PRIVATE SECTOR PARTICIPATION IN WASTEWATER TREATMENT
BOT Financing Mechanism

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Abstract

This paper presents a pilot project that is designed to test a strategy for mobilizing private investment in wastewater treatment without increasing the tariff burden on the consumers.

Developing countries needs to undertake a comprehensive effort to rehabilitate, modernize and strengthen their basic infrastructure so that they can create the conditions for sustainable economic growth. The lack of adequate water and wastewater infrastructure to support self-sustained economic growth and social wealth is a major obstacle to economic development. The quality of basic services influences the competitiveness of local communities in attracting industries and other real state investment.

Most wastewater treatment facilities are financed either from the governments' grants fund or from foreign donor loans and grants. Often, these facilities are not designed, procured, built and operated in a cost effective and financially viable manner. On the other hand, the demand for investment in this sector greatly exceeds the financial capacity of governments. For example, in 2010, Egypt will be in need for LE 12 billions per year to satisfy wastewater treatment requirements. Governments have tried different mechanisms to finance such facilities such as assessments against property ownership and increasing taxes. Yet, these measures have failed to mobilize sufficient fund given the scale of demands of the large amount of fund required. Another option gaining attention is attracting private investment to participate in this field.

The main challenge to this approach is that these utilities do not recover cost and are not credit worthy, while the private sector seeks a high IRR and to minimize risks. On the other hand, utility must generate revenues sufficient to pay the O&M costs, retire capital cost and rehabilitation cost, future expansion cost and adequate return on investment to the investor.

This may exceed the willingness of the consumer to pay for service. Furthermore, the challenge is how in reconciling the needs of the private sector in making a profit, protecting the customer from over payment, and assisting government in meeting development and financing aims.

To solve this difficult equation, the legal framework, the economic structure, the macro and micro management aspects are issues to consider on the national level.

On the project level, this pilot project tests the following measures for mobilizing investment resources. The first project design based on avoiding mechanical and electrical equipment, chemicals, and skilled labors revealed an IRR of -5% to -4% which is repulsing to any investor. The second trial based on applying treatment methods that generate by-products of economic value resulted in an IRR of 4% to 5%, which is still not attractive to investor. The third attempt based on using the treated effluent in agricultural activities resulted in an IRR of 12% to 36% which is considered very attractive to all private sector investor.

Assumptions are given in the paper for the quality of influent and effluent and annual rate of price increase. O&M cost, rehabilitation cost and depreciation cost are estimated as a percentage of the capital cost.

Introduction

Fresh water resources are diminishing at alarming rates all over the world and are of particular concern to Egypt where 88 % of the water demand is utilized for agricultural activities. Since 1978, the Government of Egypt (GOE) has expanded and upgraded both water and wastewater facilities to protect water resources and human health in Egypt. This will improve quality of life and building sustainable local infrastructure for operation of vital community services. Treating wastewater is very important to avoid pollution of surface and ground water.

The World Bank predicts that over the next 40 years, production of food must increase by 300 % and recommends that nutrients from wastewater should be utilized in agriculture instead of Fossil fertilizers and pesticides to decrease environmental pollution as well as any potential economic burden. Sustainable development is interrelated to water conservancy, wastewater treatment, and reuse programs.

Getting red of wastewater from a community is very important. It will protect the environment and encourage the business. Treating and reusing and/or disposing of wastewater deem to be feasible in agricultural or fish farming business. Water reclamation and reuse around the world has become a viable for conservation and management of available water supplies. Water reuse can also present a method of pollution prevention when it replaces effluent discharge to sensitive water bodies. In addition, water reuse can eliminate or reduce the need for costly and complicated advanced wastewater treatment processes. In particular, the removal of nitrogen and phosphorus is unnecessary for most non-potable water reuse.

Reclaimed wastewater can be used for landscape and recreation grounds irrigation, industrial process, cooling towers, air conditioning, fire fighting, crop and fiber production, and environmental enhancement such as maintaining certain stream flows and wetlands. In this paper, reuse of treated wastewater in agricultural business is mainly considered, while fish farming is another alternative.

This paper is based on some parameters to be considered in order that it will be feasible. Each involved party is going to have input and consequently gain an output or save some expenses. The parties are the Government of Egypt (GOE), an investor who will build a treatment plant and farm, the businessmen in the area, and the domestic people living in the community, in addition to other benefits such as saving the environment.

The government is required to make the land area needed to build the treatment plant and the agricultural farm available to the investor. In addition, it will provide the site with potable water and electric power for operation purposes. The government will help the investor overcome encountered bureaucratic problems. In this proposal, the government is obliged to provide the plant with the raw wastewater. Depending on the feasibility study and type of contract between the government and the investor, making the land available to the investor can be wither giving it for free, leased, or rented. In return, the government will have the wastewater problem solved without financial burden.

The investor is required to build the plant, considering the local environmental law, and prepare the farm on his own. He is also required to operate, maintain, and may transfer it to the government after a period of time. Feasibility study will identify this period. Moreover, it may dictate a sort of payment from the government to the investor for treating the wastewater and/or giving him a piece of land that he uses the treated water in agricultural business.

The community investors, the government, and the people in the project area are required to finance the cost of the collection system including gravity sewers, pumping stations, and forcemain. In return, they will solve their wastewater problem.

Purpose of the Paper

The purpose of the paper is to expand and speed up the development of sustainable, reliable wastewater facilities by attracting the private sector to invest in this sector.

Collection System

To make it easy for the party which will undertake constructing the collection system, a proposed low cost collection system, such as the small diameter gravity sewer, can be applied together with the conventional gravity sewer system. This will reduce the total cost of it.

Treatment

Because the land area required for building the plant will be available to the investor without high financial burden; the proposed treatment process is as follow:

1. Preliminary treatment: Screening and grit removal
2. Advanced primary treatment: Up-flow-Anaerobic-Sludge-Blanket (UASB) reactor
3. Secondary treatment: aquatic farming system as an aqua-culture system using duckweed (lemna gibba) macrophytes

Wastewater Treatment Plant Design Capacity

1. Year of planning:	2020	
2. Population served:	100,000	Person Equivalent (PE)
3. Water consumption	220	lpcd
4. Design capacity	15,840	m^3/d
	5,780,000	m^3/y

5.	Percent of wastewater generated	80	%
6.	Percent of water evaporation	10	%
7.	Consumed potable water	22,000	m^3/d
8.	Generated wastewater	15,840	m^3/d

Land Requirement

1.	Wastewater treatment plant	100	feddan (fd)
2.	Water requirement for irrigation	2,000	m^3/fd/year
3.	Agricultural farm	2,900	fd

Job Opportunities

Dividing the farmland to pieces each of 5, 10, or 20 fd, this will create 580, 290, or 145 small farms. If a 5-person family handle a small farm of 5 feddans, a total of 580 families can benefit form this project. As an average, a 5-feddan farm needs 3 workers, 1,740 job opportunities will be available. However, it is the investor's decision to run his business either one big farm or some small farms. In all cases, a 2,900 fd farm will be added to the agricultural land in Egypt by building one wastewater treatment plant.

Project Indicators

1. More than 100,000 person are served by wastewater system without capital or running cost to the government.
2. Creation of 1,740 job opportunities.
3. Conservation and rationalization of water resources.
4. Improvement of public health of the community.
5. Increasing agricultural land by 2,900 fd.

Capital and Operating Costs

Capital Cost

1.	Wastewater treatment plant	15,000,000	LE
	(Other wastewater treatment plants)	60,000,000	LE
2.	Per person	150	LE
3.	Per one cubic meter of wastewater	13	PT
	(Depreciating the plant over 20 years)		
4.	Reclamation of land for the farm	10,000,000	LE
5.	Per fd	3,450	LE

Operating cost

1.	Wastewater Treatment plant	900,000	LE/year
2.	Per person	9	LE/year
		75	PT/month
3.	Per one cubic meter of wastewater	15.6	PT
4.	Reclamation of land for the farm	1,450,000	LE/year
5.	Per fd	500	LE/year

Anaerobic Enhanced Primary Treatment: UASB Reactor

Anaerobic treatment not only removes solids, but includes active biological stabilization of the majority of oxygen consuming substances. Anaerobic treatment process can achieve an effluent quality intermediate between the primary and secondary treatment that can be classified as an enhanced primary treatment effluent. Anaerobic treatment removes major part of the carbonaceous oxygen demand from raw wastewater, but typically the residual nitrogenous oxygen demand in the effluent requires further treatment to be competitive with a conventional secondary treatment process.

The up-flow anaerobic sludge blanket (UASB) reactor is a high rate, suspended growth type of reactor that is becoming popular for municipal and industrial wastewater treatment in many developing countries. Design parameters developed for UASB reactor is available on request.

Organic loading of up to 15 kg COD/m^3 (15,000 mg/l) can be applied to the UASB reactor for most types of wastewater effluents. Depending on the composition of the wastewater, the removal efficiency of the UASB process may vary between 60-70% for COD and 75-85% for BOD_5, at influent temperatures between 20-35° C.

The UASB reactor traps particles of organic material in a "sludge blanket" and digests them over a long time period, while passing the liquid fraction through in a matter of a few hours. As a result, the volume of the reactor is kept to a minimum and the treatment plant is compact. The UASB reactor is designed around two main criteria: hydraulic retention time, the average amount of time that the liquid part of the wastewater stays in the reactor, and solids retention time, the average residence time of the solids in the reactor. A properly designed UASB reactor eliminates the need for mechanical mixing and has few moving parts. Typically, a UASB treatment plant may need pumps only to remove excess sludge from the reactor.

Capital and operating costs for municipal wastewater treatment range from \$5/person and \$0.03/person respectively in India, to \$13.9/person and \$0.43/person respectively in Colombia. Details about the design, effectiveness and costs for these treatment plants are available on request.

Advantages of treatment with anaerobic reactors

Anaerobic treatment of wastewater is an effective enhanced primary treatment option for developing countries, particularly those with mild climate, and has important advantages over aerobic processes:

1. Easier to manage with relatively less skilled labors than conventional treatment plants;
2. Costs on the order of 3-6 less than aerobic secondary treatment plants;
3. Few moving parts, lower operating costs, little or no power consumption;
4. High strength waste streams can be handled efficiently at no energy penalty;
5. Shock loads handled better than aerobic systems;
6. Large flow variations and prolonged shutdown are not problematic;
7. Reduced inorganic nutrients in effluent are ideal for plant uptake;
8. Low amounts of residual sludge byproducts; sludge has good settling properties, is easily de-watered and needs no additional treatment;
9. Bio-gas fuel may be economical to utilize for large scale facilities;
10. Can attenuate or degrade many refractory organic compounds;
11. Virtually complete stabilization of organic material to CO_2 and methane.

Disadvantages of treatment with anaerobic reactors

1. Best reactor temperature is 20°C and above; lower temperatures slow reaction rate;
2. Longer reactor startup time because of slow growth rate of anaerobic bacteria;
3. Additional treatment is typically required to meet secondary quality standards;

4. Odor control measures are more important than for aerobic treatment;
5. Toxic effect of high concentrations of heavy metals, toxic organic, free ammonia (>50 mg/l) and free H_2S (>250 mg/l) may inhabit methanogenic activity;
6. Chemical buffering may be required to maintain alkalinity in reactor;
7. Corrosion resistant materials, such as plastics and masonry coatings are required for the reactor vessel and pipes.

Post-Treatment: Aquatic Farming System

There has been increasing interest in recent years in using aquaculture systems as natural sinks for oxygen consuming substances and wastewater-borne and recognition of their capacity to provide an advanced quality final effluent. The common duckweed are group of floating macrophytes with excellent potential as a commercial crop plant because of their high growth rate, high nutritional value and low fiber content. The duckweed plants cover the surface of the water in a dense mat that interferes with mosquito breeding, and the quiescent conditions under the mat are ideal for sedimentation of suspended solids.

Agronomic management of the duckweed plants on wastewater can result in production rates of about 300-400 metric tons of fresh bio-mass per hectare per year (ha/year) or 126-336 metric tons per feddan per year (fd/year). This is the equivalent of dried meal of about 20-40 metric tons ha/year or 9-17 metric tons fd/year. Dried duckweed meal can substitute for equal quantities of soybean meal in balanced poultry feeds, and fresh duckweed satisfies the nutritional requirements of certain fish grown in ponds, such as tilapia and a carp poly-culture.

Integration of anaerobic enhanced primary treatment of wastewater and duckweed farming constitutes synergistic processes that is (a) a complete wastewater treatment technology and (b) a farming system that is capable of producing more high quality protein than soybeans on an equivalent land area.

Land for a duckweed post-treatment system is similar to a waste stabilization pond series. The amount of treatment surface area necessary to achieve an advanced quality treated effluent was about 1.6 m^2/PE (Person equivalent) in a pilot project in Bangladesh.

The potential revenues to an owner/operator of a treatment and duckweed-fed fish production system in Bangladesh are attractive. For example, at an average live weight price of fish of \$1.5/kg, the gross revenues from duckweed-fed fish production in Bangladesh is on the order of \$2.4-\$3.6/PE/year, or about \$0.38-\$0.56/m^2/year in gross revenues from the total amount of land used for the treatment and production system.

Duckweed aquaculture that does not include fish production has dried duckweed meal as the final product. The total amount of land needed for duckweed production in Bangladesh is 2.1 m^2/PE. If duckweed production is priced the same as soybean meal, between \$0.25-\$0.30/kg, gross revenues from duckweed meal sales will be about \$0.38-\$\$0.46/m^2/year of total land used, or about \$0.80-\$0.96/PE/year.

Due to the fact that duckweed covers the water surface, it prevents sunlight from penetration into the lagoon body. Consequently, harmful bacteria are still alive. To overcome this problem, another lagoon is constructed for a detention time not less than one week. Depending on the quality of the influent, aeration may be added.

A polishing lagoon is required afterwards and it will be used as storage tank for irrigation water or may be used as a fish farm.

Byproducts

1. Poultry and/or cattle.
2. Fish
3. Natural gas: heat and/or electric power
4. Natural fertilizer from sludge and cement kiln dust
5. Silage
6. Plywood

Agriculture

In this part of the paper, the investor is also given the land for cultivation from the government in the same way as for the treatment plant. Giving the land by the government will also help it solve its wastewater problem. For the investor, he is required to reclaim the land and make it ready for cultivation including the infrastructure such as irrigation canals and other facilities. On return, the investor is going to sale the crops and offset the cost of construction, operation, and maintenance.

The proposed system for irrigation is the leaky pipe irrigation system, which is the only system to reuse the treated wastewater in irrigation. It can be adapted for irrigation of trees or fresh vegetables.

Advantages of the leaky pipe irrigation system

1. Save water and energy, increase crop yield; improve crop quality as well as low maintenance requirement.
2. Easily installed.
3. Eliminates runoff, evaporation, erosion and soil compaction.
4. Keeps surface dry for easy cultivation and harvest.
5. Easily fertigation process.
6. The method can be used in soil having relatively low water holding capacity and high intake rate.
7. Low labor requirements.

To use this leaky pipe irrigation system, a filter needs to be added at the end of the wastewater treatment plant. This will help the irrigation system perform better with little operation and maintenance cost.

Project Impacts

Environmental Impact

- Reserves surface and ground water resources by not dispose untreated or partially treated wastewater into the fresh water bodies not on the ground.
- Improve air quality by increasing oxygen generated from planting desert and decreasing cement dust from cement factories.
- Full treatment of sludge avoids misuse of it in agricultural purposes.
- Conservation of water resources by reuse of treated wastewater and using subsoil drip irrigation method.
- Recycling agricultural waste saves the environment by producing natural fertilizer and cattle feeds.
- Proposed treatment technology does not almost use power either from electricity or from fuel and does not use chemicals, so it is and environment friend. On the contrary, it generates power in the form of natural gas for use in the plant.
- Providing people with sanitary service enhance their public health.
- Using reed in sludge drying beds decrease heavy metals in the sludge that will be used as natural fertilizer. Reed concentrates heavy metals

in its roots. These roots can be collected, burned and barred in a safe place.

Impact on Water Resources Management

- This project does not conflict with Toushka project, which is developed and implemented to maximize utilization of available water resources.
- It increases agricultural land.
- It is an invitation to improve water usage before increasing water resources by building costy project on the Nile outside Egypt.

Social Impact

By dividing the reclaimed land to pieces each of 5 to 10 feddans, we can:
- Create new communities of 580 families (family size of 5 persons).
- Create 1,700 new jobs either in the plant or in the farms, which improve unemployment.
- Loosen over crowded areas in the old valley by planting the desert and new communities. This will decrease crimes caused by over population and informal areas.

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Average sewage characteristics after each stage of treatment

Treatment Process Steps	BOD mg/l	SS mg/l	TDS mg/l	Amm. N mg/l	Nitrate mg/l	Phosphate mg/l
Raw sewage	400	480	1500	85	Nil	40
Pre-treated Sewage -Screening & grit removal	390	460	1500	85	Nil	40
Primary Treatment -Primary settling	280	200	1500	85	Nil	40
Secondary Treatment -Activated sludge process	20	30	1500	Nil	20	15
Tertiary Treatment -Chemical treatment/settling	5	5	1500	Nil	20	Nil
Final Treatment (polishing) -Micro filtration & Reverse osmosis	Nil	Nil	500	Nil	5	Nil

Recommended Microbiological Quality Guidelines for Wastewater Use in Agriculture, World Health Organization (WHO)

Category	**Reuse Conditions**	**Group Exposed**	**Intestinal Nematodes**[a] **(arithmetic mean of no. eggs/liter** [b]**)**	**Fecal coliforms (geometric mean of no. per 100 ml** [b]	**Wastewater treatment expected to achieve required microbiological quality**
A	Irrigation of crops likely to be eaten uncooked; sports fields, public parks [c]	Workers, consumers	≤1	≤1,000[c]	Series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal, industrial and fodder crops, pasture and trees [d]	Workers	≤1	No standard recommended	Retention in stabilization ponds fro 8-10 days for equivalent helminth and fecal coliform removal
C	Localized irrigation category B crops if worker and public exposure does not occur	None	N/A	N/A	Pretreatment is required by irrigation technology less than primary sediment

[a] Ascaris and Trichurus species and hookworms.
[b] During the irrigation period.
[c] A more stringent guideline (>200 fecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
[d] In the case of fruit trees, irrigation should cease two weeks before fruits is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

Performance of Most Common Aerobic Wastewater Treatment Technologies:

Treatment Technology	Removal Efficiency				Effluent	Sludge production
	BOD_5	TKN	N_{total}	P	TSS	(dry weight)
	(%)				(mg/l)	(kg/kg $_{BODremoved}$)
Primary sedimentation	20-30	5-20	0	-	-	-
Activated sludge High load Low load	 90 95	 25 75	 30 55	 30 45	 25 10	 0.9-1.0 0.5-0.7
Oxidation ditch	95-98	80-90	50-70	10-20	10-15	0.3
Trickling filter High load Low load	 80 90	 20-35 60-80	 25 35	 - -	 45 25	 0.6 0.4
Rotating biological contactor	90-95	50-75	-	-	-	0.6
Aerated lagoon	70-80	-	-	-	-	0,03-0.08 m^3/person/year
Waste stabilization ponds	80-90	-	50-90	-	50-75% removal	0,03-0.08 m^3/person/year

Health risk assessment of water reuse:

The principal infection agents which may be presented in raw wastewater are classified into three groups: bacteria, parasites, and viruses usually found in the raw wastewater.

Bacteria: salmonella, shigella and variety of other bacteria of lesser importance.

Parasites or protozoa and metazoa: Entamoeba histolytica, (inform of cysts), helminthic parasites as intestinal worms Ascaris lumbricoides, tapeworms Taenia saginata and solium, the whipworms and hookworms etc. Free living nematode larvae are not pathogenic to humans. The eggs and larvae are resistant to environmental stresses and may survive disinfecting procedures. The eggs are easily removed by most wastewater treatment processes such as sedimentation, filtration, or stabilization ponds.

Viruses: Not all the 100 plus different enteric viruses capable of causing infections or diseases that excreted by humans have been determined to case waterborne diseases. The most common human enteric viruses are: entero-viruses (polio, echo and coxzackie), rota-viruses, reo-viruses, parvo-viruses, adeno-viruses, and hepatitis A viruses.

Health hazards of wastewater reuse:

Viruses and other pathogens do not penetrate plants, fruits or vegetable unless the skin is broken. Although absorption of viruses by plant roots has been reported (Murphy, and Syverton 1958), it does not occur with sufficient regularity to be a mechanism for transmission.

Chemical hazards:

Chemical components potentially present in wastewater are not a major concern when reclaimed water is used for irrigation and when none of the components causes phytotoxicity to crops. The processes of crop contamination by chemicals include:

- Physical contamination where repeated application and evaporation may result in build up of contaminants on the crops.
- Uptake through the roots from the applied water.
- Foliar uptake with the exception of possible inhalation of volatile organics.

Chemicals are not a concern when sprinkler irrigation is not used.

Sources of nutrients enrichment in groundwater:

- Nitrogen loading of groundwater
- Sources of nitrogen to groundwater.
- Nitrogen stimulates algae growth which competes with other aquaculture.

Analysis plan's criteria:

- Water use patterns associated with typical farming practices in the region.

- Nutrient loading is in keeping with crop uptake rates, crop/plant selection must be made accordingly.
- Future land application systems will be designed to maintain loading nitrogen to presents levels or to reduce the loading rate.
- Population increase will require changes in the wastewater use scheme.
- The nutrients load in the wastewater will not be sufficient to support max. economic yield.
- The total balance plan and a nutrient balance plan will be required of the scheme manager to use all wastewater at all time and to avoid loss of nitrogen from the root zone to the groundwater.
- The irrigation use model for wastewater reuse for commercial crop/plant enterprise must accommodate two seemingly conflicting factors:
  - The season of maximal wastewater supply may not be the same as the seasonal period of greatest water demand by the crops/plants.
  - Wastewater supply may exceed total crop water demand in the annual season of coolest weather.

Nutrient balance:

The goal of the nutrient balance plan for the reuse scheme will be to have nutrient uptake by crops/plants to equal or exceed the nutrient loading rate from the effluent. These factors are expected to influence the plan for balancing nutrients received with nutrients taken up by the crops/plants.

- The nitrogen requirements of crops with high water demand are greater than the nitrogen supply in the wastewater.
- In order to reach economic yield, the scheme manager will apply supplemental nutrients.
- Supplemental nitrogen applied to crops may leach beyond the root zone if crop production is to be maximized.

Water balance:

The goal of a water balance plan for a reuse scheme will be to provide a crop rotation such that the total water demand of all crops/plants will equal or exceed the available effluent in any and all 10-day periods during the year.

Monthly irrigation demands can be projected from a production plan includes the crops/plants selected for production and the relative proportion of the land that is to be occupied by each crop/plant type. The first estimates of land occupied by each crop/plant type will require adjustments to meet the water balance goal.

Plant Layout