

Ecological engineering for controlling water pollution in Latin America

M.E. Hernández¹

¹*Red de Manejo Biotecnológico de Recursos, Instituto de Ecología, A.C. México.*

Abstract

Ecological engineering is a discipline that combines ecology and engineering to design, construct, restore and manage ecosystems. The design of constructed wetlands (CWs) and anaerobic digesters (ADs) are two applications of ecological engineering to control water pollution. CWs are inspired in the ability of natural wetland ecosystems to improve water quality; they are low cost systems that do not require fossil fuels inputs. ADs are closed systems without oxygen in which a sludge or liquid is degraded by the action of anaerobic bacteria, improving water quality and producing biogas. In Latin American countries there is a great need of low-cost and maintenance wastewater technologies that take advantage of the climatic conditions and biodiversity in the region. Conventional wastewater treatment are maintenance and energy intensive, consequently, their performance in the region have not been adequate. Ecological engineered systems such as CWs and ADs has a great potential to be developed in the region. However, ecological engineering as discipline lack of identity and presence in Latin American universities and research centers. Despite of the small development of ecological engineering in the region, CWs and ADs to improve water quality has been applied in the last 20 years. The majority of these systems have been guided and funded by ecological engineer groups from developed countries. It is concluded that ecological engineered systems are the best option to control water pollution in Latin America and it is necessary the development ecological engineering discipline in the universities and research centres of the region.

Keywords: Constructed wetlands, anaerobic digesters, ecotechnologies, environmental manipulation, self- design.

1 Introduction

Latin America is the region of the American continent where Romance languages are primarily spoken. Latin America has an area of approximately 21,069,500 km², and in 2010, its population was estimated at more than 580 million and its combined GDP at 5.16 trillion USD, International Monetary Fund [1]. The geographical sub-regions of Latin America include North America, Central America, the Caribbean, and South America. Latin America is the most unequal region in the world. Inequality in Latin America has deep historical roots that have been difficult to eradicate. The differences between initial endowments and opportunities among social groups have constrained the poorest's social mobility, thus poverty is transmitted from generation to generation, becoming a vicious cycle. Inequality is limiting the region's economic potential and the well-being of its population. Differences in opportunities and endowments tend to be based on race, ethnicity, rurality and gender. Those differences have a strong impact on the distribution of income, capital and political standing.

Regarding water issues, inequality is also a common denominator in Latin American countries. Fifty million persons lack access to water supply and almost 130 million to sanitation; wastewaters from 370 million urban inhabitants (86%) are discharged without any treatment; and there is poor service quality and deficient infrastructure, Idelovitch & Ringskog [2]. The situation is critical despite of the extensive reforms that the governments have done in most of countries in the past two decades. This situation has important social implications in terms of human and environmental health.

Ecological engineering is a discipline that combines natural and applied sciences, especially ecology, with the discipline of engineering to design, construct, analyze, and manage ecosystems and develop eco-technologies. The goal of ecological engineering is the design of man-nature systems in which living ecosystems are the major component.

In this chapter the principles of ecological engineering, its context in Latin America and the potential to mitigate water pollution in the region are discussed.

2 Concepts and principles of ecological engineering

Ecological engineering combines the disciplines of ecology and engineering in order to solve environmental problems. Several authors have put forward definitions for ecological engineering. The term itself is attributed to H.T. Odum, who defined ecological engineering as "environmental manipulation by man using small amounts of supplementary energy to control systems in which the main energy drives are still coming from natural sources" Odum *et al.* [3].

A more recent definition of ecological engineering is "the design of human society with its natural environment for the benefit of both", provided by Mitsch & Jørgensen [4]. This definition was slightly refined as "the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both" Mitsch & Jørgensen, [5, 6].

Teal [7] defined ecological engineering as “the use of ecological process within natural or constructed imitations of natural systems to achieve engineering goals”. In other words, the ecosystems are designed, constructed and operated to solve environmental problems otherwise addressed by conventional technology.

Barrett [8] provides a straightforward definition of ecological engineering as “the design, construction, operation, and management (that is, engineering) of landscape/aquatic structures and associated plant and animal communities (that is, ecosystems) to benefit humanity and, often, nature”.

Kangas [9], in an introductory text on ecological engineering, stated simply that “ecological engineers design, build and operate new ecosystems for human purposes.”

Ecological engineering is a new approach to both ecology and engineering which justified a new name. In the past, ecologists and engineers not always shared the common view of nature, because of this situation an adverse relationship between them has evolved. The challenge for ecologists and engineers is to break down the stereotypes of ecology and engineering and to combine the strengths of both disciplines, by using a design with nature philosophy and by taking the best of the both worlds.

Although there are some similarities, ecological engineering should not be confused with environmental engineering, wherein the focus is on solving problems of pollution using advanced technologies heavily dependent on fossil resources. Traditional engineering relies mainly on human control processes occurring in human-created, “hard” structures, and it is reliant upon fossil resources, including both energy and materials. In contrast, ecological engineering attempts to utilize natural processes occurring in natural land- and waterscapes (i.e., “soft” structures), which are driven primarily by natural energy (solar and gravity). Ecological engineering differs from environmental management because the latter, often means humans making the environment to suit their wishes. Contrasting, ecological engineering involves light management that joins human design and environmental self-design so that they are mutually symbiotic, [10, 11, 12, 13, 5].

Mitsch & Jorgensen [5] described the following basic concepts that collectively distinguish the approach of ecological engineering to solve environmental problems from conventional technologies:

- 1) It is based on self-designing capacity of ecosystems: Self-design and self-regulation comprises the basic premise behind ecologically engineered systems. There are natural adjustments in food chains and shifts in species within populations and communities. In fact, a considerable degree of resiliency is inherent in self-organization, which allows ecosystems to adapt to both natural and human-induced changes. Within this framework, engineers participate as a choice generator and as a facilitator of matching environment with ecosystem, but nature does the rest of the engineering. In this way, nature is a collaborator.
- 2) It can be the acid test of ecological theories: Ecological theories developed over the past 100 years serve as bases for practicing ecosystem restoration

and ecological engineering. However, just as there is the possibility of these theories helps the engineering design of ecosystems, there is also a possibility of finding that some of these ecological theories are wrong. Thus, ecological engineering is an important tool for fundamental and applied ecological research.

- 3) It relies on system approaches: Ecological engineering planning, design and monitoring should be founded within the framework of natural systems. In essence, it involves using nature as our guide and moves us toward a symbiotic relationship between human society and the natural environment. Ecological engineering has been dubbed "green technology" because it relies on photosynthetic plants and natural biological systems, which are useful and environmentally friendly. Moreover, systems with living plants are often both aesthetically and economically appealing. Property values may increase because of the cost-effectiveness and fuel savings, aesthetics and novelty of an ecologically designed project.
- 4) It conserves non renewable energy sources: Ecological engineering is based on a solar energy philosophy. It does not depend on fossil fuels and other potentially damaging energy sources. Furthermore, greenhouse gas emissions are minimized by the possible sequestration of carbon in the biomass of the organisms comprising the ecosystem. Once a system is designed and put in place, it sustains itself indefinitely with only a modest amount of human intervention. Moreover, most projects have direct and indirect, expected and unexpected, spin-off benefits.
- 5) It supports ecosystem conservation: A consequence of an ecologically engineered system is preservation of ecosystems. In part, this effect occurs in response to increased recognition of the value of ecosystems. For example, when the abiotic values of wetlands were recognized for flood control and water quality enhancement in addition to the provision of habitat for fish and wildlife, then the protection of natural wetlands and construction of wetlands have increased dramatically.

In the late 60s, the term Ecological Engineering was coined for a scientific, ecological approach of designing services for humans by using the toolbox of nature. Today the term is used in a broad sense; it encompasses any engineered service that uses ecological principles as major guideline. Ecological engineering include new applications as restoration ecology, phyto-remediation, ecotoxicology, agro-ecosystem management, soil bioengineering, stream restoration, environmental landscape planning, and sustainable development, Kangas [9].

3 Ecological engineering in the context of developing countries

Ecological Engineering is an old practice and a new discipline at the same time. In the past, when people were still largely depending on their immediate environment, sustainable practices were a means to survive and this led to the development of sustainable practices, such as the polyculture systems, still found in India and China. Currently, applications of ecological engineering are of great significance in the developing countries because of their low cost, eco-friendly

nature, easy operation and the large diversity of tropical ecosystems with high purification capacity. However, despite of all benefits that ecological engineering could provide to the poor countries, only China and India have developed the ecological engineering discipline. In Latin America, applications of ecological engineering, specially constructed wetlands, have been conducted in the last 20 years. However, the identity of ecological engineering as a discipline in universities and research centres is scarce. One possible reason to this situation is the fact that the majority of constructed wetlands in Latin American countries have been guided for international ecological engineering groups which design and built the wetlands, evaluate their performance and train the operators. Sometimes these international groups have a national counterpart with local governments or universities; however the training provided is about the operation of the specific constructed wetlands but not about ecological engineering principles. This has limited the development of ecological engineering in Latin America. Only Argentina has an ecological engineering major offered as a new carrier by the network Universia Argentina S.A. This is a big contrast with the growth and development of ecological engineering in the developed countries where today, ecological engineering is a department or program in several public and private universities. Moreover, in these countries, eight ecological engineering books, table 1, has been published in the last 25 years and one peer review monthly journal, called Ecological Engineering is published by Elsevier.

4 Water pollution in Latin America

The urban population of Latin America is growing quickly, and it is expected to rise from the current 77 percent to 80 percent by the year 2015, UNDP [14]. This urban growth has caused a large demand of water supply and the need for wastewater treatment infrastructure. A good municipal system of water management should consider four major components: water purification, potable water distribution, wastewater collection and wastewater treatment. In the last decades, in Latin America has been an effort to cover the first three components. However, wastewater treatment has lagged far behind the other three components, only 13.7 % of the collected wastewater receives treatment before it is discharged to the environment or reused in agriculture, [15, 16]. Many large cities, such as Bogotá, Buenos Aires, Lima, México city and Santiago discharge almost all their wastewater into the environment virtually untreated. Unfortunately this problem is not only exclusive of the large cities, the model is repeated in medium and small towns where economic constraints are even more severe than in large urban areas. The consequence of this practice is that the rivers on which some Latin American cities were founded are heavily polluted with domestic and industrial waste, [2, 17]

Table 1: Ecological engineering books, published in the last two decades.

Book title	Publisher and year of publication	Authors
Ecological engineering: an introduction to eco-technology	Wiley, 1989	William J. Mitsch & Sven Erik Jørgensen
Ecological engineering for wastewater treatment	CRC Press, 1997	Carl Etnier & Björn Guterstam
Ecological engineering and ecosystem restoration	John Wiley & Sons Inc. 2004	William J. Mitsch & Sven Erik Jørgensen
Ecological engineering for pest management: advances in habitat manipulation for arthropod	Cornell University Press, 2004	Geoff Gurr, Stephen D. Wratten & Miguel A. Altieri
Ecological engineering: principles and practice	Lewis Publishers, 2004	Patrick C. Kangas
Ecological engineering: bridging between ecology and civil engineering	Aeneas Technical Publisher, 2005	Hein “van” Bohemen
Applications in Ecological Engineering	Elsevier, 2009	Sven Erik Jørgensen
Ecological Engineering Design: Restoring and Conserving Ecosystem Services	John Wiley & Sons, 2011	Marty D. Matlock & Robert Morgan

4.1 Point source water pollution

Sewerage systems are the preferred solution to conveying wastewater out of urban areas. However, only a small percentage of the recollected wastewater in the region receives treatment. Therefore one of the most important point source pollution in Latin American countries is domestic or municipal wastewater. Several rivers of Brazil, Cuba, México has been found heavily polluted by fecal coliforms, ammonia and emergent pollutants which are indicators of sewage pollution, [18, 19, 20]. This situation not only has important impacts in the environment but in human health because untreated wastewater discharges into rivers causes a high rate of diarrhoea and similar diseases.

Other important point sources of pollution in the region are the rich organic wastewaters from agro industries such as sugar cane refineries and coffee processors, [21, 22].

4.2 Non point source water pollution

Surface runoff is water from rain, snowmelt, or other sources that flows over the land surface, and is a major component of the water cycle, Hottenroth *et al.* [23]. When runoff flows along the ground, it picks up soil contaminants such as petroleum, pesticides, or fertilizers that become discharge or overland flow. If surface runoff contains man-made contaminants, the runoff is called nonpoint source pollution (NPS), which unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution moves over and through the ground, as the runoff moves, it picks up and carries away natural and human-made compounds, finally depositing them into lakes, rivers, wetlands, coastal waters, and sources of drinking water, Chen *et al.* [24]. Nonpoint source pollution includes excess herbicides, pesticides and fertilizers from residential neighbourhoods and agricultural areas, sediment caused by erosion from land development and failing stream banks, salt from irrigation practices and acid mine drainage from abandoned coal mines, bacteria and nutrients from livestock, pet wastes, and faulty septic systems, and oil, grease, and toxic chemicals from urban runoff and energy production.

While nonpoint source (NPS) water pollution is currently a great concern in developed countries because it is the dominant cause of water quality problems, in Latin America little is known about non point source water pollution. This is mainly due to the fact that the priority is to control point source water pollution. However, increases in farming intensity have also led to increases in both the application of chemical fertilizers and pesticides and the production and agglomeration of livestock wastes. This has resulted in increased runoff and leaching of pesticides and nutrients into neighbouring water bodies. Some studies in wetlands in the south-eastern state of Chiapas México, found that their sediments are polluted with agrochemicals, Hernández-Romero *et al.* [25]. Therefore monitoring and controlling non point source water pollution should be integrated in the water management programs in Latin American countries.

5 Experiences of ecological engineered systems to mitigate water pollution in Latin America

5.1 Constructed wetlands

Beginning in the late 1960s, the applications of ecological engineering were demonstrated with the initial research on the ability of wetland ecosystems to effectively treat municipal wastewater, Ewel & Odum [26]. Since that time, the use of constructed wetlands for treating wastewaters of all types has flourished and is normally considered a prototypical example of ecological engineering, Kadlec & Knight [27].

Constructed wetlands (CWs) are those wetlands intentionally created from non-wetland sites for the unique purpose of treating wastewater or storm water. These systems must be managed and monitored continuously, Hammer [28]. Constructed wetlands are shallow ponds or channels which have been planted

with aquatic plants. The treatment process of CWs is based on biological filtration by aerobic and facultative bacteria. The efficiency of the aerobic treatment processes depends on the relation between oxygen demand (load) and oxygen supply (design) and it needs professionals with knowledge of wastewater treatment to design these “low-tech” but biologically complex systems. The idea to use an ecosystem type (wetlands) to address a specific human need that ordinary requires a great deal of engineering (wastewater treatment) is probably the best example of ecological engineering because the mix of ecology and engineering is nearly even.

According to the water flow, constructed wetlands can be classified as follow:

- a) Surface flow or free water surface constructed wetland SF, fig. 1a. These systems are strongly related to natural wetlands. The “technology” arose in the 1970s in North America with the ecological engineering of natural wetlands for wastewater treatment, Kadlec & Knight [27].
- b) Subsurface horizontal flow constructed wetland SSHF, fig.1b, this type of wetlands was first investigated in Germany in the 1960s, but it was only about 25 years ago that constructed wetland systems were applied to the decentralized wastewater treatment of single houses, institutions, and small to medium-size settlements.
- c) Subsurface Vertical flow constructed wetland SSVF, figure 1c, the vertical flow type was developed as an alternative to the SSHF constructed wetland, consists of shallow sand or gravel filter beds. A distribution system on the surface of the constructed wetland allows the wastewater to percolate vertically through the unsaturated filter bed. Plants support the vertical drainage process. An important feature of this type is the intermittent hydraulic loading with resting intervals between the single discharges to the vertical bed. This intermittent loading provides an effective aeration mechanism because pores of the filter bed refill with oxygen during the intervals. As a result, high nitrification rates¹ can be achieved in the filters. Denitrification can be carried out by recirculating the effluent into the primary treatment unit (septic tank) to eliminate nitrogen
- d) Hybrid constructed wetlands: Various types of constructed wetlands may be combined in order to achieve higher treatment effect, especially for nitrogen. SSVF systems have a much greater oxygen transport capacity and, therefore, provide much better conditions for nitrification. However, very limited or no denitrification occurs in SSVF systems. Hybrid systems used to comprise most frequently SSVF and SSHF systems arranged in a staged manner, however, all types of constructed wetlands could be combined. In hybrid systems, the advantages of various types of wetlands can be combined to complement each other. It is possible to produce an effluent low in Biochemical Oxygen Demand, which is fully-nitrified and partly denitrified and hence has much lower total-N concentrations .In Latin America few hybrid CW systems has been developed combined horizontal with vertical subsurface flow, Belmont *et al.* [29], however combination of subsurface and free surface flow has not been documented.

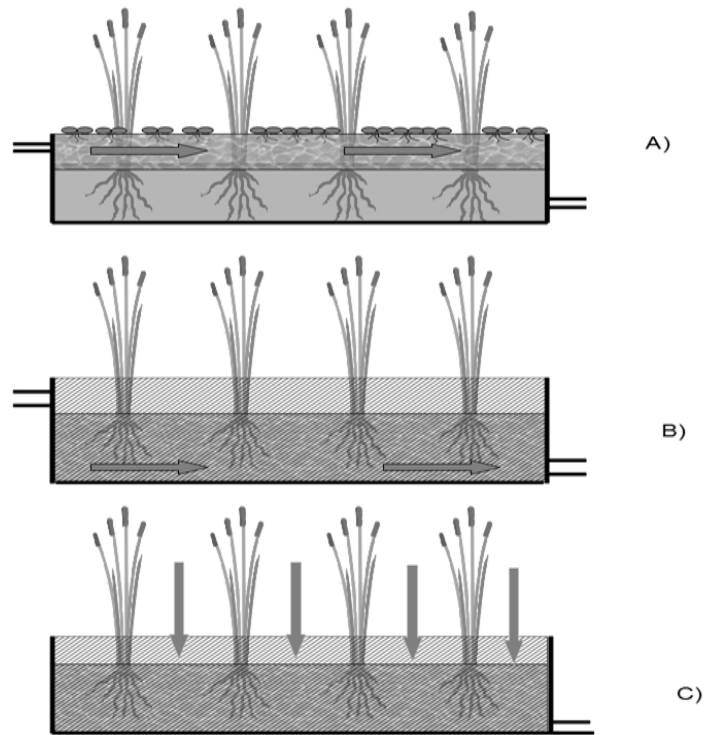


Figure 1: Type of constructed wetlands: a) Surface flow wetland SF, b) Horizontal subsurface flow wetland HSSF and c) Vertical subsurface flow wetland.

Constructed wetlands are natural treatment systems that offer a variety of advantages that make them suitable for small to medium-size communities in developing countries, particularly in tropical regions. Comparative advantages of constructed wetlands to conventional wastewater treatment systems include the following:

- a) Low costs of operation and maintenance because they require low or no external energy and there is no need for sophisticated equipment, spare parts, and chemicals.
- b) Operation of CWs does not consume fossil fuels as the majority of conventional wastewater treatment.
- c) Constructed wetlands are characterized by robustness, performance reliability, and resistance to flow fluctuations. They can be used as part of decentralized wastewater treatment systems, due to their characteristics as

“robust”, “low-tech” systems with none or few moving parts (pumps) and relatively low operational requirements.

- d) Certain wetland plant species grown on the constructed wetland can be reused as animal fodder (such as elephant grass) or ornamental flowers (such as *Heliconia* species) and can generate income.
- e) Constructed wetlands (CWs) can be aesthetically landscaped for backyard and park areas, providing shade, wildlife habitat and water treatment.

Latin American countries are in the great need of low-cost, low-maintenance wastewater management strategies that take advantage of the country’s climatic conditions. Mechanical treatment systems are maintenance- and energy intensive, Tchobanoglous *et al.* [30], consequently, their performance is affected when these requirements cannot be properly provided. Thus, it should be clear that in regions where mechanical treatment technologies cannot be effectively maintained, promoting less energy-intensive wastewater treatment technologies could result in improved water quality, benefiting the health, economy, and aesthetics of the region. CWs should result in a much lower monetary and resources investment in comparison to a conventional treatment system. An energy study comparing conventional wastewater treatments and constructed wetlands in Colombia concluded that CW demonstrated the best performance for investment (i.e., treatment indicators), and the most value for the investment (i.e., energy to lifetime price). When increased pollutant removal performance is needed (especially nutrients) and when land area is available at a reasonable price and wastewater flows are not very large (i.e., rural areas), CW should be used instead of conventional wastewater treatment that municipalities cannot afford to maintain, Arias & Brown [31]. The performance of CW facilities under tropical conditions has not been extensively studied. Despite of this, it is generally assumed that CW processes are more efficient in equatorial regions than those featuring more temperate conditions as the year-round plant growth and microbiological activity encouraged by warmer weather has a positive effect on treatment parameters, Katsenovich *et al.* [32].

In general few CWs have been studied and documented in Latin America table 2, despite the recognized benefits of low-cost, year-long plant growth and bacterial activity in tropical climates, Okurut *et al.* [33]. The majority of documented constructed wetlands in Latin American countries deal with domestic or municipal wastewater and in few cases with treatments of agro industries wastewaters, [21, 22].

In México, the first studies about constructed wetlands were published in 1997, however the number of documented constructed wetlands is still small and many of the published papers are referred to small scale constructed wetlands. Pilot-scale wetland constructed at Santa María Nativitas, México was evaluated by Belmont *et al.* [29], the system, consisting of sedimentation terraces, stabilization pond, subsurface flow wetland (SSHF) and vertical flow wetland (SSVF), removed more than 80% of total solids, Chemical Oxygen Demand and nitrate from domestic sewage. Removal of ammonium was less efficient at about 50%. In the mid-1990s the Planetary Coral Reef Foundation (PCRF) sponsored the construction of several subsurface flow constructed wetlands in the village of

Table 2: Experiences with constructed wetlands to improve water quality in Latin American countries.

Location	Type of CW	Area m ²	Type of wastewater	Reference
Hidalgo México	HSSF	1144	Domestic wastewater	Rivera <i>et al.</i> [42]
Akumal Quintana Roo, México	HSSF	81.2	Domestic wastewater	Whitney <i>et al.</i> [34]
Santa Maria Nativitas, México	HSSF and VSSF	370	Domestic wastewater	Belmont <i>et al.</i> [29]
Tapachula, Chiapas, México	HSSF	300	Combined domestic and <i>coffee Processing plant wastewaters</i>	Orozco <i>et al.</i> [21]
Veracruz, México	HSSF	0.9	Diluted sugarcane molasses stillage	Olgúin <i>et al.</i> [22]
Massaya, Nicaragua	HSSF	1400	Domestic wastewater	Platzer <i>et al.</i> [36]
San José las Flores, El Salvador	HSSF	-	Domestic wastewater	Gauss [40]
Los Sobojales, Nicaragua	HSSF	930	Domestic wastewater	Platzer <i>et al.</i> [36]
Teupasenti, Danlí Honduras	HSSF	4200	Domestic wastewater	Gauss[40]
La Providencia León Nicaragua	HSSF	4200	Domestic wastewater	Platzer <i>et al.</i> [36]
Ventanilla Lima, Peru	HSSF	9600	Domestic wastewater	Gauss [40]
Pereira Colombia	HSSF		Domestic wastewater	Villegas[44]
El pasto, Colombia	HSSF	157	Domestic wastewater	Villegas [44]
Florianópolis, Santa Catarina, Brazil	HSSF	-	Domestic wastewater	Gauss[40]
Jardim Petrolar, Alagoinhas, Brazil	HSSF	250	Domestic wastewater	Gauss[40]
Agronómica, Brazil	HSSF	450	Domestic wastewater	Vymazal & Kröpfelová [43]
Videira, Brazil	HSSF	84	Domestic wastewater	Vymazal & Kröpfelová[43]
Tubaro, Brazil	HSSF	50	Domestic wastewater	Vymazal & Kröpfelová [43]
San Joaquim	HSSF	40	Domestic wastewater	Vymazal & Kröpfelová [43]

CW= Constructed wetland, HSSF=Horizontal subsurface flow, VSSF=Vertical subsurface flow

Akumal, Quintana Roo, México. These wetlands were of variable design, and varied in the extent of engineering protocols followed during construction. Few studies on monitoring these subsurface flow constructed wetlands in Akumal have been conducted. Whitney *et al.* [34] performed a preliminary evaluation in one of these wetlands. They found that the organic matter removal efficiency for the wetland was found to be about 68%, lower than expected. The effluent Chemical Oxygen Demand COD concentration was approximately 100 mg l⁻¹. Ammonia and nitrate measurements showed that little or no nitrification was occurring in the wetland. Later, Krekeler *et al.* [35], surveyed twenty subsurface flow constructed wetlands in the village of Akumal, Quintana Roo, México to determine the general status of the wetland systems and provide baseline information for long term monitoring and further study. They found common problems observed in the systems, for example they were overloading, poor plant cover, odour, and no secondary containment. Bulk mineral composition of aggregate from two subsurface flow constructed wetlands was determined to consist solely of calcite.

In México, also CWs have been applied to treat wastewater from tropical agro industries, Orozco *et al.* [21], evaluated a 300 m² subsurface vertical flow constructed wetland in Chiapas, México. The system consisted in three cells and treats the combined secondary effluent from municipal wastewater with the effluent from coffee plant processors. They found 92 % COD removal and 95-96 % removal of faecal coliforms.

In 1996 the Austrian Development Agency introduced constructed wetland technology to Nicaragua by financing the implementation of a SSHF constructed wetland system. Located in the outskirts of the city of Masaya, Nicaragua, the system is treating the domestic wastewater. Four subsurface flow constructed wetland beds fed in parallel with a total area of 1400 m² were built. Removal efficiencies of 93% for COD, 33 % for total nitrogen and 18% for total phosphorus has been registered in those wetlands, Platzer *et al.* [36].

In Colombia, Williams *et al.* [37] published the first study on the design and initial performance of a 4000 m² constructed wetland in Chinchina, Province of. In addition, several pilot studies have been conducted in Colombian universities, [38, 39]. Nonetheless, few medium or large-scale, municipal wastewater treatment wetland had been documented.

The government of Peru installed in 2006, three subsurface flow horizontal constructed wetland schemes in the arid outskirts of Peru's capital. All treatment schemes operate under gravity flow conditions and are located between the settlement and the coastline; the wetland sites are cut into the steep, sandy slopes of the terrain. As for treatment performance, the constructed wetland scheme removes more than 95 percent of organic contamination and reduces the concentrations of total coliforms by 2–3 log units, Gauss [40].

In Brazil, the first studies with constructed wetlands were the result of observations made from the Amazon flood plains. The first attempt to use wetlands capacity to improve water quality was published by Salati *et al.* [41]. After that, endless efforts were done focused attempt to increase the efficiency of the system and reduce investments. At the end of the 90s decade major

institutions responsible for sewage treatment and potable water supply were interested in this type of technology for solving real problems. These institutions are as follows: SABESP (Basic Sanitation Company of São Paulo State), SANEPAR (Sanitation Company of Paraná State) and CESP (Electric Company of São Paulo State). One of the private institutions that has systematically worked in the design and projects of constructed wetlands is the Institute of Applied Ecology. This institution has enhanced and developed a water depuration system based on the purifying capacity of the soil. The wetlands with filtering soils are systems formed by overlapping layers of crushed stone, gravel and soil planted with rice.

5.2 Anaerobic digesters

Anaerobic digestion is a group of processes in which microorganisms break down biodegradable material in the absence of oxygen. The process produces a methane and carbon dioxide rich biogas suitable for energy production that helps to replace fossil fuels. The nutrient-rich effluent which is also produced can be used as fertilizer, Lettinga [45].

The anaerobic digestion process begins with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers such as carbohydrates and make them available for other bacteria. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Acetogenic bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Finally, methanogenic bacteria convert these products to methane and carbon dioxide.

There are three categories of anaerobic treatment systems. The first category include the conventional anaerobic digester which can be designed as plug flow system that consist of long channels in which the manure and other inputs move along as a plug, or as completely mixed systems that as the name implies, consist of a large tank where fresh material is mixed with partially digested material. The second category of anaerobic reactors is similar to the aerobic activated sludge process; because it includes a set of reactors in series, often with recycle. Since the material leaving the reactor is a gas-liquid-solid mixture, a vacuum degasifier is required to separate the gas and avoid floating sludge in the clarifier. The last anaerobic reactors are the Submerged Media Anaerobic Reactors (SMARs). These contain an additional internal media which supports bacterial growth; they use either rocks or synthetic media as the support material. Because the media provides a stationary adherence place for the bacteria, the bacteria are able to grow and fill the cracks between the support media, thus creating the ability to maintain a large stock of biomass, Lettinga [45]. The following design has been developed within this category of anaerobic reactors:

(1) Anaerobic Filter. The anaerobic filter is similar to a trickling filter in that a biofilm is generated on media. The bed is fully submerged and can be operated either up flow or down flow. For very high strength wastewaters, a recycle can be employed.

(2) Fluidized Bed. This reactor consists of a sand bed on which the biomass is grown. Since the sand particles are small, a very large biomass can be developed in a small volume of reactor. In order to fluidize the bed, a high recycle is required.

(3) Upflow Anaerobic Sludge Blanket (UASB). Under proper conditions anaerobic sludge will develop as high density granules. These will form a sludge blanket in the reactor. The wastewater is passed upward through the blanket. Because of its density, a high concentration of biomass can be developed in the blanket.

The digestion process results in the following benefits: (1) the captured methane becomes a source of renewable energy, (2) greenhouse gas emissions, wastewater pollution, and noxious odours are sharply reduced, and (3) an organic fertilizer is created, as microorganisms transform the organic pollutants into dissolved nutrients, Lansing [46]. In addition, small-scale agricultural digesters are inexpensive and easy to build, which makes them an appropriate technology to enhance the environment and livelihoods of farmers, [47, 48].

It is important to underline that plug flow anaerobic digesters and anaerobic filters are low-cost systems that relies on ecological engineering principles by using self-organization with minimal external inputs to treat wastewater and capture a renewable energy source.

Industrialized digesters are usually continuous stirred tank reactors, in which a portion of the produced biogas is used to heat and mix the digester, Berglund & Börjesson [49]. These technologies have not been shown to be practical or economical for developing countries, Lansing *et al.* [46]. Anaerobic fluidized bed and UASB reactors require a lot of controlled conditions during their operation. Therefore industrialized anaerobic reactors are not considering within the scope of ecological engineering, instead they are considering as environmental biotechnologies.

Studies in Costa Rica have shown that Taiwanese model bio digesters can produce biogas with methane concentration above 60%, when they operate at or below mesophilic range and the cost of construction of these systems was approximately USD \$ 200 for 10 m³, [46, 47], evaluated an electricity generation plant using biogas from a Taiwanese-model bio digester as the fuel source. The study was conducted at EARTH University, located in the humid tropics of Costa Rica. The digester receiving flushed cow manure from a milking facility and flushed manure. The hydraulic retention time at the dairy farm digester was 46 days and 16 days at the swine facility. The biogas produced was transported via PVC pipeline, cleaned and compressed at 5 psi and sent to a 40 kW, electric, internal combustion Cummins Power Generation generator. The concentration of organic matter in the wastewater was significantly reduced during the digestion process. At the dairy farm, there was a 78 percent decrease in COD and a 63 percent decreased in TS. At the swine facility, there was a 91 percent decrease in COD and a 64 percent decreased in TS from the EARTH University digesters would provide 40 kW h⁻¹ for 2.53 hours a day.

6 Conclusion

In Latin American countries only a small portion of the wastewater generated receive treatment; the rest is dumped in creeks, rivers and lakes causing severe water pollution. Non point source water pollution is not considered in the water quality management programs, and little is known about the effects of this type of pollution in the aquatic ecosystems of this region. This situation is due to several factors, one of the most important is the economic constraints in the region. Therefore, it is necessary implement low-cost and maintenance wastewater strategies that take advantage of the region's climatic conditions. Constructed wetlands and anaerobic digesters are two eco-technologies based on ecological engineering principles that have shown work efficiently under the tropical climatic conditions that prevail in the majority of Latin American countries. However, ecological engineering as a discipline needs more identity and development in the universities of the region.

References

- [1] International Monetary Fund, World Economic Outlook database. www.imf.org/, 2010.
- [2] Idelovitch, E. & Ringskog, K., *Wastewater in Latin America: old and new options*, The world bank: Washington D.C., pp. 34-68, 1997.
- [3] Odum, H.T., Silver, W.L., Beyers, R.J. & Amstrong, N., Experiments with engineering of marine ecosystems. *Publications of the Institute of Marine Science, University of Texas*, **9**, pp. 374-403, 1963.
- [4] Mitsch, W.J. & Jørgensen, S.E., Introduction to ecological engineering (Chapter 1). *Ecological Engineering: An Introduction to Ecotechnology*, eds. W.J. Mitsch, & S.E. Jørgensen, John Wiley & Sons, New York, NY., pp. 3-12, 1989.
- [5] Mitsch, W.J. & Jørgensen, S.E., *Ecological engineering and ecosystem restoration*. John Wiley & Sons, New York, NY, pp. 25-66, 2004.
- [6] Mitsch, W.J. & Jørgensen, S.E., Ecological engineering: a field whose time has come. *Ecological Engineering*, **20**, pp. 363-377, 2003.
- [7] Teal, J.M., Contributions of marshes and salt marshes to ecological engineering (Chapter14). *Ecological engineering for wastewater treatment*, eds. C. Etnier and B. Guterstam, CRC Press/Lewis Publishers, Boca Raton FL, pp. 175-182, 1997.
- [8] Barrett, K.R., Ecological engineering in water resources: The benefit of collaborating with nature. *Water International*, **2(3)**, pp. 182-188, 1999.
- [9] Kangas, P., *Ecological engineering: Principles and Practice*. CRC Press.
- [10] Odum, H.T., Scales of ecological engineering. *Ecological Engineering*, **6**, pp. 7-19, 1996.
- [11] Mitsch, W.J., Ecological Engineering: The roots and rationale of a new Ecological Paradigm (Chapter 1). *Ecological engineering for wastewater*, eds. C. Etnier & B. Guterstam, CRC Press/Lewis Publishers, Boca Raton FL, pp. 1-20, 1997.

- [12]Kells, J.A. & Warner, B.G., The emergence of Ecological Engineering and green technology. *The Canadian Civil Engineer*, **17**, pp. 11-13, 2000.
- [13]Allen, T.F.H., Giampietro, M. & Little, A.M., Distinguishing ecological engineering from environmental engineering. *Ecological Engineering*, **20(5)**, pp. 389-407, 2003.
- [14]UNDP United Nation Development Program, Human Development Report, Beyond scarcity: Power, poverty and the global water crisis. New York, NY, pp. 102-107, 2006.
- [15]IADB, Inter-American Development Bank, Workshop on Financing Water and Sanitation Services: Options and Constraints, Inter-American Development Bank, Washington, D.C., pp. 25-34, 2003.
- [16]García, L.E., Water Quality Issues in Latin America (Chapter 8). *Water Quality Management in the Americas*, eds. A.K. Biswas, B. Braga, C. Tortajada & J.D. Rodriguez, Springer Berlin Heidelberg New York, pp. 1-15, 2006.
- [17]Arreguín-Cortés, F.I. & Mejía-Maravilla, E., Water Quality Management in México (Chapter 8). *Water Quality Management in the Americas*, eds. A.K. Biswas, C. Tortajada, B. Braga, & J.D. Rodriguez, Springer Berlin Heidelberg New York, pp. 119-136, 2006.
- [18]Martinelli, L.A., Krusche, A.V., Victoria, R.L., De Camargo, P.B., Bernardes, M., Ferraez, E.S., De Moraes, J.M. & Ballester, V., Effects of sewage on the Chemical Composition of Piracicaba, River, Brazil. *Water, Air and Soil Pollution*, **110**, pp. 67-79, 1999.
- [19]Hernández, M.E. & Ruiz, P., Humedales construidos para mejoramiento de la calidad del agua de ríos contaminados. *Proceedings of the XXII Reunión Científica- Tecnológica forestal y agropecuaria Veracruz 2009*, eds. H.B. Barradas-Lagunes, I. Ceja Romero & L.M. Vazquez Castro, pp. 326-331, 2009.
- [20]Navarro, A.E., Hernández, M.E., Bayona, J.M., Morales, L. & Ruiz, P., Removal of selected organic pollutants and coliforms in pilot constructed wetlands in southeastern México. *International Journal of Environmental Analytical Chemistry*, **91(7-8)**, pp. 680-692, 2011.
- [21]Orozco, C.E., Cruz, A.M., Rodriguez, M.A. & Pholan, A.J. Humedal subsuperficial de flujo vertical como sistema de depuración terciaria en el proceso de beneficiado de café, *Higiene y sanidad ambiental*, **6**, pp. 190-196, 2006.
- [22]Olguin, E.J., Sánchez-Galván, G., González-Portela, R.E., & López-Vela, M.E., Constructed wetland mesocosms for the treatment of diluted sugarcane molasses stillage from ethanol production using *Pontederia sagittat*, *Water Research*, **42(14)**, pp. 3659-3666, 2008.
- [23]Hottenroth, D., Harper, C. & Turner, J., Effectiveness of integrated stormwater management in a Portland Oregon Watershed. *Journal of the American Recourses Association*, **35(3)**, pp. 633-641, 1999.
- [24]Chen, Y.S., Lin, L.S., Viadero, R.C, & Gang D.C., Nonpoint source pollution. *Water Environmental Research*, **79(10)**, pp. 2032-2048, 2007.

- [25]Hernández-Romero, A.H., Tovilla-Hernández, C., Malo, E.A. & Bello-Mendoza, R., Water quality and presence of pesticides in a tropical coastal wetland in southern México. *Marine Pollution Bulletin*, **48(11-12)**, pp. 1130-1141, 2004.
- [26]Ewel, K.C. & Odum, H.T., *Cypress Swamps*, University Presses of Florida, Gainesville, FL, pp. 23-28, 1984.
- [27]Kadlec, R.H. & Knight, R.L., *Treatment Wetlands*, Lewis Publishers Inc Ann Arbor, MI. pp. 68-80,1996.
- [28]Hammer, D.A., *Creating freshwater wetlands*. Lewis Publishers Inc, Chelsea MI, pp. 42-47, 1992.
- [29]Belmont, M.A., Cantellano, E., Thompson, S., Williamson, M., Sánchez, A. & Metcalfe, C.D., Treatment of domestic wastewater in a pilot-scale natural treatment system in Central México. *Ecological Engineering*, **23**, pp. 299–311, 2004
- [30]Tchobanoglous, G., Burton, F.L., & Stensel, H.D., 2003. *Wastewater Engineering: Treatment and Reuse*. McGraw Hill, New York, NY, pp. 80-87, 2003.
- [31]Arias, M.E. & Brown, M.T., Feasibility of using constructed treatment wetlands for municipal wastewater treatment in the Bogotá Savannah Colombia. *Ecological Engineering*, **35**, pp. 1070-1078, 2009.
- [32]Katsenovich, Y.P., Batista, H.A, Ravine, A.J. & Miller, J.F., Performance evaluation of constructed wetlands in a tropical region, *Ecological Engineering*, **35**, pp. 1529-1537, 2009.
- [33]Okurut, T.O., Rijs, G.B.J. & van Bruggen, J.J.A., Design and performance of experimental constructed wetlands in Uganda, planted with *Cyperus papyrus* and *Phragmites mauritianus*. *Water Science and Technology*, **40(3)**, pp. 265–271, 1999.
- [34]Whitney D., Rossman A. & Hayden, N., Evaluating an existing subsurface-flow constructed wetland in Akumal México. *Ecological Engineering*, **20**, pp. 105–111, 2003.
- [35]Krekeler, P.S.M., Probst, P., Samsonov, M., Tselepis, M.C., Bates, W., Kearns, L.E. & Maynard, J.B., Investigations of subsurface flow constructed wetlands and associated geomaterial resources in the Akumal Reforma regions, Quintana Roo, México. *Environmental Geology*, **53**, pp. 709-726, 2007.
- [36]Platzer, M., Cáceres, V., & Fong, N., The Reuse of Treated Wastewater for Agricultural Purposes in Nicaragua, Central America, *Water, Science and Technology*, **50(2)**, pp. 293–300, 2004.
- [37]Williams, J.B., Zambrano, Ford, M.G., May, E., & Butler, J.E., Constructed wetlands for wastewater in Colombia, *Water Science and Technology*, **40(3)**, pp. 217–223, 1999.
- [38]Lara, J.A., & Vera, I., Implantación y evolución de un humedal artificial de flujo subsuperficial en Cogua, Cundinamarca, Colombia. *Ingeniería y Universidad*, **9(1)**, pp. 47–64, 2005.
- [39]Castaño, J.M., Humedales artificiales para el tratamiento de aguas residuales en el corregimiento de la Florida, Municipio de Pereira-Risaralda.

- Proceedings to Conference on Ecotechnology Applied to Wastewater*, Risaralda Polytechnical University: Pereira, Colombia, pp. 25-37, 2005.
- [40]Gauss, M., Constructed wetlands: A promising wastewater treatment system for small localities, experiences from Latin America. Water and Sanitation program. The World Bank, pp.15-50, 2008.
- [41]Salati, E. Jr, Salati, E. & Salati, E. Wetland projects developed in Brazil. *Water Science and Technology*, **40(3)**, pp. 19-25, 1999.
- [42]Rivera, F., Warren, A., Curds, C.R., Robles E., Gutierrez, A., Gallegos, E. & Calderon, A., The application of the root zone method for treatment and reuse of high-strength abattoir waste in México, *Water Science and Technology*, **35**, pp. 271-278, 1997.
- [43]Vymazal, J. & Kröpfelová, L., Wastewater Treatment in Constructed Wetlands with Horizontal Sub-Surface Flow. Springer Science +business Media B.V. Berlin and New York, 404-410, 2008.
- [44]Villegas Gómez, J.D., Guerrero Erazo, J., Castaño Rojas, J.M. & Paredes Cuervo, D., Variaciones al sistema Tanque Séptico (TS)-Filtro Anaeróbico de Flujo Ascendente (FAFA)-Humedal artificial de Flujo Subsuperficial (HAFSS) con miras al tratamiento de aguas residuales en pequeños municipios de Colombia. *Revista Técnica de la Universidad de Zulia*, **29(3)**, pp. 269-281, 2006.
- [45]Lettinga, G., Anaerobic digestion and wastewater treatment systems. *Antonie van Leeuwenhoek*, **67**, pp. 3-28, 1995.
- [46]Lansing, S., Viquez, J., Martinez, H., Botero, R., & Martin, J., Optimizing electricity generation and waste transformations in a low-cost, plug-flow anaerobic digestion system. *Ecological Engineering*, **34**, pp. 332-348, 2008a.
- [47]Viquez, J., Lansing, S. & Martínez, H., Evaluating digester design for electricity generation. *BioCycle: Advancing Composting, Organics Recycling and Renewable Energy*, **49(2)**, pp. 51-54, 2008.
- [48]Lansing, S., Botero, R. & Martin, J., Wastewater treatment and biogas production in small-scale agricultural digesters, *Bioresource Technology*, **99**, 5881-5890, 2008b
- [49]Berglund, M., & Börjesson, P., Assessment of energy performance in the life-cycle of biogas production. *Biomass Bioenergy*, **30**, pp. 254–266, 2006.