however, represent the true labour demand within the system. Traditional operation of the waste reuse production systems depended on the employment of workers when required e.g. at harvest time, however, it has been suggested that the intervention of unions has resulted in the permanent employment of an excessively large workforce, Mukherjee (1996) describes this situation as 'disguised unemployment'. This author noted that only ~25% of those working in peri-urban aquaculture are engaged in full-time employment, the remainder being temporary employees. Permanent employees include managers, skilled workers who weave nets and look after equipment and infrastructure and unskilled workers who undertake menial tasks including cooking. Temporary employees are engaged in harvesting, guard duties and transporting fish to wholesale markets. Lower wages received by temporary workers compared to full-time employees reflect the amount of time spent actively engaged in employment activities, carriers, harvesters and guards work on average 1, 3 and 6 h d^{-1}, respectively; furthermore, temporary employees work on average for only half the year.

From a regional perspective, the creation of jobs in associated support services e.g. supplying inputs and marketing products, can benefit populations not directly involved in the management of waste reuse system. For example, inputs required for wastewater aquaculture include fry, supplementary feed, nets, bamboo and boats (Mukherjee, 1996), the supply of which provides a range of employment opportunities for all sectors of society. The adoption of management techniques described by Morrice et al. (1998) i.e.

multiple stocking, partial harvesting and marketing live fish may also have implications for the demand for labour in the system, both in terms of amount and timing. Informal reports suggest that formal waste reuse practices provide a significant number of employment opportunities to individuals from marginal communities at the Calcutta peri-urban interface (Giri, pers. comm.; cited in Bunting et al., 1999).

At the household level, full-time employment of one or more individuals in large-scale production systems e.g. shrimp farming, can provide a valuable source of income (Hamid and Alauddin, 1998). However, while employment in the major LWI at the Calcutta peri-urban interface may play a similar role, homestead level production, cultivating vegetables and rearing livestock, may be an important component in the income of poor households. Owing to the physical dominance of the large-scale systems, the role of production systems managed by households has been largely neglected in appraisals of peri-urban production systems in Calcutta. Reports from other geographical locations indicate that homestead farming may play a role in contributing to the income of poor households (Brummett, 1995; Setboonsarng and Edwards, 1998), suggesting that this facet of peri-urban farming practice around Calcutta requires consideration. Le (1995) reported that poor households in Hanoi derive between 3-40% of their income from rearing livestock, fed primarily on household waste. However, the contribution of homestead farming activities to food security in poor households is probably more important than income generation and this is discussed in the next section. Although peri-urban farming practices may contribute significantly to the income of households through the provision of employment and the sale of produce from homestead farming enterprises, inequity may result in benefits being divided unfairly amongst household members (Harrison et al., 1994). Furthermore, inequality within households may influence the distribution of tasks associated with the adoption of homestead farming.

The inequitable distribution of benefits derived from peri-urban farming systems has also been implicated in limiting the motivation of those operating and managing large-scale systems, and constraining investment and innovation. With respect to wastewater aquaculture in peri-urban Calcutta, there is sometimes a lack of motivation to improve the efficiency of the system due to the inability of stakeholders i.e. employees, managers and landowners, to agree on a mutually acceptable strategy for dividing the risks and potential rewards associated with investment (Muir et al., 1994). To address this problem, it has been suggested that the division of benefits derived from waste reuse practices operating under a variety of management regimes, for example, individual ownership, absentee owners and cooperatives, need to be clearly defined (Bunting et al., 1999). Government institutions may be in a position to ensure that potential operators are in situation where they can reap the benefit of their labour. The development of guidelines, contracts and legislation to clarify the rights of various stakeholders could be a key role for government.

5.2. Contribution to food security in poor households and communities

The recovery of nutrients from solid waste, agricultural by-products and wastewater produced by households will contribute to the poor resource base of small-scale farmers in peri-urban areas. Furthermore, products from farming systems in peri-urban areas may make a significant contribution to household food security. Edwards, Little and Yakupitiyage (1997) note that farmers in northeast Thailand employing traditional artisanal production techniques in small ponds produce 0.4-0.5 t ha^{-1} of fish annually, while, in contrast, production levels of 5 t ha^{-1} y^{-1} have been recorded for similar ponds in West Java receiving manure (human and livestock), bran and vegetation. Typical production figures presented by Mara, Edwards, Clark and Mills (1993) indicate that recycling nutrients in the waste from a family of five through aquaculture has the potential to produce ~84 kg of fish per year, close to the expected demand from a household where fish consumption represents an important contribution to the diet (Edwards et al., 1997). However, if the fish cultured are destined for market, the relatively low level of production from a household pond may be difficult or uneconomic to market; a similar constraint was identified for operators of small-scale fishponds in Africa (Harrison et al., 1994).

Developing small-scale wastewater aquaculture practices that may be carefully integrated into existing subsistence farming systems, for example the traditional inland artisanal aquaculture systems described by Edwards et al. (1997), could potentially help small-scale farmers realise their rising expectations. Realistically, however, poor households at the Calcutta peri-urban interface are unlikely to have access to sufficient land or resources to construct a pond in which to undertake wastewater aquaculture. Furthermore, individual households may not generate sufficient nutrient or wastewater flows to justify investment in a system for wastewater aquaculture, especially when the possible need for waste storage and treatment is considered. Small-scale pond systems are evident in many peri-urban settings, and it is not uncommon for water flowing into these ponds to contain domestic waste (Bunting et al., 1999), however, these systems represent an informal approach to wastewater aquaculture, where the benefits of waste reuse are exploited, but not given public recognition. Risks, possible costs and potential benefits associated with waste reuse in small-scale peri-urban farming systems are poorly defined and understood and this lack of knowledge may prohibit the investment of time, money or resources in developing formal systems. Risk assessment in relation to household level farming practices in peri-urban areas may be critical if sustainable practices are to be identified and promoted more widely.

In peri-urban settings, homestead horticulture and livestock husbandry have been shown to be important in the food security of poor households (Brummett, 1995; Nunan, 2000). However, from reviewing the literature it is evident that little has been published regarding this facet of food production at the Calcutta peri-urban interface. Knowledge on the nature and extent of homestead horticulture and livestock farming at the Calcutta peri-urban interface may therefore make a significant contribution to understanding the importance of these production systems in the livelihoods of poor people. The literature on peri-urban farming around Calcutta is dominated by descriptions of the major wastewater aquaculture and garbage-fed horticulture production systems, and it has been proposed that products from these enterprises may play an important role in the food security of poor communities, both peri-urban and urban.

Due to the limited distance between the culture system and market place and the constant availability of wastewater for aquaculture and irrigation, peri-urban farming systems have the potential to supply fresh, low cost produce, all year round, to urban and peri-urban markets. This is an important consideration for poor communities that depend on these markets for their food supply and are unable to store perishable products. Morrice et al (1998) found that small fish harvested from ponds managed for wastewater were available in markets servicing the poor, however, the profiles of those individuals actually purchasing such fish were not investigated. Demonstrating that fish and other produce from peri-urban farming systems around Calcutta are accessible to, and purchased by, members of poor communities would have important implications for poor people. For example, assisting local institutions in ensuring food security in poor communities, contributing to the positioning, design and development of improved marketing outlets and sources of consumer information and assessing the health risks associated with products. Operators of peri-urban production systems may also benefit from improved knowledge regarding the consumers of the products they produce. Those without access to employment, or unable to purchase products from markets, may still benefit from the productivity of major peri-urban LWI production systems. Depending on rights of access and availability, poor people may be able to appropriate unexploited resources such as fodder, fuel wood, medicinal plants and self-recruiting aquatic species.

5.3. Household and community health

The potential contribution of products from peri-urban farming systems to the food security of poor households and communities was discussed in the previous section, however, access to such food sources may also play a role in improving the nutrition and health of poor people. The diet of poor people in West Bengal is likely to be dominated by rice, as is the case in neighbouring Bangladesh (Thilsted, Roos and Hassan, 1997). However, these authors note that rice is a poor source of nutrients such as vitamins A and C, iron, calcium, zinc and iodine, and that vegetables and fish make a significant contribution to the availability of these nutrients in the diets of poor people. Therefore, it appears reasonable to assume that vegetables and fish cultivated in major peri-urban production systems and sold in markets servicing the poor may make a significant contribution to the vitamin and mineral intake of poor people, leading to a decrease in the incidence of vitamin A deficiency causing blindness in children and iron deficiency causing anemia in women and children.

In several cases the managed reuse of solid waste and wastewater in peri-urban production systems is an important component in the sanitation strategies of poor communities in developing countries (Mara and Cairncross, 1989). The World Bank estimated that in 1990, a total of 1.7 billion people were without access to adequate sanitation and that by 2030 this could increase to around 3.2 billion people (World Bank, 1992). Providing sanitation is an important development process, and is recognised as being of prime importance in improving the general health of the population. Through the provision of sanitation, infant mortality caused by communicable diseases e.g. cholera, typhoid and diarrhoea is greatly reduced, as is the incidence of severely malnourished individuals with associated physical and mental health problems (Ahmed, Zeitlin, Beiser, Super and Greshoff, 1993). In more general terms, it has been suggested that the life expectancy of the population can be expected to increase as a result of providing sanitation (World Bank, 1992). Inadequate sanitation results in the degradation and contamination of groundwater and surface water (World Bank, 1992), in such situations it is often recommended that contaminated water be boiled, a process that uses large amounts of fuelwood, the combustion of which results in atmospheric pollution and may lead to an increase incidence of respiratory disease (Birley and Lock, 1999).

5.4. Economic benefits to society

Economic benefits generated through the productive reuse of waste resources in horticulture, livestock production and aquaculture could potentially subsidise the development and maintenance of formal collection, treatment and delivery strategies for solid and liquid waste used in the farming system. For example, in Trujillo, Peru, the cost allocation formula recommended for the construction of a lagoon-based wastewater treatment facility was to charge the costs of construction to the municipality and charge local farmers that were to use the treated water for irrigation, for the cost of land and operation (Mara and Cairncross, 1989). Responding to a survey, local farmers indicated that this was an equitable solution and in some cases the cost of treated wastewater was expected to be half that paid for groundwater. The management of rubbish and wastewater from Calcutta by operators of peri-urban production systems may reduce the demand for resources placed on local authorities. These authorities provide an important service in collecting rubbish and wastewater from the city and conveying it to the main dumping area in peri-urban Calcutta. However, the managed processing of waste through reuse in peri-urban production systems operated by the private sector removes the need for local authorities to manage the disposal of such wastes. Wetlands accommodating LWI production systems facilitate a wide range of physical, chemical, bio-chemical and biological contaminant removal processes (Watson, Reed, Kadlec, Knight and Whitehouse, 1989). Furthermore, wetlands constitute an ecologically sound and cost-effective means of sanitation, especially when compared with conventional waste treatment and management strategies (Breaux, Farber and Day, 1995; Brix, 1999).

Employing pond-based systems to treat wastewater prior to use in irrigation or aquaculture represents a low cost solution to ensuring the water is of a sufficient quality to safeguard the microbiological quality of the product, and in the case of aquaculture, maintain water quality within the culture ponds (Mara, 1997). At the local or median scale, the sanitary disposal and reuse of wastewater in systems managed by operators with a vested interest in the correct functioning of the system ensures that both the production components and treatment system are maintained. An experimental wastewater aquaculture facility developed in association with the Kalyani sewage treatment plant, north of Calcutta, is managed by a cooperative of fishermen; these fishermen maintain both the maturation ponds in which fish are cultured and the anaerobic and facultative lagoons that precede the production system. It should, however, be noted that cooperatives, with responsibility shared amongst members, frequently result in the establishment of effective management regimes, therefore, it may be prudent to suggest that the level of maintenance achieved will also depend to some extent on the capabilities and organisation of those responsible for operating the system. Cooperative management is playing a key role in the management of both established and new wastewater aquaculture facilities in peri-urban Calcutta (Bunting et al., 1999).

Establishing structures and processes e.g. cooperatives, that contribute to the efficient collection, transportation and treatment of waste resources prior to use may be critical in ensuring that production is constant and the quality of products is safeguarded. In certain circumstances products destined for export markets may be grown using wastewater for irrigation. In such circumstances the economic benefits associated with selling products to export markets may be considerable, however, the cost of failing to safeguard the microbiological quality of these products may also be significant. As mentioned previously, during the first ten weeks of a cholera epidemic in Peru, the reduction in agricultural exports and tourism cost the country an estimated one billion dollars (World Bank, 1992). Ensuring that only treated wastewater is used for irrigation would mean that export crops of fruit and vegetables are able to meet stringent safety standards in target countries, and that the safety of consumers is protected.

Boiling contaminated water supplies prior to drinking may contribute indirectly to negative environmental and public health impacts, however, the cost involved is also significant. The population of Jakarta spends in excess of fifty million dollars per year on boiling water, equivalent to 1% of the city's gross domestic product (World Bank, 1992). The impact of inadequate sanitation is most pronounced in those sectors of communities that have little choice in the water resources they have access to, most commonly the poor. In Bangladesh the cost of boiling drinking water has been estimated to account for as much as 11% of the income of poor families; in Peru, an outbreak of cholera prompted the Ministry of Health to recommend that all residence boil drinking water for ten minutes, it was estimated that this could cost families living in squatter camps a significant proportion (29%) of their income (World Bank, 1992).

5.5. Resource recovery

Reusing waste resources, garbage, wastewater and by-products from agriculture and food processing in peri-urban farming systems offers a possible solution to the problem faced by many farmers in developing countries of limited access to nutrient inputs and water resources. Ensuring that the maximum possible benefit is derived from appropriated water resources and nutrients contained in both solid and liquid waste will reduce pressure on the remaining renewable freshwater resource and non-renewable mineral resources. This will reduce conflict over controversial dam building and mining schemes, and limit environmental degradation. Furthermore, compared to conventional approaches to managing domestic waste, the productive reuse of waste resources in peri-urban farming systems offers a greater degree of environmental protection.

5.5.1. Nutrients

Reusing nutrients contained within waste flows from societal systems reduces the loss of non-renewable resources; this is of particular importance where nutrients such as phosphorus may become entrained in the unidirectional flow of matter in the hydrological cycle. The assimilation of nutrients through ecological systems, as opposed to the mechanical removal of nutrients from the wastewater, avoids the problem of developing '*h*ampered *e*ffluent *a*ccumulation *p*rocesses (HEAP) traps, where former point source pollution is ultimately converted into non-point source pollution' (Gunther, 1997). Production systems that exploit waste resources have the potential to avoid the creation of HEAP traps, nutrients discharged within waste produced by society being assimilated into biomass that can be harvested and either recycled through the city, incorporated into agricultural systems or removed from the watershed. Furthermore, although conventional technologies may be efficient at removing certain waste fractions depending on the design and operation of the treatment plant, discharge water may still contain significant quantities of nutrients that may result in environmental degradation in the receiving environment. The productive reuse of wastewater as a resource, as opposed to the indiscriminate discharge of this nutrient rich organic solution into wetland, coastal and oceanic ecosystems, reduces the risk of cultural eutrophication (Edwards, 1993).

Furthermore, the assimilation of waste in peri-urban production systems would contribute to reducing the ecosystem area appropriated to supply environmental goods and services, leading to a reduction in the ecological footprint of the society (Folke, Jansson, Larsson and Costanza, 1997).

5.5.2. Water

Wastewater reclamation and reuse is currently practiced in a number of countries and fulfils a wide variety of functions. With adequate treatment, water can be returned to consumers; water of a lower quality may be used by industry or in the production of a multitude of biomass products including food, fodder, fiber, fuelwood and timber. The productive reuse of wastewater in irrigation schemes and macrophyte production is of particular importance in dry climates where the production of biomass via photosynthesis consumes approximately 1,000 m^3 of water per ton of biomass produced (Falkenmark, 1989). Postel, Daily and Ehrlich (1996) estimated that in 1990, approximately 2,880 km^3 of freshwater were used by agriculture to irrigate 240 million hectares of land. Depending on climatic factors, the crops under cultivation and the efficiency of the irrigation system, between 50% and 80% of irrigation water is consumed. Assuming that 65% of irrigation water is consumed, global agriculture consumes 1,870 km^3 of water, equivalent to 82% of water consumed directly for human purposes.

Overexploitation of renewable freshwater resources has been recognised by several authors and Ohlsson (1995) states quite succinctly that ‘we have come to a point where water scarcity is increasingly perceived as an imminent threat, sometimes even the ultimate limit, to development, prosperity, health, even national security’. This impending water crisis is considered a serious cause for concern and a possible prelude to international conflict (Rodda, 1995). Ismail Serageldin of the World Bank is quoted as saying, ‘The wars of the next century will be over water’ (Ohlsson, 1995). At the regional scale, augmenting this demand through the use of wastewater may contribute to dissipating tensions amongst upstream and downstream consumers of the freshwater resource.

Where groundwater and surface water resources have been polluted, uncontaminated water supplies are often appropriated through sinking wells into previously untapped aquifers. In certain situations, this can lead to subsidence, damaging infrastructure and increasing the likelihood of flooding; in coastal regions seawater can intrude into underground aquifers. Subsidence due to groundwater abstraction has been observed along the Mediterranean coast in Israel; in Bangkok, both subsidence and saline intrusion have been recorded (Falkenmark and Lundqvist, 1995). The protection of water quality in surface waterbodies reduces the need to develop alternative systems e.g. tube wells, desalination plants and rainwater harvesting to appropriate potable water. This also leads to the reduced exploitation of underground water resources, which limits the potential for disruptions in soil water chemistry, e.g. arsenic contamination.

Although there appears to be some uncertainty as to the extent of the world's freshwater resources (Rodda, 1995), evidence provided by Postel et al. (1996), supports the hypothesis that human appropriation of accessible runoff is approaching an upper limit. The alternatives to using accessible runoff include the expensive option of desalination, constructing new dams with their associated economic, social and environmental costs (Postel et al., 1996). In several arid and semi-arid regions, the freshwater resource is indeed being depleted from surface and groundwater sources at a rate exceeding replenishment; in this situation, wastewater reclamation is the most economically viable source of water (Okun 1991). At the local level protecting surface-water quality enables the safe reuse of the water resource for various non-productive functions e.g. drinking, laundering cloths, bathing, washing utensils and recreation. In some cases these may have a greater priority in poor communities than using this water in agriculture or for growing fish.

5.6. Functional and non-functional values

Burbridge (1994) presents a valuable summary of the most important functions that can be attributed to wetland systems. These include production of biomass, the storage of sediments and carbon, filtration and cleansing of water, providing pathways or linkages among ecosystems, acting as buffers and regulating the rate of surface water flow and groundwater recharge within catchments. It is possible that a similar range of benefits to those suggested by this author may be attributed to agro-ecosystems supporting LWI production systems in peri-urban settings. Potentially one of the most important of these functions is the regulation of local hydrological conditions. Extensive wetland areas have the capacity to contribute to the stabilisation of the local hydrology, providing a spill area for floodwaters from upstream, acting as a buffer against flooding in downstream systems, increasing infiltration to recharge groundwater resources and promoting percolation that will recharge underground aquifers. Flood protection afforded to Calcutta by the peri-urban wetlands that accommodate the major LWI production systems, may represent a significant benefit that would be lost should this land be developed.

As discussed in the previous section, peri-urban production systems have the capacity to recover nutrients from solid waste, agricultural by-products and wastewater, and nutrient assimilation in these systems will contribute to reducing environmental degradation. Agro-ecosystems supporting peri-urban farming practices also represent a valuable habitat for wildlife and may act as a refuge for wildlife, both aquatic and terrestrial, that is displaced by the process of urbanisation. Where peri-urban LWI production systems include practices such as dike-cropping, trees planted on the embankments provide shade and increase the thickness of the boundary layer, reducing the loss of water via evaporation; these two factors contribute to an enhanced microclimate. Furthermore, the integration of additional cropping strategies e.g. of aquatic macrophytes and terrestrial plantations, has the potential to produce a diverse mosaic of microhabitats within agro-ecosystems at the LWI.

On a cautionary note, the conversion of natural peri-urban wetland systems to agriculture or aquaculture could represent a reduction in the value of the wetland area as a habitat for wildlife. For example, the conversion of shallow wetland areas to deeper ponds and lagoons suitable for wastewater aquaculture may physically preclude the colonisation of emergent plants and insects that inhabit the euphotic zone; the culture of fish in these wetland areas could also increase the pressure from predation on aquatic insects. Welcomme (1988) states that the introduction of non-native aquatic organisms can result in degradation of the environment, disruption to the resident community assemblage, genetic degradation of native stock and the introduction of diseases, all of which may result in the loss of species diversity.

The ecological value of the wetlands supporting LWI production systems at the Calcutta peri-urban interface has been recognised by the International Union for Conservation of

Nature and Natural Resources (IUCN), leading to the establishment of wastewater-fed fishponds as a special category of man-made wetlands due to their contribution to preserving nature (Edwards, 1996). In addition to providing a valuable habitat for migratory birds the wetlands support a diverse range of species that contribute to global biodiversity. The value of these systems in protecting the environment, providing habitat and sustaining livelihoods also means that individual may attribute a value to preserving the resource in order that the individual, other individuals and future generations have the option of using the resource at a later date (Muir, Brugere, Young and Stewart, 1999). The impact of an activity, such as urbanisation, on this *option value* may be estimated by assessing the change in an individual's willingness-to-pay for the preservation of the resource. Environments also have an intrinsic or *existence value* that is unrelated to humans and their present or potential direct or indirect use of the resource (Turner, 1991; Muir et al., 1999). Changes in existence value arising from environmental impacts associated with solid waste and wastewater disposal have not been widely described, however, they may be expected to be negative. This suggests that environmental protection afforded to downstream ecosystems through the managed reuse of waste resources contributes to them having a more positive existence value.

5.7. Summary

The principal benefits that may be associated with peri-urban production systems have been described in the preceding sections. For poor people the most tangible of these benefits appear to be employment, income generation and food security. However, wider benefits afforded to society by such production systems i.e. health protection, economic benefits, resource recovery, environmental protection and additional functional and non-functional values may also play an important role in the livelihoods of poor people. According to Goodland (1990) the World Bank has acknowledged the need to include a wider range of issues in economic decisions and to revise the economic appraisal of projects to include externalities and sustainability. From this review it is evident that a more thorough assessment of the wide range of benefits associated with peri-urban production systems will be useful in informing target institutions, planners and policy makers of the true value of these systems to both poor people and society in general.

6. Conclusions

Building on key accounts of the nature, extent and management of LWI farming practices in peri-urban Calcutta a comprehensive literature review has been compiled. The review outlines previous development initiatives that focused on farming systems at the Calcutta peri-urban interface, namely exploratory studies during the last decade focusing on the prospects for improving the design and management of the wastewater aquaculture system. The review continues with an assessment of the origins of peri-urban LWI production systems around Calcutta and describes what is known regarding the nature of farming systems employed and management regimes undertaken. Accounts regarding the diversity of horticultural, aquacultural and agricultural products cultivated are described and the level of production and economic returns reported for some large-scale farming enterprises are summarised.

Although pressure is increasing to develop land managed for LWI production system at the Calcutta peri-urban interface, a number of benefits derived from these systems have been cited as reasons for their preservation. Widely reported benefits include employment, income generation and the supply of fresh food to urban markets; the review attempts to consolidate knowledge relating to these factors. Further benefits reported in the literature are associated with the managed reuse of solid waste and wastewater from Calcutta; the sanitary disposal of waste limits possible negative public health problems and provides a degree of environmental protection, limiting cultural eutrophication. Other benefits attributed to wetland areas that accommodate LWI production systems are also considered, these include a range of environmental goods and services that support societal systems, the provision of sanctuary for wildlife and a repository for biodiversity and various non-use and existence values.

Despite the benefits associated with the managed reuse of waste resources through LWI production systems in peri-urban Calcutta a number of factors have been reported as threatening the continued operation of these traditional practices. Encroachment by urban development appears to represent the most significant threat, although problems may be more severe closer to the urban fringe or in areas with good communications. A further constraint reported in the literature concerns uncertainty regarding the supply of waste resources, a situation arising due to poor management of the delivery system and competition from other users. When threatened by development, a key argument for safeguarding LWI production systems in peri-urban Calcutta is to ensure the continued supply of products to urban markets, however, with the construction of new roads improving communications with rural communities, competition with other producers has reduced this advantage. The competitive advantage of the peri-urban production systems has also been eroded due to falling productivity which has been attributed to a number of factors e.g. limited investment in maintaining the system, a decline in the quality of inputs i.e. seed and waste resources and sub-optimal management. Contamination of waste resources has also been associated with declining production but the possible impact on the risk to public health may be more significant, especially as consumers become more aware of the quality of food they consume. Changing consumer perceptions have also been implicated in reducing the demand for products cultured using waste resources, furthermore, changing institutional perceptions have lead to the abandonment of traditional waste-reuse practices in several countries. Dynamic labour markets at the peri-urban interface mean another constraint facing the operators of these systems is the migration of skilled employees to more highly paid employment, however, information on this aspect of the systems is largely absent from the literature.

Despite the numerous constraints elucidated during the review, a number of factors contribute to the continued operation of the LWI production systems at the Calcutta peri-urban interface and demand for products from peri-urban production systems remains high. Furthermore, although the migration of skilled labour to higher wages represents a constraint, the recruitment of replacement labourers may not constitute a serious problem as migrants from rural areas and members of displaced communities are often without work. Several accounts outlining the wider social and environmental benefits derived from the peri-urban farming activities around Calcutta have also been published and have contributed to the raised awareness of stakeholder groups. In turn this has lead to legislation preventing the filling-in of wetlands that has to a degree safeguarded the LWI production systems.

However, from this review it is evident that to develop peri-urban natural resource management strategies that benefit the poor, new knowledge is required on the role of production systems at the Calcutta peri-urban interface in the livelihoods of poor people. This will entail an assessment of who is engaged in managing and operating these systems, and what contribution these activities make to the livelihoods of those involved and their households. This assessment may also be extended to consider those engaged in activities associated with the operation of these production systems e.g. supplying seed and transporting produce to market. To ascertain whether those engaged in such activities are actually poor the relative wealth of participants should be assessed, this is a necessary step if future initiatives are to directly target the poor. An alternative approach to developing natural resource management strategies that benefit the poor is to consider the wider implications of these production systems on poor communities, the role they play in the food security of these communities and the contribution they make to safeguarding the environment through the managed reuse of waste resources.

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