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Wastewater Treatment and Reuse: Sustainability Options

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Abstract

Water is one of the world's most valuable resources, yet it is under constant threat due to climate change and resulting drought, explosive population growth, and waste. One of the most promising efforts to stem the global water crisis is industrial and municipal water reclamation and reuse. The WateReuse Association defines reused, recycled, or reclaimed water as "water that is used more than one time before it passes back into the natural water cycle." Thus, water recycling is the reuse of treated wastewater for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing, or replenishing a groundwater basin (referred to as groundwater recharge). Water reuse allows communities to become less dependent on groundwater and surface water sources and can decrease the diversion of water from sensitive ecosystems. Additionally, water reuse may reduce the nutrient loads from wastewater discharges into waterways, thereby reducing and preventing pollution. This 'new' water source may also be used to replenish overdrawn water sources and rejuvenate or reestablish those previously destroyed. The objective of the present paper is to give insight into the appropriate technology for treatment of wastewater. The paper discusses sustainable wastewater treatment systems in the context of urban areas of the developing world. The paper concludes that, "Since the urban areas of many developing countries are growing rapidly, ecological sanitation systems must be implemented that are sustainable and have the ability to adapt and grow with the community's sanitation needs." In order to determine the appropriate treatment system, the developer must consider the area's climate, topography, and socioeconomic factors.

Keywords: Developing countries, ecological engineering, high efficiency production, sustainable wastewater treatment & reuse, urban areas, and environmental quality.

1. Introducion

Water scarcity and water pollution are crucial issues in today's world. One of the ways to reduce the impact of water scarcity and pollution is to expand water and wastewater reuse. The increasing scarcity of water in the world along with rapid population increase in urban areas gives rise to concern about appropriate water management practices. In the context of trends in urban development, wastewater treatment deserves greater emphasis. Currently, there is a growing awareness of the impact of sewage contamination on rivers and lakes. Accordingly, wastewater treatment is now receiving greater attention from the World Bank and government regulatory bodies.

Urban wastewater treatment has received less attention compared to 'water supply & treatment.' Water scarcity coupled with the bursting seams of our cities and towns have taken a toll on our health and environment. The sewage contamination of our lakes, rivers, and domestic water bodies has reached dangerous levels and is being recognized by leading organizations like the World Bank. The current urban wastewater management system is a linear treatment system that is based on disposal. The traditional system needs to be transformed into a sustainable, closed-loop urban wastewater management system that is based on the conservation of water and nutrient resources. A huge loss of life-supporting resources is the result of failed organic wastewater recovery. A wastewater management team is well equipped to create a wastewater management strategy that will result in the reduction of pathogens in surface and groundwater to improve public health.

In a developing urban society, the wastewater generation usually averages 30-70 cubic meters per person per year. In a city of one million people, the wastewater generated would be sufficient to irrigate approximately 1500-3500 hectare. This urban epidemic needs to be tackled ecologically because of so many pressing issues that are afflicting our waste management process:

- New immigrants to cities have low incomes and cannot afford municipal amenities like waste disposal and sanitary functions;
- In developing countries, approximately 300 million urban residents have no access to sanitation;
- Approximately two-thirds of the population in the developing world has no hygienic means of disposing excreta and an even greater number lack adequate means of disposing of total waste water;
- It is often an acceptable practice to discharge untreated sewage directly into the bodies of water.

According to the World Bank, "The greatest challenge in the water and sanitation sector over the next two decades will be the implementation of low cost sewage treatment that will at the same time permit selective reuse of treated effluents for agricultural and industrial purposes" (Green Arth, 2012). It is crucial that sanitation systems have high levels of hygienic standards to prevent the spread of disease. Other treatment goals include:

- The recovery of nutrient and water resources for reuse in agricultural production;
- Reducing the overall user-demand for water resources.

In order to achieve ecological wastewater treatment, a "closed-loop treatment system" is recommended. Many present day systems use a "disposal-based linear system." The traditional linear treatment systems must be transformed into the cyclical treatment to promote the conservation of water and nutrient resources. Using organic waste nutrient cycles, from "point-of-generation" to "point-of-production," closes the resource loop and provides a better approach for the management of valuable wastewater resources. Failing to recover organic wastewater from urban areas means a huge loss of life-supporting resources that, instead of being used in agriculture for food production, fill rivers with polluted water. The development of ecological wastewater management strategies will contribute to the reduction of pathogens in surface and groundwater to improve public health. The goal of ecological engineering, in this particular context, is to attain:

- High environmental quality,
- High yields in food and fiber,
- Good quality/high efficiency production, and
- Full utilization of wastes.

In the growing number of conflicts between agricultural and domestic use of scarce water resources, an increased use of treated wastewater for irrigation purposes is vital. Based on extensive successful experience in Canada and elsewhere on cost effective and environmentally sound practices of sludge application on agricultural land, there is tremendous potential for the safe disposal of sewage sludge on agricultural land.

The objective of the present paper is to consider the appropriate technology for treatment of wastewater. It also discusses sustainable wastewater treatment systems in the context of urban areas of the developing world.

2. Problem Statement

Problems concerning water sanitation stem from the rise in urban migration and the practice of discharging untreated wastewater. The uncontrolled growth in urban areas has made planning and expansion of water and sewage systems very difficult and expensive to carry out. In addition, many of those moving to the city have low incomes, making it difficult to pay for any water system upgrades.

Industrial development has always been afflicted with the issue of residue disposal, and it has become accepted by all bodies of knowledge that industrial effluents are one of the largest sources of water pollution and one with the most lethal composition of toxins. The most popular and widespread industrial pollutants include:

- ***Asbestos***: It is carcinogenic and its fibres can be inhaled and cause illnesses such as Asbestosis, mesothelioma, lung cancer, intestinal cancer, and liver cancer.
- ***Lead***: It is non-biodegradable and is hard to get rid of once it has permeated our environment. Lead is harmful as it can inhibit the action of bodily enzymes.
- ***Mercury***: It is also non-biodegradable, and mercury poisoning is a serious health hazard for humans and livestock.
- ***Nitrates & Phosphates***: It is one of the most common components in fertilizers and is often washed from the soil and into rivers and lakes. This can cause eutrophication, which can be very problematic to marine environments.
- ***Sulphur***: It is extremely harmful for algae and other marine life.
- ***Oils***: Oil does not dissolve in water; instead it forms a thick layer on the water surface. This can prevent marine plants form receiving enough light for photosynthesis. It is also harmful for fish and marine birds.
- ***Petrochemicals***: These are formed from gas or petrol and can be toxic to marine life.

Industrial effluents are the major source of toxins for groundwater. Mega industrial parks require an in-plant waste segregation and pretreatments in lieu of a traditional central treatment of the combined park's wastewater.

Figure 1: Industrial wastewater. Source: Green Arth (2012)

The problem with the current treatment technologies is that they are not sustainable. The conventional centralized system flushes pathogenic bacteria out of the residential area, using large amounts of water, and often combines the domestic wastewater with rainwater, causing the flow of large volumes of pathogenic wastewater. In fact, the conventional sanitary system simply transforms a concentrated domestic health problem into a diffuse health problem for the entire settlement and/or region. In turn, the wastewater must be treated where the cost of treatment increases as the flow increases. The abuse of water use for diluting human excreta and transporting them away from settled areas is increasingly questioned and being considered unsustainable.

Another reason many treatment systems in developing countries are unsustainable and unsuccessful is that they were simply copied from Western treatment systems without considering the appropriateness of the technology for the culture, land, and climate. Often, local engineers educated in Western development programs supported the choice of the inappropriate systems. Many of the implemented installations were later abandoned due to the high cost of running the system and repairs. On the other hand, conventional systems may even be technologically inadequate to handle the locally produced sewage. For example, in comparison to the US and Europe, domestic wastewater in arid areas such as the Middle East is up to five times more concentrated in the amount of oxygen demand per volume of sewage.

3. Sustainable Treatment and Reuse of Wastewater

The uncontrolled disposal to the environment of municipal, industrial and agricultural liquid, solid, and gaseous wastes constitutes one of the most serious threats to the sustainability of human civilization by contaminating the water, land, and air and by contributing to global warming.

With increasing population and economic growth, treatment and safe disposal of wastewater is essential to preserve public health and reduce intolerable levels of environmental degradation. In addition, adequate wastewater management is also required for preventing contamination of water bodies for the purpose of preserving the sources of clean water.

Effective wastewater management is well established in developed countries but is still limited in developing countries. In most developing countries, many people lack access to water and sanitation services. Collection and conveyance of wastewater out of urban neighborhoods is not yet a service provided to all the population, and adequate treatment is provided only to a small portion of the collected wastewater. In slums and peri-urban areas throughout the world, it is common to see raw wastewater flowing in the streets. The inadequate water and sanitation service is the main cause of diseases in developing countries.

In the year 2011, the population of the planet was 7 billion. Population growth forecasts indicate rapid global population growth that will reach 9 billion in 2030. The forecasts also indicate that:

- Most of the population growth will occur in developing countries, while the population of developed countries will remain constant at about 1 billion; and
- A strong migration from rural to urban areas will take place.

Considering the expected population growth and the order of priorities in the development of the water and sanitation sector in developing countries—water supply and sewerage first, and only then wastewater treatment—as well as the financial difficulties in these countries, it cannot be assumed that the current low percentage of the coverage of wastewater treatment in these countries will increase in the future, unless a new, innovative strategy is adopted and affordable wastewater treatment options are used.

A key component in any strategy aimed at increasing the coverage of wastewater treatment should be the application of appropriate wastewater treatment technologies that are effective, simple to operate, and low cost (in investment and especially in operation and maintenance). Appropriate technology processes are also more environment-friendly since they consume less energy and thereby have a positive impact on efforts to mitigate the effects of climate change. Also, with modern design, appropriate technology processes cause less environmental nuisance than conventional processes—for example they produce lower amounts of excess sludge and their odor problems can be more effectively controlled.

Appropriate technology unit processes include (but are not limited to) the following:

- Preliminary Treatment by Rotating Micro Screens;
- Vortex Grit Chambers;
- Lagoons Treatment (Anaerobic, Facultative and Polishing), including recent developments in improving lagoons performance;
- Anaerobic Treatment processes of various types, mainly, Anaerobic Lagoons, Upflow Anaerobic Sludge Blanket (UASB) Reactors, Anaerobic Filters and Anerobic Piston Reactor (PAR);
- Physicochemical processes of various types such as Chemically Enhanced Primary Treatment (CEPT); (vi) Constructed Wetlands;
- Stabilization Reservoirs for wastewater reuse and other purposes;
- Overland Flow;
- Infiltration-Percolation;
- Septic Tanks; and
- Submarine and Large Rivers Outfalls.

Out of these processes, various combinations can be set up. Combinations can also include some other simple processes such as Sand Filtration and Dissolved Air Floatation (DAF), which are not considered appropriate processes per se but are in fact appropriate processes. One interesting combined process is the generation of effluents suited for reuse in irrigation based on pretreatment by one of the mentioned unit processes followed by a stabilization reservoir.

4. Results

4.1 Appropriate Treatment Technology

Based on experience from past mistakes in sewage treatment technology, the definition of what is sustainable is clearer. Developers should base the selection of technology upon specific site conditions and financial resources of individual communities.

One approach to sustainability is through decentralization of the wastewater management system. This system consists of several smaller units serving individual houses, clusters of houses, or small communities. Black and gray water can be treated or reused separately from the hygienically more dangerous excreta. Non-centralized systems are more flexible and can adapt easily to the local conditions of the urban area as well as grow with the community as its population increases. This approach leads to treatment and reuse of water, nutrients, and byproducts of the technology (i.e. energy, sludge, and mineralized nutrients) in the direct location of the settlement.

Communities must take great care when reusing wastewater, since both chemical substances and biological pathogens threaten public health as well as accumulate in the food chain when used to irrigate crops or in aquaculture. In most cases, industrial pollution poses a greater risk to public health than pathogenic organisms. Therefore, more emphasis is being placed on the need to separate domestic and industrial waste and to treat them individually to make recovery and reuse more sustainable. The system must be able to isolate industrial toxins, pathogens, carbon, and nutrients.

4.2 Sustainable Treatment Types

Now that the requirements for a sustainable wastewater treatment system have been presented, there are several options one can choose from in order to find the most appropriate technology for a particular region. This paper will discuss sustainable wastewater treatment systems including:

a) Lagoons/wetlands,
b) USAB (anaerobic digesters), and
c) SAT technologies.

- **Lagoons and wetlands:** In wetland treatment, natural forces (chemical, physical, and solar) act together to purify the wastewater, thereby achieving wastewater treatment. A series of shallow ponds act as stabilization lagoons, while water hyacinth or duckweed act to accumulate heavy metals. Multiple forms of bacteria, plankton, and algae act to further purify the water. Wetland treatment technology in developing countries offers a comparative advantage over conventional, mechanized treatment systems because the level of self-sufficiency, ecological balance, and economic viability is greater. The system allows for total resource recovery (Rose, 1999). Lagoon systems may be considered a low-cost technology if sufficient, non-arable land is available. However, the requirement of available land is not generally met in big cities. The demand for flat land is high for the expanding urban developments and agricultural purposes. The decision to use wetlands must consider the climate. There are disadvantages to the system that in some locations may make it unsustainable. Some mechanical problems may include clogging with sprinkler and drip irrigation systems, particularly with oxidation pond effluent. Biological growth (slime) in the sprinkler head, emitter orifice, or supply line causes plugging, as do heavy concentrations of algae and suspended solids.

- **Anaerobic Digestion:** Another treatment option available, if there is little access to land, is anaerobic digestion. Anaerobic bacteria degrade organic materials in the absence of oxygen and produce methane and carbon dioxide. The methane can be reused as an alternative energy source (biogas). Other benefits include a reduction of total bio-solids volume of up to 50-80 percent, and a final waste sludge that is biologically stable can serve as rich humus for agriculture. So far, anaerobic treatment has been applied in

Colombia, Brazil, and India, replacing the more costly activated sludge processes or diminishing the required pond areas. Various cities in Brazil have shown an interest in applying anaerobic treatment as a decentralized treatment system for poor, sub-urban districts. The beauty of the anaerobic treatment technology is that it can be applied on a very small and very large scale. This makes it a sustainable option for a growing community.

- **Soil Aquifer Treatment:** SAT (soil aquifer treatment) is a geopurification system where partially treated sewage effluent artificially recharges the aquifers and is then withdrawn for future use. By recharging through unsaturated soil layers, the effluent achieves additional purification before it is mixed with the natural groundwater. In water scarce areas, treated effluent becomes a considerable resource for improved groundwater sources. The Gaza Coastal Aquifer Management Program includes treated effluents to strengthen the groundwater, in terms of both quantity and quality. With nitrogen reduction in the wastewater treatment plants, the recharged effluent has a potential to reduce the concentration of nitrates in the aquifer. In water scarce areas such as in the Middle East and parts of Southern Africa, wastewater has become a valuable resource that, after appropriate treatment, becomes a commercially realistic alternative for groundwater recharge, agriculture, and urban applications.

SAT systems are inexpensive, efficient for pathogen removal, and are not highly technical to operate. Most of the cost associated with an SAT is for pumping the water from the recovery wells, which is usually $20-50 USD per m3. In terms of reductions, SAT systems typically remove all BOD, TSS, and pathogenic organisms from the waste and tend to treat wastewater to a standard that would generally allow unrestricted irrigation. The biggest advantage of SAT is that it breaks the pipe-to-pipe connection of directly reusing treated wastewater from a treatment plant. This is a positive attribute for those cultures where water reuse is taboo.

The pretreatment requirements for SAT vary depending on the purpose of groundwater recharge, sources of reclaimed water, recharge methods, and location. Some may only need primary treatment or treatment in a stabilization pond. However, pretreatment processes should be avoided if they leave high algae concentrations in the recharge water. Algae can severely clog the soil of the infiltration basin. While the water recovered from the SAT system has much better water quality than the influent, it could still be lower quality than the native groundwater. Therefore, the system should be designed and managed to avoid intrusion into the native groundwater and use only a portion of the aquifer. The distance between infiltration basins and wells or drains should be as large as possible, usually at least 45 to 106 m to allow for adequate soil-aquifer treatment.

All the systems described allow for the reuse of treated wastewater in order to have a cyclic, sustainable system. These treated wastewaters provide essential plant nutrients (nitrogen, phosphorus, and potassium) as well as trace nutrients. Phosphorus is an especially important nutrient to recycle, as the phosphorus in chemical fertilizer comes from limited fossil sources.

5. Discussion

5.1 Treated Wastewater Reuse

Wastewater reuse must meet certain controls:

- First, wastewater treatment to reduce pathogen concentrations must meet the WHO (1989) guidelines;
- Second, crop restrictions must be specified to prevent direct exposure to those consuming uncooked crops as well as defining application methods (irrigation) that reduce the contact of wastewater with edible crops,
- Finally, control of human exposure is needed for workers, crop-handlers, and final consumers.

Benefits of safely recovering and reusing human wastes include the reduction in effluents to bodies of water and the opportunity to re-build soil with valuable organic matter. The nitrogen in reclaimed water can replace equal amounts of commercial fertilizer during the early to midseason crop-growing period (Table-1). Excessive nitrogen in the latter part of the growing period may be detrimental to many crops, causing excessive vegetative growth, delayed or uneven maturity, or reduced crop quality.

S. No.	Country	Nutrient Equivalent in Commercial Fertilizer Applied (%) (Assumes 50% loss of nitrogen due to volatilization)
1.	Kenya	136
2.	Tunisia	25
3.	Indonesia	49
4.	Zimbabwe	38
5.	Columbia	31
6.	Mexico	31
7.	South Africa	29
8.	Egypt	28
9.	India	26

Figure 2: Nutrients in human waste compared to commercial fertilizer.
Source: Worldwatch Institute, 1998

5.2 Strategies for Implementing New Treatment Technology

Many countries have the problem of a severe water imbalance. This imbalance in water demand versus supply is due mainly to the relatively uneven distribution of precipitation, high temperatures, increased demands for irrigation, and the impacts of tourism. To alleviate water shortages, serious consideration must be given to wastewater reclamation and reuse. Reclaimed wastewater can be used for a number of options including agricultural irrigation.

A wastewater treatment developer must perform an appropriate risk assessment before implementing the reuse of wastewater. Proper consideration of the health risks and quality restrictions must be a part of the assessment. Source-point measures rather than end of pipe solutions are essential. Source-point measures require extensive industrial pre-treatment interventions, monitoring and control programs, and incentives for the community to not dispose of any harmful matter into the sewers (World Bank, 2010).

For the implementation and promotion of new technology, strategies must include local participation as well as municipal action. Local participation is a positive and important growing trend in government projects. The participation must fit with the local population to meet particular local needs. Local communities can contribute valid indigenous ideas for cost savings in the project. Agreement on key issues between design engineers and the local residents is necessary early on in the project, and if local participation is extensive, capital costs can ultimately be reduced. According to the Inter-American Development Bank, "Citizen participation, properly channeled, generates savings, mobilizes financial and human resources, promotes equity and makes a decisive contribution to the strengthening of society and the democratic system."

There is a strong sense of ownership by members of the community in their projects. This pride in the new development helps to ensure the sustainability of the water supply and sanitation systems. Once the project is implemented, local participation contributes to the community's confidence in the new technology and allows them to take on other challenges such as accessing financial aid for other infrastructure projects. On the governmental level, institutional strengthening is usually needed to assist small to medium-sized cities in dealing with new administrative and financial management responsibilities. One program that has been developed to address the problems associated with decentralization is RIADEL (Local Development Research and Action Network). It is a network for sharing information about local community development in Latin America, including decentralization and the training of social leaders and civil servants.

6. Case Study of Peru

Peru's Ministry of Housing, Construction and Sanitation has approved a series of policy guidelines supporting the promotion of wastewater reuse in the country for urban irrigation purposes. The guidelines are an outcome of the SWITCH project, coordinated globally by IHE-UNESCO, and carried out in Peru by local organizations in collaboration with the Ministry of Housing. They build on existing small-scale private wastewater treatment initiatives in the Lima area, and are intended to result in the scaling-up of wastewater treatment reuse at a city and country level in order to make it a sustainable economic option (Fabiola, 2010).

Whilst the initial scope will focus on the irrigation of urban green spaces (which lies within the Ministry of Housing's area of competence), it is expected that the next step could involve the reuse of treated effluent in agriculture with the potential to expand to other productive uses at a later date.

The private sector will play an important role in seizing the economic benefits of reusing treated wastewater in other sectors beyond the irrigation of urban green spaces and agriculture. This will prove particularly important on the Peruvian coast, where there is a severe scarcity of fresh water resources.

The most significant evidence of Peru's commitment to adopting wastewater reuse on a large scale is the pair of wastewater treatment plants currently being established at Taboada and La Chira, which are designed to treat 100% of Lima's wastewater flows by 2015. Together, the plants will create more than 2 million m3/d of new capacity and will involve significant capital commitments from the private sector. The policy guidelines focus on following five key elements:

- The inclusion of the reuse of treated wastewater for the irrigation of green urban areas in national water resource management;
- The use of operationally and economically efficient treatment technologies;
- The facilitation of the participation of public and private sectors as well as of communities and international organizations in the investment and development of sustainable treatment and reuse systems;
- The promotion of citizens' participation and access to information to ensure the transparency, control, and efficiency of reuse systems management; and
- The strengthening of the capacity of the water sector in general in terms of treatment and reuse.

Priority activities include the drafting of a specific national strategy promoting wastewater reuse as well as a suitable institutional and legal framework, including the harmonization of existing laws and responsibilities within the water sector. The incorporation of sanitation quality standards for treated wastewater to be reused in the irrigation of green urban areas is also a priority. Peru is also considering ways to use the Clean Development Mechanism (CDM) in wastewater treatment systems in order to obtain certificates for emissions reduction (CER) as a way of financing such systems.

7. Concluding Remarks

Water has a precious value and each drop must be accounted-for in water scarce regions such as the Middle East and North Africa. Therefore, wastewater has to be reclassified as a renewable water resource rather than waste as it helps increase water availability and, at the same time, prevents environmental pollution. Utilization of this resource requires collection, treatment, and use of all generated wastewater. Although reuse of wastewater is recognized in most water-scarce countries, the reuse of wastewater is still very low.

Once freshwater has been used for an economic or beneficial purpose, it is generally discarded as waste. In many countries, these wastewaters are discharged, either as untreated waste or as treated effluent, into natural waterways from which they are abstracted for further use after undergoing "self-purification" within the stream. Through this system of indirect reuse, wastewater may be reused up to a dozen times or more before being discharged. Such indirect reuse is common in the larger river systems of Latin America. However, more direct reuse is also possible.

This paper discussed several options to achieve sustainability in wastewater treatment. The first was by decentralizing the treatment rather than installing expensive sewer systems that combine and increase the volume of the waste. The next part discussed choosing an appropriate treatment technology for the community. The common characteristic of all of the described types is that they involve "zero-discharge technology." This cyclical, rather than linear, approach includes the reuse of the treated effluent for agricultural reuse. The reuse of the wastewater decreases the money spent on fertilizers, and the resulting water is considered safe, since it has been treated for pathogens. To come to this point, the urban areas of many developing countries are growing rapidly, and ecological sanitation systems that are sustainable and have the ability to adapt and grow with the community's sanitation needs must be developed. In order to decide what the appropriate treatment system is, the developer must consider the area's climate, topography, and socioeconomic factors.

To successfully implement the strategies for wastewater reuse, it is vitally necessary for institutional and policymaking capacities to be improved, public awareness of related issues to be increased, and appropriate financial mechanisms to be created. To sum up:

a) Water scarcity and water pollution pose a critical challenge in many developing countries;

b) In urban areas, it is becoming difficult for the authorities to manage water supply and wastewater;
c) Strategies for wastewater reuse can successfully improve urban water management.

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