CASE

Wastewater for the production of fish feed (Bangladesh)

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Supporting case for Business Model 18	
Location:	Mirzapur, Bangladesh
Waste input type:	Hospital complex-derived raw wastewater
Value offer:	Protein-rich feed to cultivate whole, fresh fish – carp species, and treated wastewater
Organization type:	Partnership of private trust and NGO
Status of organization:	Fully operational since 1993; phased out in 2013–2015
Scale of businesses:	Medium
Major partners:	PRISM Bangladesh / Kumudini Welfare Trust (KWT)/ Kumudini Hospital Complex (KHC)

Excutive summary

The for-profit business case describes the experience in Bangladesh to locally treat wastewater for fish production and crop cultivation, generating over 20 years net profits and improvements in environmental quality. The business known as ‘Agriquatics’ started full operations in about 1993 and run till about 2015 when the treatment system was decommissioned and replaced. The system at the town of Mirzapur received raw sewage and grey water from the local Kumudini Hospital Complex (KHC), water which would otherwise flow untreated to a nearby river. The treatment involved duckweed-based phytoremediation on a 0.6-hectare zig-zag plug flow. No fees were charged for the treatment, no subsidies received from the government and no water sold, but fish was reared on the harvested duckweed in adjacent tanks fed by groundwater and topped up with treated wastewater. Perennial crops such as papaya and bananas were grown along the pond perimeter providing additional income. The fish and crops produced were sold on-site and the income received did not only cover operational and maintenance costs of the combined system, but also recovered several times the original capital investments.

KEY PERFORMANCE INDICATORS (AS OF 2012)	
Land use:	1.6 ha
Wastewater treated:	ca. 300m^3/day
Capital investment:	USD 20,000 for the plug flow treatment system, of which 32% as loan for land development and equipment; and 68% long-term land lease
Labor:	4-persons for 1 hour each day – 7 days per week (0.7 full-time equivalent)
O&M cost:	The major O&M costs were harvesting and feeding the duckweed to fish, fish harvest, and seasonal cleaning of the fish tanks. No chemicals were required

Output:	About 7.5 tonnes/yr of mixed carp species fish sold on-site at an average price of USD 1/kg, earning USD 7,500 from fish (an equal amount possible pilfered) and about USD 1,000 from crops. With costs deducted the annual net revenue was around USD 2,000–3,000					
Potential social and/ or enviornmental impact:	Several part time jobs, inexpensive source of fish and a non-chlorinated treated effluent that meets US advanced tertiary standards (Alaerts et al., 1996)					
Financial viability indicators:	Payback period:	6 years (loan); less than 10 years all	Post-tax IRR:	26%	Gross margin:	20%

Context and background

Mirzapur town (ca. 28,600 inhabitants) in central Bangladesh is well known to the community for the Kumudini Welfare Trust (KWT) and its hospital complex with college and schools. This is also where the *Shobuj Shona* system – continuous duckweed farming and feeding to mixed carp species – for wastewater treatment was first developed. Initially, the local hospital had a four-cell facultative wastewater treatment system but this proved over time inadequate. The KWT contacted PRISM[1], an NGO that had a rural development and healthcare project in the area, and in a collaborated effort it was agreed to build, operate and manage a *Lemnaceae*[2] (duckweed)-based wastewater treatment system which supports fish farming on the condition that the operating entity would keep any profits that the system might generate. The development of duckweed-based, conventional wastewater treatment began in the 1980s with the finally installed plug flow system for the hospital complex starting full operations in 1993 (Gijzen and Ikramullah, 1999; UNEP, 2002). The interlinked aquaculture system continued over the years to supply the local Mirzapur population with a reliable, twice per week harvest of carp and free of charge wastewater treatment service for the local hospital, schools and staff housing complex.

Market environment

Situated on the banks of a largely perennial river, and with water still being relatively abundant in the Mirzapur area, there is no demand for (treated) water, but fruits and in particular fish which provides in Bangladesh more than 50% of total animal protein intake (FAO, 2014a). Agriquatics therefore adopted the Shobuj Shona system of duckweed farming to produce a protein-rich fish feed for its own aquaculture system and revenue generation. Despite a boom of aquaculture in the country, the large Dhaka city market is absorbing a huge share of what gets produced by formal aquaculture operations, allowing Agriquatics to focus on local demand. Fish sale was complemented by the production of fruit and vegetables including bananas and taro around the ponds. According to Gijzen and Ikramullah (1999) a substantial portion of the fish produced was bought by the Kumudini Hospital Complex (KHC), which reduced costs for distribution and marketing, and pressure from competitors in Mirzapur. The opportunity that Agriquatics exploited was the combination of the need for the treatment of wastewater, and the locally strong demand for fish, combined with the low-cost availability of land and potential fish tanks.

Macro-economic environment

Bangladesh ranks for many years globally among the top five countries in view of aquaculture production (FAO, 2014a). Aquaculture has been one of the fastest-growing economic subsectors of the economy, providing high-protein food, income and employment and earning foreign exchange. More than 4 million fish farmers, mostly small-scale, and more than 8.5 million other people derive a livelihood from it directly or indirectly. In 2012, farmed fish contributed some 1.73 million tons to the country's total fish production of 3.26 million tons (FAO, 2014a). This is an almost 19-fold increase from the 1980 aquaculture production of about 91,000t, and for example ten times the reported production in the USA. Export revenue in 2012 was estimated at USD 450 million (FAO, 2014b).

The macro-economic situation reflects a positive business driven investment climate for aquaculture in Bangladesh. However, Edwards (2005) and Parkinson (2005) stated that direct governmental support, institutional assistance and a lack of a national funding mechanism to support, e.g. the capital investments in aquaculture in general, or duckweed-based systems in particular are missing. This might be changing under the National Aquaculture Development Strategy and Action Plan 2013–2020 which is aligned with and draws guidance from the National Fisheries Policy, Country Investment Plans, the National Fisheries and Livestock Sector Development Plan and the preceding national fisheries strategy and action plan of 2006–2012. The new plan is however not addressing linkages between sanitation and aquaculture and leaves the model Agriquatics pioneered in a grey area, even more as also wastewater management and reuse are typically not acknowledged as a major element of water management in existing laws and policies in Bangladesh. The sector is hampered, in addition, from a considerable complexity with regard to the power of implementing authorities from both the agricultural and urban wastewater management perspectives.

Business model

The overall value proposition is high quality wastewater treatment paid through the production of fish feed, crops and fish at competitive market prices, making the system independent of fees and tariffs. The enterprise employs a value-driven and for profit, end-sales model whereby an even larger value derives from environmental and social responsibility impacts beyond sales revenues (Figure 221). Essential for the business model start-up was the partnership of the Hospital (via Kumudini Welfare Trust) and PRISM Bangladesh, enabling expertise-supported and cost-effective implementation of the duckweed water treatment and fish rearing system. This ensured that two important economic values were created: (i) wastewater that is treated to an advanced tertiary level at no extra cost to the hospital and thus adding value for the hospital in terms of avoided costs for financing an additional treatment level; (ii) a reliable and guaranteed supply of wastewater generated fish feed at no extra costs, and high quality water supporting crop and fish farming. The symbiosis between the non-profitable wastewater treatment and the highly profitable fish production made the Agriquatics model financially viable, not only to break even, but to pay back the initial loan taken for the setup of the treatment system.

PRISM inherited a defunct pond system which was redesigned for fish production while its capital investment went into the duckweed zig-zag treatment system (see below). Land, fish tanks, water and nutrients were effectively free. Since conventional fish feed is scarce and (consequently) prices are high, the use of alternative sources of quality fish feed remains until today very attractive.

Unlike conventional wastewater treatment systems in more developed countries, where treatment quality is enforced by regulatory agencies, the revenue generation of Agriquatics provided sufficient incentive for the highest quality of treatment found in Bangladesh.

Value chain and position

The Agriquatics initiative was developed under the Kumudini Welfare Trust-PRISM Bangladesh partnership. These two partners provided the business with its most critical resources (wastewater, treatment ponds, technology and expertise). Having these in place, the business was positioned to buy its other inputs such as fingerlings and seeds from up-chain suppliers and sell its products (fish and crops) directly to end-users (local fish consumers; Figure 222).

FIGURE 221. BUSINESS MODEL CANVAS FROM THE PERSPECTIVE OF PRISM BANGLADESH (AGRIQUATICS)

KEY PARTNERS

- Kumudini hospital complex (KHC)
- Kumudini Welfare Trust (KWT)
- PRISM HQ
- Local community

KEY ACTIVITIES

- Treatment of wastewater
- Growing and harvest of crops, duckweed, fish
- Fish and crops sales
- Technical advice

KEY RESOURCES

- Land use rights; ready ponds
- PRISM technical expertise
- Wastewater, duckweed
- Capital access
- Fingerlings

VALUE PROPOSITIONS

- High quality wastewater treatment paid through the production of fish feed, crops and fish at competitive market prices, making the system free of fees or tariffs

CUSTOMER RELATIONSHIPS

- Recurrent purchase based on customer satisfaction (low price and availability)
- Contractual relation
- Strong (non-financial) public support

CHANNELS

- Direct selling on-site
- Contracts and direct interaction of partners at hospital site

CUSTOMER SEGMENTS

- Fish buyers (incl. Kumudini hospital complex)
- Crop buyers
- KWT (demanding wastewater treatment)

COST STRUCTURE

- Capital investment (loan and land lease)
- Regular fingerlings purchase/breeding costs
- O&M (mostly labor employed for duckweed farming, fish feeding, harvest and sale; and crop irrigation, harvest, sale); debt repay

REVENUE STREAMS

- Sales of fish
- Sales of crops

SOCIAL & ENVIRONMENTAL COSTS

- Laborers' health risk due to contact with wastewater
- Possible human health hazard from consumption of fish if contaminants are transported via duckweed to the fish and not destroyed by fish cooking

SOCIAL & ENVIRONMENTAL BENEFITS

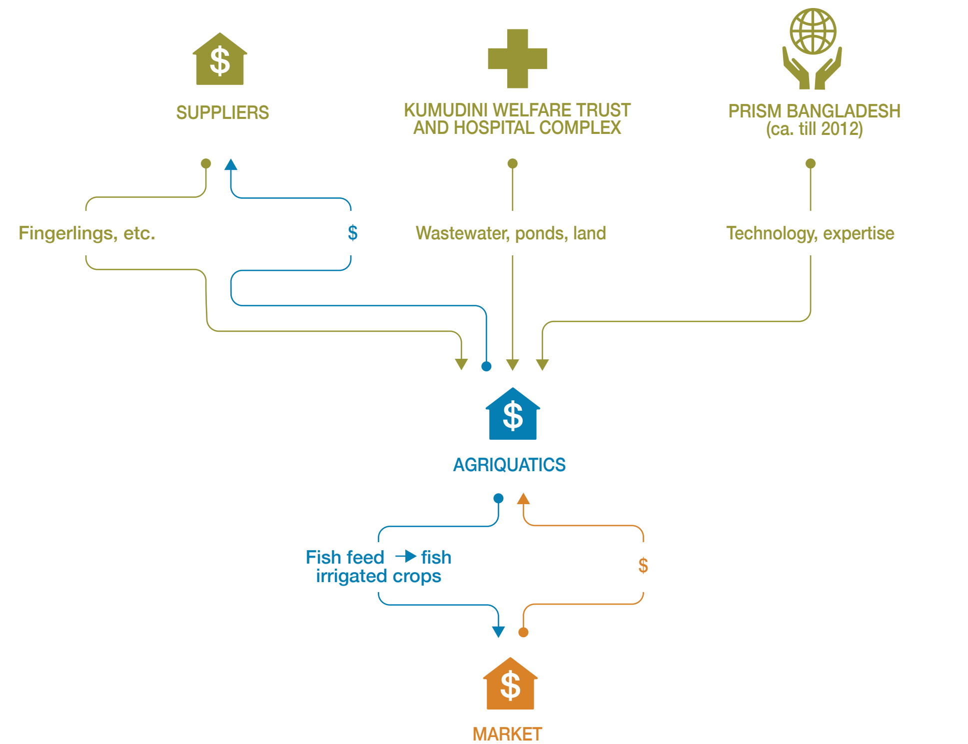
- Wastewater efflux from hospital is treated, which results in reduced environmental pollution
- Support of jobs and protein supply for the local community
- Cheap food supply to the hospital supporting its free service to the poor

A notable portion of the fish and crops produced was bought by the hospital complex. Additional profits from water sales were not realistic in the local context as there is no market for the treated water due to the availability of adequate fresh water for agriculture, even in the dry season.

Institutional environment

The Kumudini Welfare Trust is a not-for-profit family trust managed by an external board of directors – one member of which is nominated by the Government of Bangladesh. PRISM Bangladesh is a not-for-

FIGURE 222. VALUE CHAIN OF THE BUSINESS MODEL



profit Bangladeshi NGO. The relationship between the two entities was specified under a succession of mutual agreements. At a later stage, PRISM's involvement phased out, while the treatment system continued to operate until 2013 when the Indian Government financed a new treatment plant for the hospital complex which was inaugurated on 7 June, 2015.

The wastewater fed aquaculture system received significant scientific interest. Public support was also strong, but involved no direct financial transaction beyond a continuing willingness by the local public to purchase fish. Agriquatics provided in-house training to the locals working as laborers. Linking between the sanitation and agricultural sector, the project fell under different policies and strategies without any direct support (see section on the Macro-economic environment above).

Technology and processes

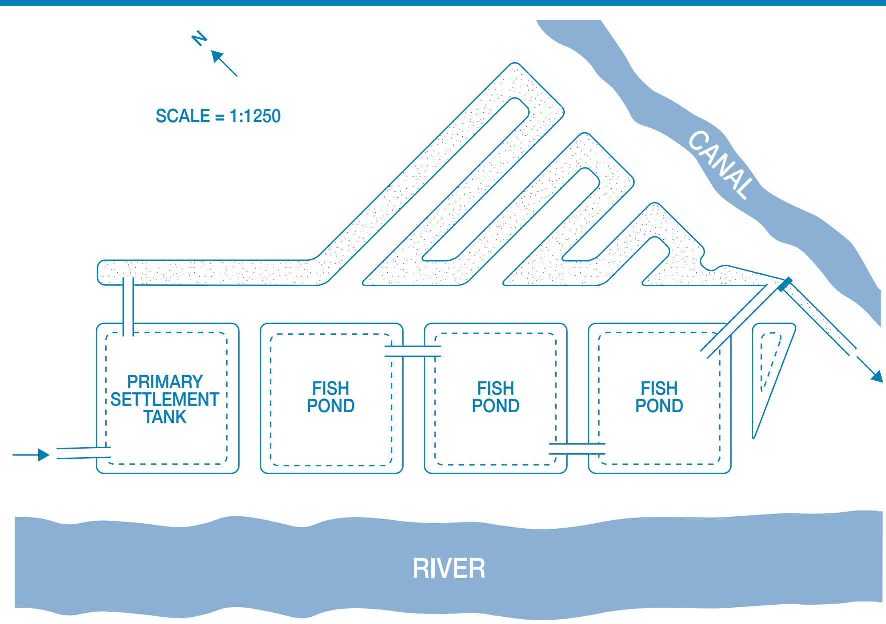
The project inherited a defunct four-cell, single hectare facultative ponds complex and added to it a 0.6-ha plug flow duckweed wastewater treatment system. Only the first of the four ponds remains connected to the wastewater treatment system serving as a primary wastewater receiving and settling tank (Figure 223). The other three ponds were converted to fish production tanks, fed by groundwater and by the final effluent of the plug-flow (Iqbal, 1999).

Except for an initial lift pump, the wastewater moves by gravity to and through the whole treatment system from the initial 0.25-ha pond with a hydraulic retention time of two to four days, and followed by the duckweed-covered, 0.6 ha plug flow lagoon constructed as a 500m long non-aerated serpentine channel with seven bends. For this, depth of the lagoon increases gradually from 0.4 to 0.9m. The system was fed with a mixture of hospital, school and domestic (staff residencies) wastewater from a population of about 3,000–4,000 people with per capita production of wastewater estimated at around 100L/day. The hydraulic retention time in the plug flow wastewater-fed duckweed lagoon was estimated by different authors as 15–22 days, with parts of the water in the zig-zag been lost as seepage to the nearby canal. The lagoon was covered by a floating bamboo grid to contain the standing (100% cover) duckweed mat, at least in the first part of the system which is naturally the richest in nutrients. Early data suggest that the system produced 220–400t fresh duckweed/ha/year (about 17 to 31t dry weight/ha/year) (UNEP, 2002). Duckweed was harvested manually with nets, drained in bamboo baskets, weighed and then placed in one of 12 floating feeding stations distributed evenly across the surface of the originally three 0.25 ha fish tanks. Fish were fed in addition with rice bran and oil cake (Edwards, 2005).

Part of the treated water was eventually used to top up the fish tanks. Analysis by the International Center for Diarrheal Disease Research, Dhaka, Bangladesh, verified that indicator pathogen transmission to fish or workers was similar to control groups and within safety margins (Gijzen and Ikramullah, 1999; Islam et al., 2004). This might however not apply to all possible pathogens and heavy metals (see below).

The fish tanks were stocked with around 10,000 to 14,000 fingerlings at the onset of the monsoon season. The polyculture includes Indian major carp (Mrigal 25%, Catla 20%, Rohu 15%) and Chinese carps (Silver Carp 10%, Mirror Carp 20%, Grass Carp 10%). Tilapia was not stocked but fingerlings entered the tanks incidentally (UNEP, 2002). Fish were usually harvested twice a week. The production numbers varied between reports from on average of 7.5 to max. 15t/ha/year (of which usually a share got stolen).

FIGURE 223. LAYOUT OF THE WASTEWATER TREATMENT SYSTEMS AND FISH FARMING AT AGRIQUATICS



Source: After Iqbal, 1999.

Movement of wind across the surface was mitigated by strategic placement of crops such as bananas, taro, papaya and lentils along the perimeter. These also contributed to the income of the system.

Funding and financial outlook

Agriquatics had the advantage that wastewater collection and channeling were already in place and so the defunct pond system was redesigned for fish production. The land was leased on favorable terms, and capital investments for the labor intensive construction of the plug flow system were limited. Financial support was provided by United Nations Capital Development Fund (UNCDF).

In view of operational cost recovery, a portion of the fish produced was bought by the hospital which provided financial security. Both initial partners (KWT and PRISM) had obvious interests in the effective operation of the system: KWT to achieve the effective treatment and proper disposal of its wastewater; PRISM to promote the duckweed technology while generating financial returns. Based on audited records from the first eight years (Table 52), revenues allowed a pay back of the initial loan from PRISM in about six years. Since then the wastewater-fed duckweed-fish system generated an annual net profit of about USD 2,000–3,000, which is larger per hectare than e.g. that of rice, the major agricultural crop in the area. The internal rate of return was calculated as about 25.9% (Gijzen and Ikramullah, 1999; UNEP, 2002; Patwary, 2013).

TABLE 52. AVERAGE ANNUAL INCOME AND EXPENDITURES 1993–2000 IN TAKA (USD 1 = 40–50 TAKA IN THIS PERIOD)

DESCRIPTION	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	8 YEARS AVERAGE
1. Recurring operational Cost									
Land rental (2 ha)	26,000	26,000	26,000	26,000	26,000	26,000	26,000	26,000	26,000
Staff salary and wages	85,600	92,020	98,922	106,341	114,317	122,891	129,036	136,480	110,701
Field supplies (duckweed)	10,000	12,000	13,500	14,300	15,200	15,960	15,678	16,512	14,144
Field supplies for agriculture & fish	28,000	29,000	30,000	31,000	33,000	32,300	34,000	33,600	31,363
Energy/fuel cost (pump)	43,500	45,500	47,900	50,430	55,720	58,500	62,400	63,100	53,381
Maintenance	13,700	14,000	14,500	15,200	16,720	17,556	18,375	18,500	16,069
Miscellaneous	6,285	6,580	7,000	7,350	7,700	7,900	7,500	7,720	7,254
Subtotal annual operation cost	**213,085**	**225,100**	**237,822**	**250,621**	**268,657**	**281,107**	**292,989**	**301,912**	**258,912**
Depreciation of loan (10 years)	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Management overhead (7.5%)	15,981	16,833	17,837	18,797	20,149	21,083	21,974	22,643	19,412
Financial costs (9.5% on work capital)	10,450	10,925	11,590	12,350	13,300	13,352	13,916	14,340	12,528
Subtotal admin & finance costs	**51,431**	**52,758**	**54,427**	**56,147**	**58,449**	**59,435**	**60,890**	**61,983**	**56,940**

DESCRIPTION	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	8 YEARS AVERAGE
Total annual recurring costs	**264,516**	**277,858**	**292,249**	**306,768**	**327,106**	**340,542**	**353,879**	**363,895**	**315,852**
2. Income from farm revenue									
Sale proceed from duckweed-fed fish	128,778	253,800	316,509	402,231	404,982	445,702	419,440	413,354	348,100
Sale proceed from agriculture & fruits	25,000	30,000	34,000	44,000	65,000	58,250	56,667	60,223	46,643
Miscellaneous sales	3,600	4,400	4,600	5,200	5,400	5,200	5,100	5,600	4,888
Total income from sales	**157,378**	**288,200**	**355,109**	**451,431**	**475,382**	**509,152**	**481,207**	**479,177**	**399,631**
3. Operational profit	**-55,707**	**63,100**	**117,287**	**200,810**	**206,725**	**228,045**	**188,218**	**177,265**	**140,719**
4. Net profit before taxes*	**-107,138**	**10,342**	**62,860**	**144,663**	**148,276**	**168,610**	**127,328**	**115,282**	**83,779**

* No tax on agro-production (tax holiday)
Source: Patwary, 2013; modified.

Socio-economic, health and environmental impact

Local studies showed that duckweed recovered a significant portion of the nutrient value inherent in the wastewater, so much that in the last part of the zig-zag system it hardly grew due to low nutrient content. The nutrient removal had a positive impact on the effluent receiving water body and its water quality, reducing potentially human health-related costs in the vicinity. But nitrogen as ammonium and nitrate was not only efficiently captured through phytoremediation, but also transformed into protein rich biomass. Based on water quality data (oxygen demand, nitrogen, phosphorus) by Alaerts et al. (1996) and fecal coliform analysis by Islam et al. (2004), treated wastewater discharged to the adjacent river could be considered among the highest quality of treated wastewater in the country attainable without use of reverse osmosis and fit for unrestricted irrigation of vegetables according to WHO standards for wastewater reuse (UNEP, 2002). Further disinfection of the treated effluent prior to its discharge into the river had been considered, but found to be prohibitive on the basis of cost.

While the harvest of duckweed significantly exposed workers to wastewater and its pathogens, scientific monitoring could not determine a cause-effect relationship between incidences of worker diarrheal disease infection and their working at the site (Gijzen and Ikramullah, 1999). Also fish was tested to be safe for consumption. However, while duckweed absorbs nutrients, it also absorbs heavy metals, and if it used as herbivorous fish feed, the metals can be bio-accumulated as it was locally verified (Parven et al., 2009). There can also be gastroenteritis-causing bacteria which persist in the treatment system and might spread to fish (Rahman et al., 2007). An impact from such a pathogen transfer on human consumers was however considered low as fish is generally not eaten raw in Bangladesh (Gijzen and Ikramullah, 1999). Data on other potential contaminants such as estrogen or pharmaceutical residues do not exist. The recommendation was made that related research be included also in any replication of the system.

Entry into aquaculture appears to have fewer gender barriers, as this sector developed outside cultural traditions. According to FAO, Bangladeshi women make up about 60% of fish farmers, and many are successful entrepreneurs[3]. And while women's involvement in aquaculture has importantly improved the economic, nutritional and social benefits for their family, their work goes largely unrecognized in official statistics.

Scalability and replicability considerations

Over its lifetime, the Agriquatics system recovered several times its investment costs, which is unique in the domain of wastewater treatment. The key drivers for the success of the business were:

- Availability of land.
- Limited capital cost with several profitable revenue streams for high-value products resulting in fast payback.
- Low-tech and -cost treatment system supported by a mutually beneficial partnership ensuring availability of water, expertise and system maintenance.
- Profit incentive for treatment of wastewater that obviates requirement for external supervision and controls.

It is important to note that the positive financial performance of the wastewater treatment and aquaculture system was a product of a mutually beneficial partnership which created favourable conditions, such as no major costs for wastewater collection and channelling, and favourable terms for capital investment, land lease and cost recovery.

A pillar of the success was the value creation in terms of fish, i.e. to capitalize on increasing revenues with moving up the value chain, compared to treatment plants only providing treated water. On the other hand, the requirement for a suitably large land area for the combined treatment – aquaculture system will be a common constraint within towns and cities. This is especially true for Bangladesh with its very high population density, land speculations and rising opportunity cost of land, in particular within urbanizing areas (Edwards, 2005). An opportunity in drier areas could be to link such systems with inner-urban or peri-urban green belts, as realized in Parque Huascar in Lima, which can create significant social value[4], or biodiversity reserves. From a health perspective, it has to be added that although the system in Mirzapur was set up at a hospital, its replication potential will be highest where the wastewater derives only from domestic settings with minimal risk of chemical contamination.

Aside its benefits of nutrient accumulation and high crude protein production, also duckweed has some biological constraints which can limit its use in other regions: its growth is adversely affected by both low and high temperatures, and high light intensity; occasional insect infestation; and rapid decomposition following harvest, i.e. the fish ponds have to be in proximity.

Summary assessment – SWOT analysis

The success story builds on a win-win situation of treatment quality and revenue generation combined with favourable low capital and O&M costs, and a high-value product allowing the recovery of both operational and investment costs. The system requires a relatively large land investment for the spatial combination of aquaculture and treatment systems. Figure 224 shows the SWOT analysis of this business case.

FIGURE 224. SWOT ANALYSIS OF AGRIQUATICS BUSINESS CASE

	HELPFUL TO ACHIEVING THE OBJECTIVES	**HARMFUL** TO ACHIEVING THE OBJECTIVES
INTERNAL ORIGIN ATTRIBUTES OF THE ENTERPRISE	**STRENGTHS** ▪ Viable business model based on multiple revenue streams, cost recovery and net profit ▪ Limited capital and low O&M costs ▪ Green infrastructure image with positive environmental impacts ▪ Mutually beneficial partnership enabling free supply of wastewater and land including lagoons at favorable terms ▪ Expertise in duckweed-fed fish farming	**WEAKNESSES** ▪ Significant land-size requirement ▪ No direct governmental support ▪ Monitoring of system safety remained fragmentary ▪ Sensitive to flooding ▪ Fish farming not possible with increasing chemically contaminated wastewater
EXTERNAL ORIGIN ATTRIBUTES OF THE ENVIRONMENT	**OPPORTUNITIES** ▪ Rising fish demand ▪ Increasing demand for green infrastructure ▪ Proof of concept for replication ▪ Short pay-back period ▪ Grey legal area	**THREATS** ▪ Possible industrial effluent ▪ Undetected human health risks ▪ Local aquaculture competition ▪ Changing government policy toward wastewater reuse in aquaculture ▪ Area wide flooding (happened twice)

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- www.adb.org/sites/default/files/publication/31230/toilets-river.pdf (p. 75–76)

Case descriptions are based on primary and secondary data provided by case operators, insiders or other stakeholders, and reflect our best knowledge at the time of the assessments 2016. As business operations are dynamic data can be subject to change.

Notes

1 PRISM: Project in Agriculture, Rural Industry Science and Medicine. The PRISM group was founded in the 1980s as an international non-profit organization focusing on the support of local and family enterprise within rural communities in developing countries. PRISM Bangladesh was created as an affiliate of the PRISM Group in 1990 (Torres 1993).

2 Lemnaceae ("duckweed"), a family of aquatic macrophytes converts nutrients from the wastewater into protein rich biomass, that can be used as poultry and fish feed. According to Leng (1999), on average 40–50 tons of dry matter can be produced per year per hectare under optimal conditions, allowing the production of more protein per ha and year than via soybean or groundnut (Patwary, 2013).

3 www.fao.org/gender/gender-home/gender-programme/gender-fisheries/en/ (accessed 5 Nov. 2017).

4 https://wle.cgiar.org/thrive/2013/09/02/wastewater-reuse-benefits-beyond-food-production (accessed 5 Nov. 2017).