Implementation of Community Wetlands for the sanitation of the Cajititlan Lake, Jalisco

Implementación de Humedales Comunitarios para el saneamiento de la Laguna de Cajititlán, Jalisco

CARO-BECERRA, Juan Luis†*[1], VIZCAÍNO-RODRÍGUEZ, Luz Adriana[1], LUJÁN-GODÍNEZ, Ramiro[1] and MICHEL-PARRA, J. Guadalupe[2]

[1]*Universidad Politécnica de la Zona Metropolitana de Guadalajara*
[2]*Centro Universitario Sur de la Universidad de Guadalajara*

ID 1st Author: *Juan Luis, Caro-Becerra* / **ORC ID**: 0000-0002-3884-2188, **Researcher ID Thomson**: K-2859-2018, **arXiv Author ID**: juanluis74

ID 1st Co-author: *Luz Adriana, Vizcaíno-Rodríguez* / **ORC ID**: 0000-0001-8301-6160, **Researcher ID Thomson**: T-1324-2018, **CVU CONACYT ID**: 175164

ID 2nd Co-author: *Ramiro, Luján-Godínez* / **ORC ID**: 0000-0003-4138-7590, **arXiv Author ID**: ramiro5302, **CVU CONACYT**: 503875

ID 3rd Co-author: *J. Guadalupe, Michel-Parra* / **ORC ID**: 0000-0002-7017-8360, **Researcher ID Thomson**: T-2648-2018, **CVU CONACYT ID**: 316532

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Abstract

Wetlands are systems that promote the sustainability and development of a society. The goal of this research was the implementation of a prototype aquatic garden to assess the quality of water in Cajititlán Lake, using sewage treatment plants with the purpose of removing nutrients, phosphates and nitrates among others parameters. This was made possible by floating structures containing aquatic vegetation species like.: *Typha latifolia*, *Lemna minor*, *Canna indica*, *Iris pseudacorus*, *Equisetum arvense*, *etc.* whose basic function is to retain nutrients through phytoremediation processes. The results indicate that the implementation of community wetlands made possible to reduce BOD levels from 220 mg/lt to 12 mg/lt across a surface of 120 m², treating a flow rate of approximately 5.30 gal/min to obtain an effluent in accordance with norm NMX-AA-012-SCFI. It is concluded that community wetlands are suitable ecological alternatives for the treatment of the wastewater discharged directly into the lake.

Community wetlands, Phytoremediation, Sustainability

Resumen

Los humedales son sistemas que favorecen a la sostenibilidad y el desarrollo de una sociedad. El objetivo de esta investigación fue la implementación de jardines acuáticos prototipo en la laguna de Cajititlán con el propósito de evaluar la calidad de agua, utilizando a su vez plantas de tratamiento de aguas residuales removiendo nutrientes, fosfatos y nitratos entre otros. Esto fue posible gracias a estructuras flotantes: *Typha latifolia*, *Lemna minor*, *Canna indica*, *Iris pseudacorus*, *Equisetum arvense*, etc. cuya función es retener los nutrientes mediante procesos de fitorremediación. Los resultados indican que con la implementación de humedales comunitarios fue posible reducir la DBO de 220 mg/lt a 12 mg/lt en una superficie de 120 m², tratando así un caudal de 5.30 gal/min y obtener un efluente que cumple la norma NMX-AA-012-SCFI. Se concluye que los humedales comunitarios son alternativas ecológicas que tratan las aguas residuales vertidas directamente al lago.

Humedales comunitarios, Fitorremediación, Sostenibilidad

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* Correspondence to Author (email: carobecerrajuanluis1974@gmail.com)
† Researcher contributing as first author.

1. Introduction

Wetlands are systems designed to treat wastewater by means of phytoremediation processes aimed to avoid as much as possible the altering of the local natural environment. This is achieved due to the fact wetlands are ecological techniques with innovative filtration technologies that make use of floating macrophyte plants, with the additional benefit of a relative small investment for an effective purification of water entering the wetland.

These water purification system requires little maintenance tasks (at least once a year) such as: dead plants replacement and excessive plant biomass elimination, generated by the biofilter.

Achieving a sustainable development for the Cajititlan Lake will foster a tourism, handicraft and recreational fishing development for the inhabitants of the region, which in recent times have experience great cultural and ecological wealth losses.

Design, development and knowledge of the community wetlands are directly related to the understanding of the site in which they are to be implemented, that is, the more knowledge about the regional ecosystems, the better the wetland performance, allowing to obtain different final results as a consequence rain, sun, humidity, land and vegetation fluctuations (Justice Center for Women, 2016).

That is the reason why community wetlands by the use of aquatic plants are becoming more relevant in Cajititlan Lake, to compensate the existing low coverage of sanitary sewage, which mostly included in situ treatments options such as septic tanks, absorption wells and filtration ditches (Juarez, 2010).

A clear example of the high rates of contamination caused by discharges of heavy metals into local rivers and streams are the numerous cardboard and mescal manufacturing facilities located in the municipality of El Salto, Jalisco (McCulligh, 2020), where 1 in 2 people lack adequate sanitation conditions, which is equivalent to two and half times the clean water deficit supply (United Nations Development Program, 2015).

There are many definitions of wetlands, however, among the most important ones is that one that states that wetlands are water purification systems that help to reintegrate wastewater into its natural hydrological cycle, with an optimal quality without causing pollution in the process.

Wetlands are classified into two types: subsurface flow type and surface flow type. Surface flow wetlands are usually supported by environmental restoration programs, which are designed to capture effluents that have already been processed, so our aquatic plant wetland system aims to additionally improve water quality (Reed, Crites & Middlebrooks, 1995).

Subsurface flow systems are key process for wastewater treatment, as they are usually used in small populations. Their advantages are greater treatment capacities, low risk of contact with water, low presence of insects, being the effluent of a subsurface type; the water circulation is underground in contact with the roots and rhizomes of the plants (García and Corzo, 2009).

Figure 1 Cross section of the aquatic plant garden where the connection with the Cajititlan Lake can see in the background
Source: Our Preparation, 2018

Talking about community wetlands in Cajititlan Lake, implies that this research work performs a hydrological balance of the surface water, identifying what is the minimum percentage of wastewater treatment in our country.

In Mexico only 23% of wastewater receive some treatment (CONAGUA, 2015), of this latter percentage 42% receives treatment using activated sludge systems which require a very high energy investment compared to natural and sustainable non-conventional alternatives such as Artificial Natural Ecological Systems (ANES).

NESS type systems allow wastewater treatment by using the same kinds of microorganism living in the root receptacles of aquatic plants, such as: *Typha latifolia, Lemna minor*, *Canna indicates*, *Iris pseudacorus, Equisetum arvense*, to name a few. These microorganisms are benefited by the presence of sunlight and nutrients in water; as a payback, they satisfy their needs through their own microbiological processes. As a result of this natural treatment by means of wetlands, clean and good quality water is obtained; this wastewater treatment system is a 100% natural process which yields no products like, fecal coliforms, pathogens and bad odors.

2. Backgroung

Cajititlan Lake is located in the municipality of Tlajomulco of Zuñiga forming part of the Guadalajara Metropolitan Area (GMA). It is located in the central region of the state of Jalisco between coordinates 20° 28´ north latitude and 103° 27´ west longitude at an average altitude of 1575 meters above sea level (Chávez Hernández, 2009).

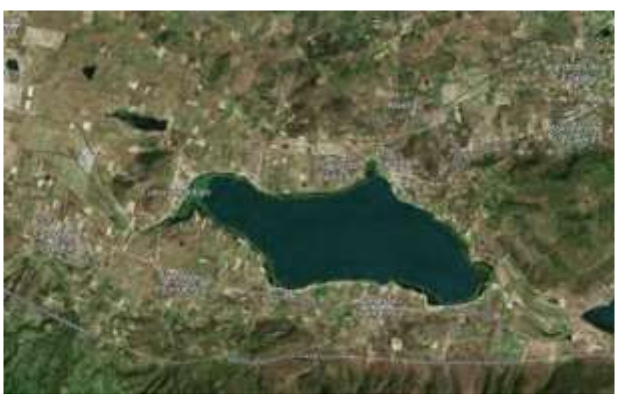


Figure 2 Satellite image of the Cajititlan Lake basin
Source: Google Earth

From a hydrological point of view, Cajititlan Lake constitutes the second most important natural reservoir in the state of Jalisco, with a storage capacity of approximately 54 million cubic meters (CONAGUA, 2015) and a surface of 4225 acres, as show in figure 2.

2.1 Historical background

The *chinampas* origin goes back to almost 2000 years before Christ. According to some experts they originated between 200 and 800 A. D. and their years of splendor were between 1400 and 1600 A. D. With the passage of time its origin has been lost, since no archaeological data have been found on the existence of the *chinampas* before the Aztec era.

The *chinampas* are agroecosystems of pre-Hispanic origin built artificially in areas of the Xochimilco-Mixquic Lake. Originally, they were squares in shape combined with features like terraces and channels, as a main feature they do not require irrigation owing to the fact that the needed water is obtained by infiltration (Molina, 1974). Generally, the *chinampas* are surrounded by rows of *Salix bonplandiana*, which is planted on the edge of the wetland to retain soil and prevent erosion.

3. Theoretical Framework

Dimensions of the wetland are dependent on the amount of water to be treated. They can be large or small, so the installation of biogardens, which are easy to maintain, is recommended.

Wetlands are closely linked to Artificial Natural Ecological Systems (ANES) and their treatment techniques can be singly applied. It is very important to keep in mind that water pollution in the environment has a cyclical character (Domínguez, 2015); therefore, the goal is to make a responsible use of water resources in order to maintain that cycle.

The ANES type technology can be considered as a highly stable ecosystem that can withstand fluctuations and unforeseen events without collapsing, sustaining the safety of users and water quality, in addition to functioning as a complete ecosystem that is integrated into its environment, achieving a fully sustainable treatment system in the process, as can be seen in figure 3.

Figura 3 Wastewater treatment by means of an ANES Type system
Source: Our Preparation, 2018

ANES systems can treat a wide variety of pollutants through physical, chemical and biological processes, including heavy metals, pathogenic microorganisms and of course BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), TSS (Total Suspended Solids) and other parameters for measuring wastewater quality such as salinity, hydraulic conductivity, suspended sediment accumulation, as well as biomass accumulation.

On the other hand, macrophyte vegetation contributes to the oxygenation of the substrate, nutrient removal in the subway part where the microbial community develops (Rabat, 2016). The pollutant scavenging processes with macrophytes occur through primary mechanisms such as:

– Filtration and sedimentation of solids in suspension.

– Incorporation of nutrients in plants.

– Degradation of organic matter by a group of facultative microorganisms associated with plant roots.

These aquatic systems are based on the maintenance of a vegetation cover of floating macrophytes on a sheet of water through ponds in series linked to each other where the effluent flows (Martelo, 2012). It is worth mentioning that the wetland constructed as a prototype in Cajititlan Lake contemplates the periodic removal of aquatic plants, as show in Figure 4.

Figure 4 Platanillo (Canna coccinea) is one of the best aquatic plants, as it has some medicinal properties; however, it is highly toxic in large quantities
Source: Our Preparation, 2019

4. Methodology

The first step in the construction of the aquatic plant garden was to locate the site, then, the sizing od the needed area; the next step was the implement the placement of *Schoenoplectus acutus* o *Salix bonplandiana* (typical wetland plant species) whose main characteristic is its ability to withstand excess water.

The following step is to bond cattails branches to form a fence, which is placed at the bottom of the aquatic plant substrate to form a base that will be left to dry during 15 days, then the mud is extracted to fill the fence that forming the *chinampa.*

The aquatic plant garden has an area of approximately 145 yd² and consisting of the following layers: the first layer is the pond which the effluent enters both by infiltration and pumping, in this layer are placed the solid sediments, as well as those also dragged by the water, the second layer consist of masonry stone; and the third layer consist of a special kind of soil named *tezontle* that will cover the ¾ parts of the wetland just where the aquatic plants do their ecosystemic function responsible for the absorption of heavy metals, used use as food through their roots.

4.1 Size of the wetland

The minimum width (B min) and minimum length (L min) were calculated for sizing the wetland. The calculation of the minimum length serves as a basis to propose an ideal distance and a program of wetland construction.

It should note that the width of the wetland is a function of depth, slope and hydraulic conductivity of the filtering material.

The size of the constructed wetland depends on the incoming effluent flow and the Biochemical Oxygen Demand (BOD) loads that need to be reduced, based on the obtained results (Jenkins, 2015) and the climatic and soil permeability conditions of Cajititlan Lake.

To determine a more precise size of the wetland (Crites & Tchobanoglous, 1998) proposes the following examples calculations to clarify 900 $gal/fam/week,$ required for a single living unit, a depth of 2 ft, width 1.5 ft and length of 6 ft is required and for a community of 400 families discharging 850 gal/min a depth of 2.5 ft, width of 16.50 ft and length of 69 ft is needed *(ibid).*

In order to calculate the size of the local wetland, climatological information from the La Huerta station in the municipality of Ixtlahuacan de los Membrillos was used; thus the reaction rate constant Kr (day^{-1}) was used as a reference, according to the following equation:

$$kr = k20 * 1.06^{(T-20)} \quad (1)$$

The reaction rate constant at 68 °F or 20 °C (k_{20}) varies depending on the system to be implemented, for example, (Crites & Tchobanoglous, 1998) estimated 1.1 day^{-1}, and (Burton, 1991) estimates a (k_{20}) of 1.35 day^{-1} for blackwater wetlands, while (Olson *et al*, 1967) showed that the reaction rate for greywater is 2.5 times bigger due to the large amount of untreated organic matter.

Obviously, these values depend on the performance of the wetland and cannot be accurately calculated until it could be constructed and monitored, so it is recommended to use a low conservative value, since most of the wastewater treatment depends on the activity of microrganisms in the wetland, which cannot be determined before the construction phase, so a (k_{20}) of 1.35 day^{-1} is recommended for blackwater treating wetlands such as the effluent from Cajititlan Lake.

$$Kr = K20 * 1.06^{(T-20)} = 1.35 * 1.06^{(27-20)}$$

$$Kr = 1.91\ day^{-1}$$

The calculation of retention time, will depend on the time the water must remain in the wetland, its equation is a follows:

$$t = \frac{-\ln\left(\frac{C}{Co}\right)}{kr} \quad (2)$$

It is worth mentioning that the aquatic plant wetland to implement as prototype in Cajititlan Lake can decrease BOD levels but cannot eliminate them.

To determine the organic loading rate *Lorg* (gr BDO_5/m^2-day), the following equation was used:

$$Lorg = \frac{(C)(dw)(\eta)}{t} \quad (3)$$

Where *C* is the BOD level in the effluent (mg/l), *dw* is the depth in the substrate ranging from1.30 ft to 2.80 ft, obviously the deeper the wetland the more anaerobic conditions can be found, which means a lesser reduction of BOD and nutrients.

In our case, a substrate depth of 2 ft was chosen taken and to be constructed with sand and gravel material, as shown in figure 5.

Figura 5 Prototype of the aquatic plant wetland in Cajititlan Lake
Fuente: Our Preparation, 2019

Using the retention time previously calculated in equation (2), the effective porosity η can be determined, which is defined as the ratio between non-solid volume and total volume of the material according to the gravel size as shown in the table 1.

Substrate	Effective size d10 mm	Effective size η
Sand (medium)	1	0.30
Sand (coarse)	2	0.32
Sand with gravel	8	0.35
Gravel (medium)	32	0.40
Gravel (coarse)	128	0.45

Table 1 Typical values for artificially constructed wetland substrates d10 is the diameter of a particle in a weight distribution that is smaller than all particles in the 10%
Fuente: Crites and Tchobanoglous

Land area factor required for the subsurface flow wetland bed is determined as follows:

$$As = \frac{Qave*t}{\eta*dw} = \frac{28.8*1.522}{0.35*0.60} = 208.73\, m^2 \qquad (4)$$

Where *Qave* is the average effluent flow rate (m^3/day), *t* is hydraulic retention time calculated from equation (2), with a substrate depth of 0.60 m and an effective $\eta = 35$ for gravelly sands, taken from table 1.

The following equation was used to determine the wetland dimensions:

$$w = \left(\frac{As}{Ra}\right)^{1/2} = \left(\frac{208.73}{2}\right)^{1/2} = 10.20\, m \qquad (5)$$

Where *w* is the width of the wetland, *As* is the surface area of the wetland and *Ra* is the length to width ratio. For artificially constructed subsurface flow wetlands (Crites y Tchobanoglous, 1998) recommend a ratio 2:1 to 4:1. Finally, the length *l* of the artificially constructed wetland was calculated with the following equation:

$$l = \frac{As}{w} = \frac{208.73}{10.20} = 20.46\, m \qquad (6)$$

5. Results

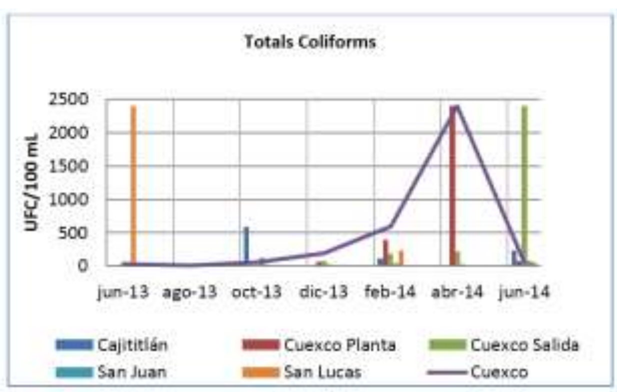
Deterioration of Cajititlan Lake has prompted various sectors of the local society to take actions aimed to rehabilitate and protect the reservoir by means forums, assemblies and agreements, carried out at a watershed council level. Researchers from the Polytechnic University of the Metropolitan Zone of Guadalajara and the University of Guadalajara have presented numerous studies on water quality, limnology, watershed hydrology, bathymetric, and an inventory of local flora and fauna.

Water quality studies indicate temperature levels ranging from 20 to 30 °C, and dissolved oxygen ranging from 0.0392 to 17.35 mg/L, records of Fecal Coliform organism varied from 7 to 2400 UFC/100mL and the count for Total Coliform organism varied from 5 to 2400 mg/L. These indicators clearly show that the lake is a highly polluted water body with low oxygen levels, so its recovery is of utmost importance for future generations, since good conservation, preservation and management practices will help to clean up and recover the Cajititlan Lake.

5.1 Diagnosis of Cajititlan Lake

According to the limnological studies of Cajititlan Lake presented by (Vizcaíno Rodríguez *et al*, 2018) and analyzing physical and biological factors such as temperature, dissolved oxygen, alkalinity, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and pH, the final results are:

1. Temperature: from 20 to 30 °C
2. Dissolved oxygen: 0.392 to 17.38 mg/L. Observed variations depend of the time, light intensity and sampling site
3. pH: 8.84 - 9.52
4. High concentration of disolved phosphate and ammonium
5. Biochemical Oxygen Demand at 5 days (27.6 – 9.6 mg/L)
6. Chemical Oxygen Demand COD (394 – 14.76 mg/L)
7. Total solids: 0.405 – 0.454 mg/L
8. Total coliforms 5 – 2400 CFU/100mL, as show in graphic 1
9. Mercury: 0.005 mg/L in water; 0.0250 – 0.0517 mg/K in sediments; 0.0250 – 0.0478 mg/kg in plants and 0.0250 – 0.0478 mg/kg in fish



Graphic 1 Total Coliform graph
Source: Vizcaíno Rodríguez, 2018

6. Prospective analysis

The current state of Cajititlan Lake does not allow to reverse the effects and consequences of the ecological deterioration in which it is found, but it is of great value to recover the watershed.

One of the most important actions is the appropriation of federal zones that belong to the riparian communities of San Juan and San Lucas Evangelista, an action which will only be achieved if there is political will on both sides of government and society, reconstructing the historical memory of the territory as well as the uses and customs of the first settlers. This goal will be achieved by carrying out Land and Ecological Management plans at both municipal and watershed levels.

To achieve the proposed objectives, it is necessary to modify the current conditions, such as high levels of pollution, insecurity, accumulation of solid waste due to tourism, to name a few.

Additionally, it is necessary to work based on the principles of sustainable development in order to establish conservation strategies in the community wetlands and their problems to solve. On the other hand, it is urgent to reduce or totally eliminate direct untreated discharges into the lake, which generate bad odors, skin and gastrointestinal diseases, and as a final consequence, a public health problem centered on the most vulnerable sectors.

7. Conclusions and recommendations

Some artificial wetlands are susceptible to clogging due to sediment entrainment; this can have avoided with a number 40 fine mesh, this will allow the effluent to remain at an optimal water level. On the other hand, it is important not to introduce species that are not from the region because some plants are more aggressive that others, as happened with the migratory plant named *Crysopogon zizanoides*.

These limitations should not be a factor to avoid the conclusion the project titled "Implementation of community wetlands in Cajititlan Lake", since the provided benefits will be greater for the community, thus generating environmental awareness and achieving a paradigm shift.

The community wetlands in Cajititlan Lake will effectively contribute to achieve the objectives of this project, additionally, it will make possible the reuse of treated wastewater is to give it reuse for agriculture purposes.

The results of this research have shown that the quality of life conditions have improved, since the living place have become self-sustainable units, in order to minimize pollution problems related to wastewater.

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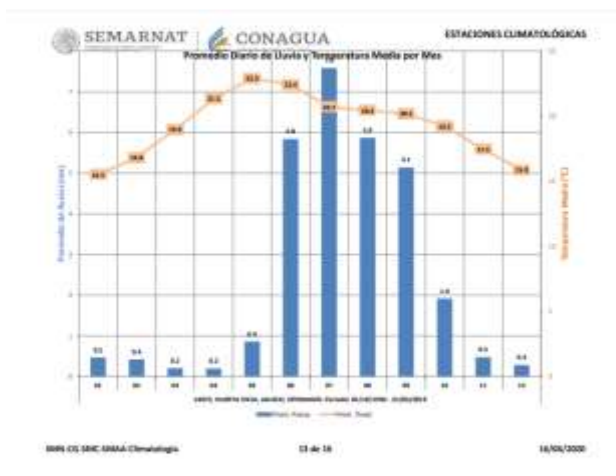
Anexes



Graphic 2 Daily rainfall and mean temperature by month, La Huerta Station
Source: CONAGUA

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