EFFICIENT USE AND TREATMENT OF WASTEWATER IN "THE MEZQUITAL VALLEY"

Luis Díaz Batalla and Herminio Baltazar Cisneros
Universidad Politécnica de Francisco I Madero, Hidalgo, México.

Abstract
Current population growth, urbanization, rapid industrialization and intensifying food production are putting pressure on global water resources. This presents a global threat to human health, environment and economy, with both immediate and long term consequences. Worldwide, almost 900 million people still do not have access to safe water and some 2.6 billion do not have access to adequate sanitation, 70 per cent of which live in rural areas. Future demands for water cannot be met unless wastewater management is revolutionized. Inadequate infrastructure and management systems for an increasing volume of wastewater are the main factors involved in the worldwide wastewater crisis. In Mexico, more than fifty cubic meters per second of rainfall, urban and industrial raw wastewater from Mexico City are disposed without treatment to the Mezquital valley in Hidalgo State, where the water is used for the irrigation of 100,000 ha of semiarid cropland since 1890, resulting in an increased crop yield and in environment and human health related problems.
Key words; *Wastewater, Mexico, Microalgae, Membrane Bioreactors.*

Introduction

Since the industrial revolution, human actions have become the main driver of global environmental change. Human activities push the earth system outside the stable environmental state, with consequences that are detrimental or even catastrophic for large parts of the world. There are nine defined planetary boundaries: climate change; rate of biodiversity loss (terrestrial and marine); interference with the nitrogen and phosphorus cycles; stratospheric ozone depletion; ocean acidification; global freshwater use; change in land use; chemical pollution; and atmospheric aerosol loading. If human activities reach a level that could damage these boundaries, it can move earth out of the desirable state (RockstrÖm et al, 2009). Wastewater is associated directly with three of these boundaries; interference with the nitrogen and phosphorus cycles; global freshwater use and chemical pollution.

In the Millennium Development Goals adopted at the United Nations Millennium Summit in September 2000, leaders from nearly 190 countries agreed on a vision for the future with a world with less poverty, hunger and disease, greater survival prospects for mothers and their infants, better educated children, equal opportunities for women, a healthier environment and a world in which developed and developing countries worked in partnership for the betterment of all. Despite of this, over 800 million people in the world are hungry and many of them live in water scarce regions, more than a billion people do not have access to safe drinking water and two billion have inadequate sanitation. Water strongly affects health status, energy and food production, industrial output, and the quality of our environment, affecting the economies of both developing and industrialized nations (Soskolne et al, 2007; Shannon et al, 2008).

Many freshwater aquifers are being contaminated and overdrawn in populous regions or suffer saltwater intrusion along coastal regions. With agriculture, livestock and energy consuming more than 80% of all water for human use, demand for fresh water is expected to increase with population growth, further stressing traditional sources. The shift to biofuels for energy may add further demands for irrigation and refining. Even industrialized nations in North America and Europe, and those in Andean countries in South America, could see major disruptions to agriculture, hydroelectric and thermoelectric generation, and municipal water supplies from reductions in snowmelt and/or loss of glaciers. In the coming decades, water scarcity may be a watchword that prompts action ranging from wholesale population migration to war, unless new ways to supply clean water are found ((Soskolne et al, 2007; Shannon et al, 2008).

Water resources. It is estimated that the world contains about 1 400 million km^3 of water. Of this water, 35 million km^3 (2.5 percent) are freshwater. The large amount of freshwater contained in ice caps, glaciers and deep in the ground is not accessible for use. Freshwater that can be used stems essentially from rainfall over land, generated through the hydrological cycle. The average annual rainfall over land amounts to 119 000 km^3, of which some 74 000 km^3 evaporate back into the atmosphere. The remaining 45 000 km^3 flows into lakes, reservoirs and streams or infiltrate into the ground to replenish the aquifers. This represents what is conventionally called "water resources". Not all of these 45 000 km^3 are accessible for use because part of the water flows into remote rivers and during seasonal floods. An estimated 9 000 – 14 000 km^3 are economically available for human use, a teaspoon in a full bathtub compared to the total amount of water on earth (FAO, 2002).

Annual withdrawals of water for human use amount to about 3 600 km^3. In stream flow needs are estimated at 2 350 km^3 per year. Adding this amount to the amount withdrawn for human use results in 5 950 km^3 of easily accessible freshwater resources that have been already subscribed. Taking into account demographic and water demand projections, the global water figures show a tightening situation. Because both water and population are unevenly distributed, the situation is already critical in various countries and regions. Increasing areas of the world are suffering from freshwater shortages and competition among users is rising (FAO, 2002).

In all regions except Europe and North America, agriculture is by far the biggest user of water, accounting worldwide for about 69 percent of all withdrawals, with domestic use amounting to about 10 percent and industry using some 21 percent. Up to 90 percent of the water withdrawn for domestic use is returned to rivers and aquifers as wastewater. Industries typically consume only about 5 percent of the water they withdraw. Wastewater from domestic sewage systems and industries should be treated before it is released into rivers and possibly re-used but it is often heavily polluted. The many problems worldwide associated with the lack of clean, fresh water are well known: 1.2 billion people lack access to safe drinking water, 2.6 billion have little or no sanitation, and millions of people die annually (3,900 children a day) from diseases transmitted through unsafe water or human excreta. Intestinal parasitic infections and diarrheal diseases caused by waterborne bacteria and enteric viruses have become a leading cause of malnutrition owing to poor digestion of the food eaten by people sickened by water (FAO, 2002; Bartram, 2008).

In both developing and industrialized nations, a growing number of contaminants are entering water supplies from human activity: from traditional compounds such as heavy metals and emerging micropollutants such as endocrine disrupters and nitrosamines. Increasingly, public health and environmental concerns drive efforts to decontaminate waters previously considered clean. Fortunately, a recent flurry of activity in water treatment research offers hope in mitigating the impact of impaired waters around the world. Conventional methods of water disinfection, decontamination and desalination can address many of these problems with quality and supply. However, these treatment methods are often chemically, energetically and operationally intensive, focused on large systems, and thus require considerable infusion of capital, engineering expertise and infrastructure, all of which precludes their use in much of the world (Shannon et al, 2008; Bartram, et al, 2008).

Water reuse and reclamation. The overarching goal for the future of reclamation and reuse of water is to capture water directly from non-traditional sources such as industrial or municipal wastewaters and restore it to potable quality. Of all the water withdrawn from rivers, lakes and aquifers, the majority is returned to the environment. Agricultural and livestock users return the least at, 30–40%, whereas industrial users return, 80–90%, power generation returns considerably more at, 95–98%, and public and municipal users return,75–85%. The rest is lost to the atmosphere or is consumed in biological or chemical processes. A large part of the cost of water for human use is pumping, transport and storage. Thus recovering water at or close to the point of use should be very efficient. However, wastewater contains a wide variety of contaminants and pathogens, and has a very high loading of organic matter, all of which must be removed or transformed to harmless compounds. Municipal wastewaters are commonly treated by activated sludge systems that use suspended microbes to remove organics and nutrients, and large sedimentation tanks to separate the solid and liquid fractions. This level of treatment produces wastewater effluent suitable for discharge to surface waters or for restricted irrigation and some industrial applications. Similarly, biological treatment via traditional trickling filters and aquacultures have been used extensively to reduce solids and remove ammonia and nitrites from water. Typically, these biological treatment systems are large with long water residence times (Shannon et al, 2008; Bixio et al, 2005).

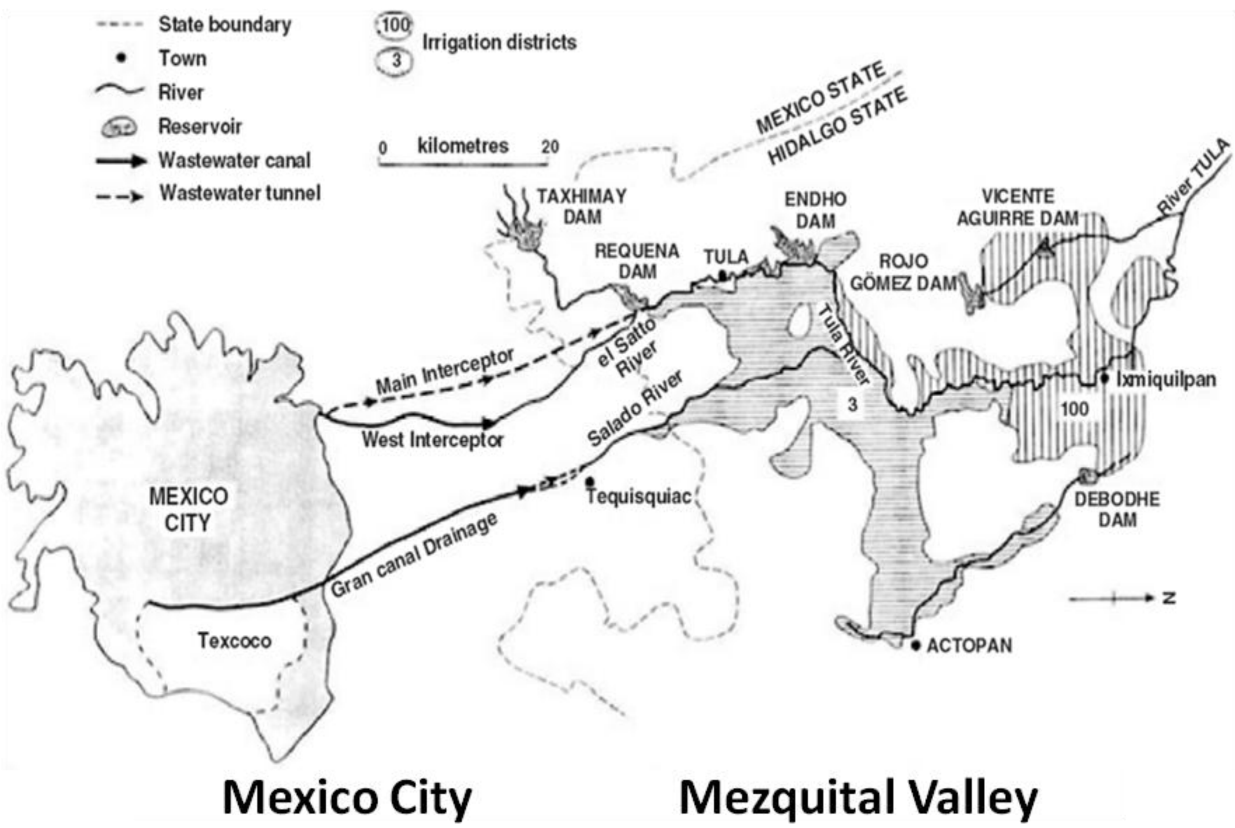
A technology now actively being pursued is membrane bioreactors (MBRs). This technology combines suspended biomass, similar to the conventional activated sludge process, with immersed microfiltration or ultra filtration membranes that replace gravity sedimentation and clarify the wastewater effluent. MBRs can produce high-quality effluent that is suitable for unrestricted irrigation and other industrial applications. MBRs have also the potential for use in developing countries to address the pressing need for improved sanitation. Possible applications in developing countries include the direct treatment of raw sewage, particularly in rapidly growing megacities, and the extraction of valuable resources from sewage, namely clean water, nutrients (mostly N and P), and energy (Daiger et al, 2005; van Nieuwenhuijzen et al, 2008).

The small footprint, flexible design, and automated operation of MBRs make them ideal for localized, decentralized sewage treatment in the developing world. One of the growing applications of MBRs is as pre-treatment for RO, which, when followed by UV disinfection, can produce water for direct or indirect potable use. Current wastewater re-use systems use a conventional activated sludge process, followed by a microfiltration MBR pre-treatment of the secondary effluent, which has high quantities of suspended and dissolved solids. The effluent water from the MBR still partially contains dissolved species and colloidal substances that act to foul the membranes of the subsequent RO system used as a final barrier to contaminants in the product water. Employing a ‘tight’ ultra filtration membrane in the MBRs lets through fewer dissolved solids than does microfiltration, allowing the RO system to operate with significantly less fouling (Daiger et al, 2005; van Nieuwenhuijzen et al, 2008).

Technology implementation is not enough to guaranty the safeness of the effluent. Is necessary to implement the Hazard Analysis and Critical Control Points (HACCP) to develop a preventative management and quality assurance approach rather than random monitoring of the end product. The system involves identification of critical points to control hazards and maintain best management practices throughout production and distribution of treated wastewater (Westrell et al, 2004).

Wastewater in the "Mezquital Valley", Mexico.
The water supply in the metropolitan area of Mexico City for 20 million people depends primarily on local groundwater sources and on inter-basin transfers from outside basins. Infrastructure for distribution of water within the city has become very large and complex. In order to supply the necessary water for the needs of the social and economic sectors of the megacity, the rates of extraction from the aquifer have been much higher than the recharge rate for decades. At present, approximately 45 to 54 cubic meters per second is abstracted per year, but the natural recharge rate is only about half of this. This has resulted in very serious overexploitation, with the groundwater table decreasing by around one meter each year. According to official figures the water extracted from the aquifer to supply water to the population of Mexico City from 1990 to 2007 has reached almost 17,000 cubic meters per second. This figure is significantly higher than the groundwater recharge rate, illustrating how this trend in groundwater extraction is unsustainable. In addition to water supply, the other main challenge for Mexico City in terms of water is collection of wastewaters and their proper treatment and disposal. It is said that 2.6 billion people lacked improved sanitation facilities in 2002, which is a number too big to be ignored by governments and by the international community. More than 50 cubic meters per second of wastewaters are disposed without treatment. Almost all of this water is used for irrigation purposes, resulting in very significant health and environment-related problems and concerns (Tortajada, 2008).
Wastewater origin. To avoid floods and to drain the sewage from the Mexico City, three artificial exits were built to send the urban and industrial wastewater to the "Mezquital Valley" since 1890. Mexico is the country with the largest continuous area irrigated with raw wastewater. This area with 90,000 ha is known as the "Mezquital Valley" and it is located in Hidalgo State 80 km north from Mexico City (**Figure 1**). Currently, expressed as mean value, 60 m^3/s are sent this way from which 80% corresponds to wastewater and 20% to rainfall.

Figure1. "Mezquital Valley" localization.



Wastewater use. The main activity in the "Mezquital Valley" is agriculture, which is practiced in three irrigation districts. Currently with 90,000 ha and receiving 60 m^3/s is the largest continuous area irrigated with raw wastewater in the world where maize, alfalfa, wheat, barley, oats, beans and vegetables like squash and chilli are produced. Irrigation is done by flooding and furrow with annual water application rates from 1500 mm to 2200 mm depending the crop and simultaneously adding nutrients (527, 227 and 781 kg/ha/y of N, P and K respectively), organic matter (1950–2860 kg of TOC/ha/year) and pollutants (organic compounds, pharmaceuticals, heavy metals, microbial pathogens and helminth ova) to the soil and agricultural system (Jimenez and Chávez, 2005).

Wastewater description. Raw wastewater quality changes between seasons and mean of some values (**Table 1**) ranged from 100 to 249 NTU for turbidity, from 83 to 153 mg/L for TSS, from 166 to 167 mg/L for DBO, from 35 to 188 mg/L for TOC, from 37 to 38 mg/L for total nitrogen, from 24 to 32 mg/L for ammonia nitrogen, from 2.7 to 3 mg/L for phosphorus, from 10^{04} to 10^{10} MPN/100 mL for fecal coliforms, from 12 to 24 ova/L for helminth, from 1.3 to 5.5 mg/L for aluminium, from 0.09 to 0.1 mg/L for lead and from 210 to 220 mg of CaCO3/L for total hardness. Is poor the knowledge about organic compounds load, but some pharmaceuticals and agrochemicals are present in the system (Jimenez and Chávez, 2005).

Table 1. Characterization of "Mezquital Valley" wastewater.

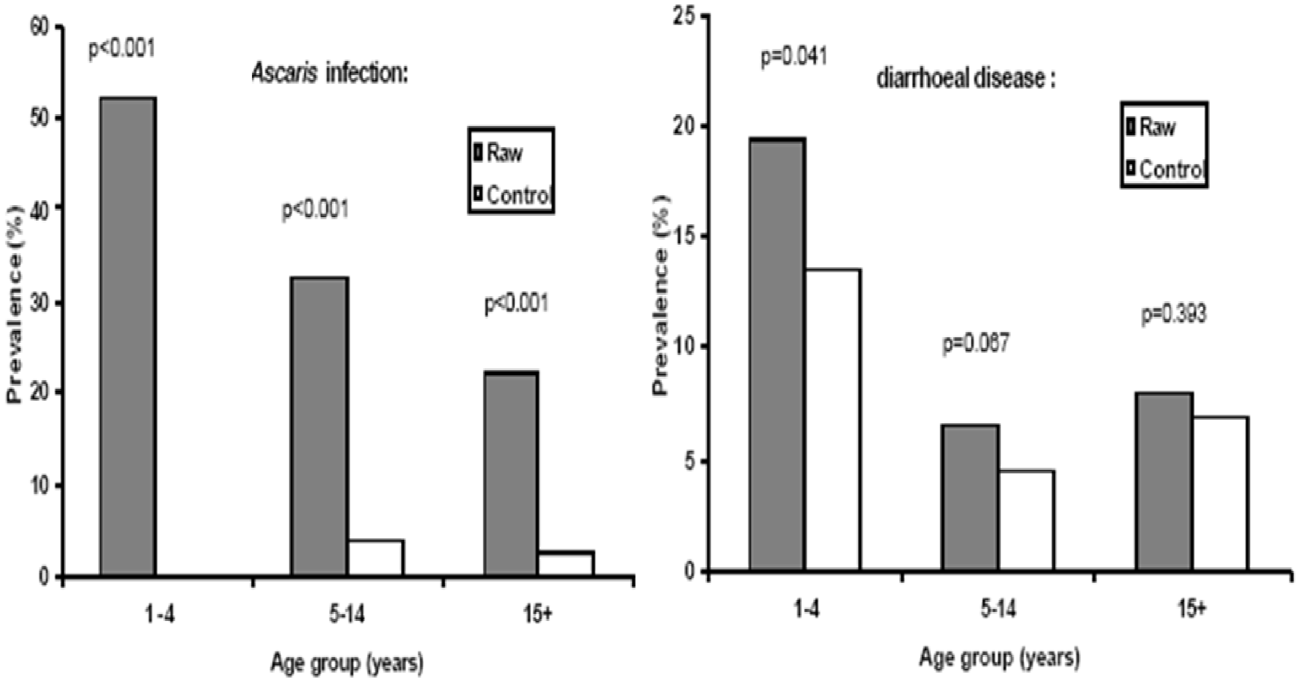
Parameter	Wastewater value
Fecal coliforms, MPN/100 mL	10^{04}–10^{10}
E. histolytica, cysts/L	0–1.5
Helminth ova, ova/L	12–24.5
Turbidity, NTU	100–249
TSS, mg/L	83–153
BOD, mg/L	166–167
Total organic carbon, mg/L	35–188
Total nitrogen, mg/L	37–38
Ammonia nitrogen, mg/L	24–32
Nitrates, mg/L	ND-1
Nitrites, mg/L	ND-0.001
Phosphorus, mg/L	2.7–3
Bicarbonates, mg CaCO3/L	485
Total hardness, mg CaCO3/L	210–220
Chlorides, mg/L	155–248
Fluorides, mg/L	0.7–4
Sulfides, mg/L	3–3.5
Aluminium, mg/L	1.3–5.5
Arsenic, mg/L	ND-0.008
Iron, mg/L	1–1.2
Mercury, mg/L	ND-0.001
Lead, mg/L	0.09–0.1
Sodium, mg/L	198–206
Calcium, mg/L	41–445
Boron, mg/L	1.–1.2
Cyanides, mg/L	0.005–0.01
o – xylene, µg/L	3.8–4
Ethyl benzene, mg/L	1.2
m – xylene, µg/L	9.2
p-cresol, µg/L	46.5
Chloroform, µg/L	0.2–0.8

Aquifer. Due to the salinity in the soils, very high irrigation rates are used which, combined with the edaphologic conditions and the wastewater transport through 858 km of unlined channels, there is an artificial recharge of the aquifer. This recharge has been estimated in 25 m^3/s, and it is equivalent to 13.3 times the original or natural recharge. As a consequence, the water table has raised and several springs have appeared with flows between 100 to 600 L/s. Also, the original flow of the Tula River, the main stream in the "Mezquital Valley", has increased from 1.6 to 12.7m^3/s in 50 years. All this water has favoured the development of the region and constitutes the main source of water. (Jimenez and Chávez, 2005). On the other hand water in the aquifer presents and increase in salinity observed in the concentration of calcium, magnesium, bicarbonates, sulfates, nitrates, nitrites, hardness, total dissolved solids, conductivity, and alkalinity.

Health. Given the chemical, microbial and physicochemical quality of the wastewater, the legal agricultural production is limited to **restricted irrigation** of two main crops; corn and alfalfa, but other no authorized vegetables like cabbages, carrots, green beans, green tomatoes, red tomatoes, onions, chillies, lettuce, radishes and cucumbers are produced. The use of wastewater in agriculture has important health implications for product consumers, farmers and their families produce vendors, and communities in wastewater irrigated areas (**Figure 2**). In the "Mezquital Valley", direct exposure to untreated wastewater was associated with an excess risk of A. lumbricoides infection in children and an increased risk of diarrhea, with stronger effects in the dry season than in the rainy season. The products produced in this condition have poor sanitary quality affecting its marked reception and economic value (Jimenez and Chávez, 2005; Blumenthal, 2001).

In the region, wastewater is very important for the producer due to its benefic effects in crop yield, but environment, economic and health effect and cost must be reconsidered in the water reuse for agricultural and others activities of the "Mezquital Valley" for he further sustainability of the system.

Figure 2. Effect of exposure to wastewater on *Ascaris* infection and diarrhoeal disease.



Efficient wastewater treatment and reuse.

Given the antiquity of more than 100 years of the wastewater reuse in agriculture and its positive effect in the crop yield of the "Mezquital Valley", there are a strong social value of this water and poor knowledge of its negative effects on health and environment. The world need for food production meet water stressed agricultural systems, were rainwater and reclaim wastewater are productive and viable options if integrated and safe systems are considered. Conventional waste water treatment use intensive chemical treatments (such as those involving ammonia, chlorine compounds, hydrochloric acid, sodium hydroxide, ozone, permanganate, alum and ferric salts, coagulation and filtration aids, anti-scalants, corrosion control chemicals, and ion exchange resins and regenerants) and residuals resulting from treatment (sludge, brines, toxic waste) can add to the problems of contamination and salting of freshwater sources. More effective, lower-cost, robust methods to disinfect and decontaminate waters from source to point-of-use are needed, without further stressing the environment or endangering human health by the treatment itself (Shannon et al, 2008).

Treatment. Wastewater treatment plant based on microalgae and membrane bioreactors included in a Hazard Analysis Critical Control Point (HACCP) system of water reuse is considered a profitable and affordable scheme of wastewater safe reuse in agriculture and other uses, without stressing environment and human health aspects (Westrell et al, 2004). Wastewater treatment plant main cost of processing is aeration, which means to pump air through wastewater for microbial activity and pollutants reduction. Algae naturally uptake nutrients, metals, and other pathogens from the water sources in which they grow, while also releasing or "injecting" oxygen back into that water. In doing so, algae essentially provide a biological method of treatment for municipal wastewater, industry effluents, eutrophic waterbodies, and other waste streams, potentially reducing the public cost burden of wastewater treatment (Ryan, 2009).

On the other hand, algae are an attractive biofuels feedstock compared to other biofuel sources. Their rapid growth rate (doubling in 6–12 hours), high oil content (4–50 percent or greater of nonpolar lipids), biomass harvest (100 percent), and nonseasonal harvest intervals have led to claims of algae biofuel yields that are theoretically orders of magnitude higher than other biofuels feedstock (**Figure 3**). Effluent treated with microalgae can be used in agriculture and urban use or can be treated with membrane bioreactor to improve quality and use in greenhouse and as potable water. The technological risks no longer represent a major concern for the development of water reclamation projects, rather issues such as the financing; failure management and social acceptance have become more critical (Ryan, 2009).

Reuse in agriculture. Water efficient reuse involves the use of irrigation technology and production of high quality agricultural products in a Hazard Analysis Critical Control Point (HACCP) system (**Figure 4**). The purposes of the implementation of this scheme are social, environmental and economic. Socially, for development of ideas of productive systems in harmony with environment, natural resources, human health and crop yield. Environmentally, for an urban development with vision of the rural and agriculture development, where natural resources and nutrients are recycled with less negative impacts on the biosphere and more sustainable systems. Economically, for a change in the productive philosophy of the region, for a less dependence of subsistence agriculture and for an increase of the crop sanitary quality, market distribution and added value.

Figure 3. Integration of microalgae wastewater treatment to energy production.

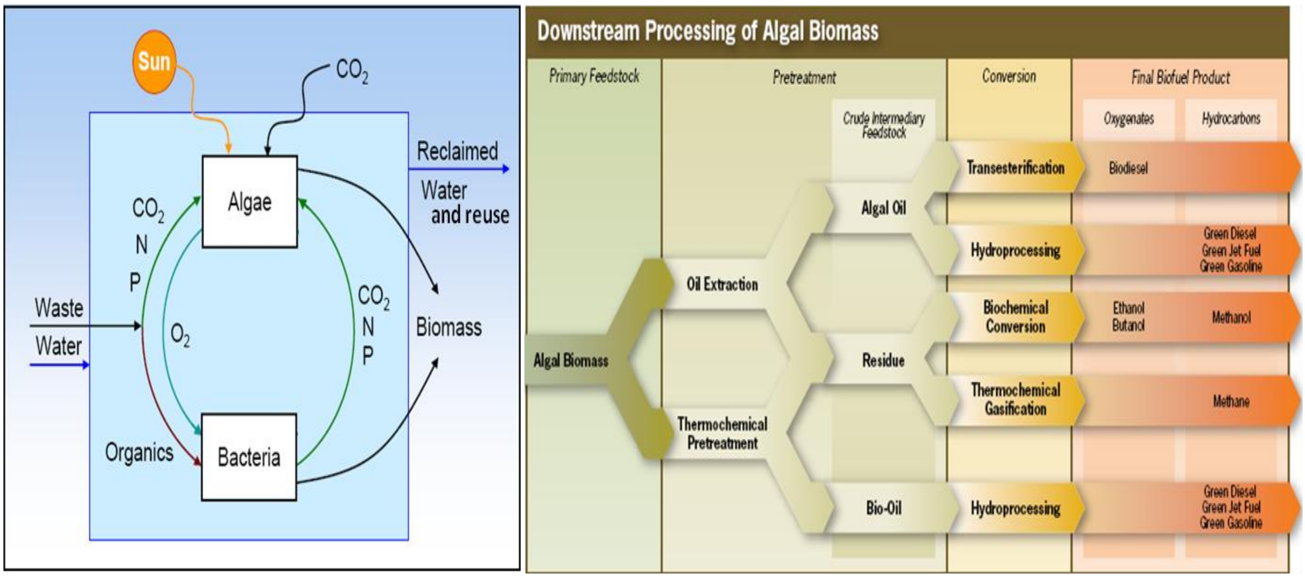
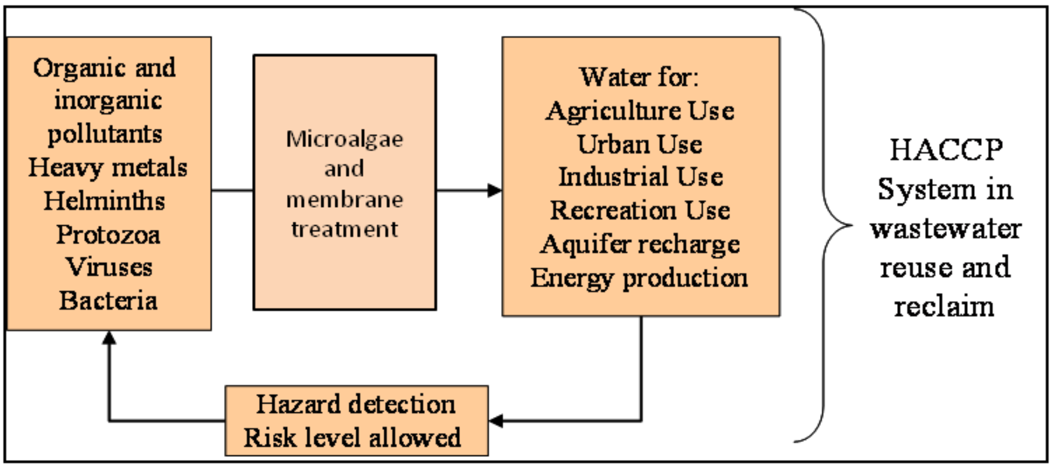


Figure 4. Wastewater reuses and reclaim in HACCP system.



Conclusions.

Since 1890, Mexico City sends its urban and industrial wastewater without treatment to the “Mezquital valley”, where is reuse in agriculture with positive effect in crop yield but a bigger negative impact on environment and human health. The centralised treatment of the 60 m^3/s of wastewater is considered and expensive investment and maintenance and decentralized treatment seems more convenient. This treatment must be an effective, lower cost; robust methods to disinfect and decontaminate waters from source to point-of-use, without further stressing the environment or endangering human health by the treatment itself. In this vision, microalgae treatment and membrane bioreactor coupled with reverse osmosis and UV disinfection offers a sustainable scheme of processing. To reach the total sanitary security of the process and products (water and crops), a HACCP system will be implemented in a wastewater treatment plant.

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