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PWC modeling due to the presence of organochlorine pesticides in Ampampilco and Apatlaco canals, Xochimilco

Modelación mediante PWC debido a la presencia de plaguicidas organoclorados en los canales de Ampampilco y Apatlaco, Xochimilco

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Abstract

Even though the use and application of most organochlorine pesticides have been prohibited in Mexico, they continue to be used in several cultivation areas, such as the Chinampera area of Xochimilco, specifically in the Apatlaco and Ampampilco canals. Consequently, this study reports the data collected from these canals and compares it to PWC modeling and international standards. The program estimates the concentrations that should be found in these canals if the pesticides were applied according to recommendations. The aim of this paper is to explain the situation in the study area by comparing the calculated theoretical concentrations of each organochlorine pesticide, as derived from the Pesticide in Water Calculator (PWC), with those detected in water and surface soil, considering international regulations. Results indicate that the concentrations of aldrin and dieldrin exceed CCME limits, but not EPA limits. For the EC, dieldrin is within acceptable limits, while aldrin exceeds them. Therefore, careful control and monitoring of these pesticides is essential. Endosulfan exceeds all three international standards (CCME, EPA, and EC), as it presents high levels in the calculations made with PWC.
Keywords: Water, canals, organochlorines, pesticides, PWC, Xochimilco.

Resumen

A pesar de que el uso y aplicación de la mayoría de los plaguicidas organoclorados ha sido prohibido en México, estos aún se utilizan en varias zonas de cultivo, como en la zona de Chinampera de Xochimilco, específicamente en los canales de Apatlaco y Ampampilco. En consecuencia, este estudio reporta los datos encontrados en estos canales donde se realizó una comparación respecto al modelado de PWC y estándares internacionales. El programa antes mencionado estima las concentraciones que se deberían encontrar en estos canales si los plaguicidas se aplicaran según las recomendaciones. El objetivo de este artículo es explicar lo que sucede en el área de estudio, comparando las concentraciones teóricas calculadas de cada uno de los plaguicidas organoclorados al utilizar el programa de cómputo Pesticide in Water Calculator (PWC), con las detectadas en agua y suelo superficial, teniendo en cuenta lo establecido por la normativa internacional. Los resultados muestran que las concentraciones de aldrín y dieldrín exceden los límites del CCME, no así para la EPA, y para la CE el dieldrín está en límites aceptables, el aldrín excede estos límites. Por tanto, es necesario tener un cuidadoso control y seguimiento sobre el uso de estos plaguicidas. El endosulfán supera en las tres normas internacionales (CCME, EPA y CE), ya que presenta niveles altos en los cálculos realizados con PWC.
Descriptores: Agua, canales, organoclorados, plaguicidas, PWC, Xochimilco.

Introduction

The use of pesticides is the most common practice for eliminating or controlling pests and unwanted species that cause damage to agricultural and forest production. Commonly used pesticides include herbicides, insecticides, fungicides, nematicides, and rodenticides (FAO, 1997; Ortiz *et al.,* 2017; Hernández & Hansen, 2011).

At the Stockholm Convention in 2001, regulations were established for 12 substances considered persistent organic pollutants (POPs), including nine pesticides, some of which are organochlorines. Following this initial agreement, 10 additional substances were added in 2009, five of which were pesticides. Notable organochlorine pesticides included in this agreement are aldrin, dieldrin, chlordane, chlordecone, heptachlor, hexachlorobenzene, endrin, lindane, and endosulfan.

The Xochimilco canals are among the few remaining aquatic environments from what was once an impressive lake ecosystem in the pre-Hispanic era, specifically the great basin of the Mexico City Valley. Despite the significant ecological loss of the watershed, the cultural significance and economic importance of the area remain intact. The canals continue to be a vital agricultural resource for the population and serve as recreational areas, much like urban water bodies in cities worldwide (López *et al.,* 2015). This paper evaluates the condition of the Xochimilco canals concerning the persistent substances that have been applied over time and continue to affect the environment, water, soil, and sediment.

Due to the absence of standards or guidelines in Mexico regarding permissible levels of organochlorine pesticides in recreational waters, this document refers to international guidelines that establish maximum permissible limits for such pesticides, including aldrin, dieldrin, and endosulfan. Table 1 reports these values in accordance with the Canadian Council of Ministers of the Environment (CCME), the United States Environmental Protection Agency (US EPA), and the European Community (CE).

Taking into consideration the parameters established by international regulations, a comparison was made using the Pesticide in Water Calculator (PWC), which estimates pesticide concentrations in surface and groundwater bodies resulting from their application to soil. The PWC is designed as a regulatory tool by the EPA's Office of Pesticide Programs and Canada Health's Pest Control Regulatory Agency. It is based on two models: the Pesticide Root Zone Model (PRZM) and the Variable Volume Water Model (VVWM) (US EPA, 2016c).

The PRZM model simulates the transport and transformation of pesticides in the unsaturated zone on a daily, one-dimensional scale. It takes into account key chemical processes that occur during pesticide infiltration as water moves through soil (Pérez *et al.,* 2018a).

On the other hand, the VVWM employs computational models to estimate pesticide exposure in surface water resulting from applications in agricultural fields. These models simulate pesticide application, its movement, and destination in surface water, and they ultimately calculate environmental concentrations (EEC) that are both protective and scientifically defensible (US EPA, 2016b).

The aim of this paper is to evaluate the condition of the study area by comparing the theoretical concentrations of various organochlorine pesticides, as calculated by the Pesticide in Water Calculator (PWC), with those detected in water and surface soil, while taking into account international regulations.

Method and study site

Study site: Xochimilco, Ampampilco and Apatlaco-canals

The Xochimilco canals are part of the Panuco region and belong to the Moctezuma River hydrological basin and the Lake Texcoco-Zumpango sub-basin (INEGI, 2005). They consist of an estimated length of approximately 203 km of interconnected canals, with some of the most significant being Cuemanco, Nacional, Chalco, Del Bordo, Apatlaco, San Sebastián, Ampampilco, Texhuilo, Zacapa, Caltongo, Santa Cruz, and Japón (RAMSAR, 2004).

Chinampas have persisted due to their ecological and cultural importance. Since 1971, they, along with the Xochimilco wetland, have received national and international recognitions and designations aimed at pro-

Table 1. Maximum permissible concentrations in international regulations

Pesticides	CCME[1](μg/L)	EPA[2](μg/L)	EU[3] (mg/L)
Aldrin	0.004	3	0.01
Dieldrin	0.004	0.24	0.01
Endosulfan	0.02	0.22	0.005

From:1 CCME (2008); 2 EPA (1985); 3 EU (2013) moting their conservation and highlighting their significance, not only for the inhabitants of Mexico but globally (Pérez *et al.,* 2018b). The Chinampera area of Xochimilco falls within the protected areas of the Ejidos of Xochimilco and San Gregorio Atlapulco, designated by UNESCO, where significant agricultural activities occur (Guevara *et al.,* 2015). Currently, efforts are underway to rehabilitate the Chinampera network and restore the habitat of native Xochimilco species (Zambrano *et al.,* 2014).

Some of the most representative species in the region include the axolotl (Ambystoma mexicanum), Moctezuma frog (Rana montezumae), marsh or casquito turtles (Kinosternon hirtipes), and "charal" fish (Chirostoma jordani) (Gil, 2015; Centro Ecoturístico Olintlalli, 2018).

Currently, there are 20,000 Chinampas in Mexico City, covering an area of 30,348 hectares. Of these, 2,441 are designated for agriculture, producing approximately 19,000 tons of food. The most significant crops include romerito (4,680 tons), broccoli (4,674 tons), lettuce (4,187 tons), and verdolaga (1,776 tons). Other vegetables produced in the region include spinach, squash, green beans, celery, chard, and coriander (SAGARPA, 2018).

According to Bojórquez (2017), sampling and monitoring for pesticide detection in the Xochimilco canals began in 1988. Hernández (2005) reported the presence of organochlorine pesticides such as endrin, endosulfan, dieldrin, DDE, and aldrin in the Chinampera area, using gas chromatography and solid-phase microextraction. Borja (2017) identified areas where the use and application of pesticides in cultivation zones have been documented. Based on this information and Hernández's findings (2005), sampling was conducted in the Apatlaco and Ampampilco canals.

Samples compilation

Sampling was carried out during rainy season, while inputs and outputs, as well as the homogenization zones of the water body, were considered. The recommendations of the NMX-AA-014-1980 for collecting water samples were followed for this activity. Soil samples were obtained in corn cultivation areas taking into consideration the NOM-021-RECNAT-2000. Figure 1 shows the sampling network for the area detected by previous studies, using agrochemicals. The location of each sampling point is reported in Tables 2 and 3 for water and soil samples respectively.

Table 2. Sampling points for water and soil

Canal/Area	Point	Geographic location	
		Latitude	Longitude
Ampampilco	AMP1	19°16′19.55″	–99°5′23.48″
Ampampilco	AMP2	19°16′21.59″	–99°5′16.29″
Ampampilco	AMP3	19°16′9.45″	–99°5′18.53″
Ampampilco	AMP4	19°15′58.95″	–99°5′21.67″
Ampampilco	APA2	19°16′23.7″	–99°5′33.6″
Apatlaco	APA1	19°15′52.30″	–99°5′25.54″
Ampampilco	MS1	19°16′8.83″	–99° 5′16.69″
Ampampilco	MS2	19°16′6.00″	–99° 5′18.70″
Ampampilco	MS3	19°16′13.68″	–99° 5′18.16″
Ampampilco	MS4	19°16′17.90″	–99° 5′23.50″

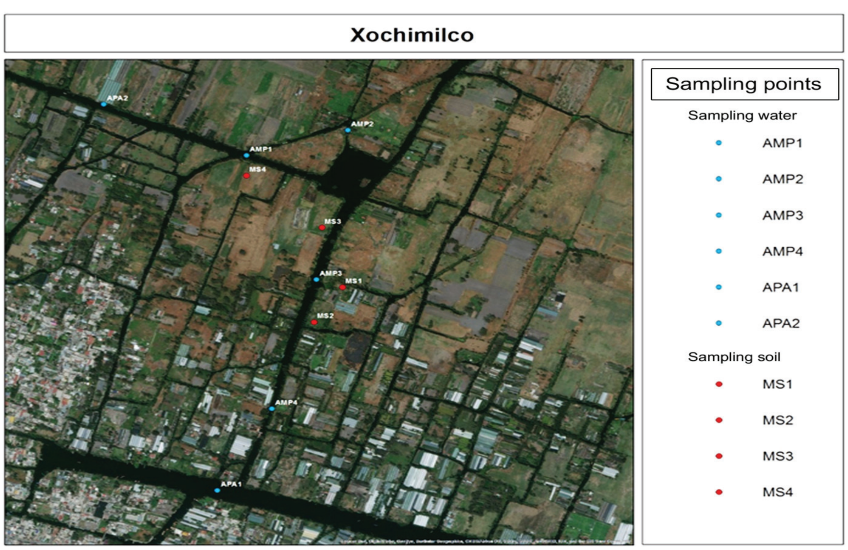

Figure 1. Water and soil sampling points

Table 3. Organochlorine pesticide detected in water samples

Pesticide	Water samples (µg/L)		
	APA 2	AMP2	APA1
Aldrin	N.D.	N.D.	9.54
Dieldrin	N.D.	48.42	N.D.
Endosulfan I	N.D.	N.D.	29.91
Endosulfan II	55.02	N.D.	63.97

For the selection of water sampling points, corn growing areas were considered. Samples were taken 20 cm below the surface and collected in duplicate at each point by placing them in one-liter polypropylene containers and then stored, in black bags, to avoid photolysis degradation. Once identified, they were kept in refrigeration and moved to the laboratory for its analysis. As for soil sampling points, composite samples were taken from corn growing areas at a depth of 20 cm, then a quartering was performed to better homogenize the sample, placed in plastic bags of 2 kg. They were labeled with their respective coordinates and were also kept at low temperature. Both water and soil samples were kept refrigerated and protected from light until analysis and detection of organochlorine pesticides.

The determination of organochlorine pesticides in water and soil samples was performed using the EPA 8081B method “Organochlorine pesticides by gas chromatography”. Finally, a Shimadzu GC-2014 electron capture detector was used for detection. The values obtained are reported in Tables 4 and 5.

Table 4. Organochlorine pesticide detected in soil samples

Pesticide	Soil samples (µg/kg)	
	MS1	MS4
Aldrin	1.43	N.D.
Dieldrin	3.72	N.D.
Endosulfan II	N.D.	3.19

Table 5. Physico-chemical properties of endosulfan, metabolite, aldrin and dieldrin

Property	Endosulfan	Endosulfan sulfate	Aldrin	Dieldrin
K_{oc} (mL/g)	11500	5190	4.7x106	4.7x105
Molecular weight (g/mol)	406.93	422.95	364.91	380.91
Steam pressure 20° C (torr)	6.23	$1x10^{-11}$	7.5x10-5	3.1x10-11
Solubility (mg/L)	0.53 (at 25 °C)	0.117 (at 25 °C)	0.011 (at 20 °C)	0.11 (at 20 °C)
Heat of vaporisation (J/mol)	37,000	86,390	65,800	69,270
Density20 °C (mg/mL)	1.745	1.94	1.6	1.75
Molar volume (g/ cm^3)	233.2	218	228.1	217.7
Diffusion coefficient (cm^2/day)	4.78	5.4	5	5.5
Half-life degradation in water (day)	23-25 (at 20 °C)	-	710 (at 25 °C)	710 (at 25 °C)
Half-life degradation in soil (day)	50 (at 20 °C)	123-391 (at 20 °C)	710 (at 25 °C)	710 (at 25 °C)
Half-life of foliar degradation (day)	3.7	4	1.7	6.8
Half-life in benthic zone (day)	120 (at 20 °C)	-	2300 (at 25 °C)	2300 (at 25 °C)
Hydrolysis in water to pH 7 (day)	11 to 19	184	760	-

Source: (Betancur 2015; Guevara, 2015; University of Hertfordshire, 2019; Céondo, 2019 and ATSDR, 2015; ATSDR, 2002; O´Sullivan & Megson, 2014)

Pesticide modeling

Pesticide modeling using Pesticide in Water Calculator (PWC)

After confirming that organochlorine pesticides such as aldrin and endosulfan are applied to corn fields in the Xochimilco canals area of Ampampilco and Apatlaco, PWC modeling was performed to verify that the concentrations detected in water match the theoretical concentrations that the PWC can obtain, placing as a restriction if they are being applied only in corn cultivation fields and in a single season.

This software includes several tabs, such as pesticide properties, pesticide application, crop type, study site characteristics and meteorology, runoff parameters according to site characteristics and water body characteristics, all these windows are intended to perform pesticide simulation at the study site.

Pesticides

Initially some pesticide properties are needed such as K_{oc} o K_d, molecular weight, steam pressure, solubility, vaporization energy and Henry's constant; in addition to these properties, it is necessary to place degradation times in various environmental counterfoils as water, soil, air, sediment, as well as the half-life time per foliar action. This is done for the pesticide and its metabolites if the information is available, as many times the substances that are generated are more toxic than the main agent. These values are set out in Tables 6 and 7.

In addition, the air diffusion coefficient was calculated for each pesticide and its metabolite, which was determined from the following equation:

$$D_{air} = \frac{0.001T^{1.75}M_r^{\frac{1}{2}}}{P\left(V_A^{\frac{1}{3}} + V_B^{\frac{1}{3}}\right)^2} \times \frac{3600\,seconds}{1\,hour} \times \frac{24\,hour}{1\,day} \quad (1)$$

$$M_r = \frac{(M_A + M_B)}{M_A M_B} \quad (2)$$

Where:

D_{air} = air diffusion coefficient [cm^2/day]

Table 6. Soil profiles in chinampas

Horizon	Depth (cm)	Classification	Max. Cap.	Min. Cap.	% sand	% clay	OC (%)	Density [g cm^{-3}]
A1	0-10	Loam	0.320	0.175	30.4	25.4	8.1	0.29
A1	11-50	Clay Loam Soil	0.380	0.210	22.8	37.4	5.9	0.69
A2	50-110	Sandy Clay Loam	0.375	0.220	24.8	35.4	7.4	0.51
A3	110-120	Silty Clay Loam	0.360	0.215	26.8	35.4	14.4	0.43

Source: (Ramos *et al*., 2001; USEPA, 2005; Ramos *et al.*, 2011; Ikkonen *et al.*, 2012 and Guevara *et al.*, 2015).

Table 7. Dates with significant runoff

Date (mm/dd/yy)	Runoff (cm)	Date (mm/dd/yy)	Runoff (cm)
06/28/2012	2.42077865	06/14/2011	12.6708848
06/06/2011	1.96253548	06/15/2011	10.3821684
06/07/2011	9.72029697	06/16/2011	15.5246978
06/08/2011	6.73517338	08/23/2011	34.5565551
06/09/2011	27.7116044	08/25/2011	12.6984125
06/10/2011	19.90449	08/26/2011	14.1282913
06/11/2011	13.0384032	10/06/2011	19.3909075
06/12/2011	11.4114119	10/07/2011	14.0170873
06/13/2011	13.0476043	-	-

T = temperature 298 K
M_A = molecular air weight approximately 29 g/mol
M_B = pesticide molecular weight [g/mol]
P = pressure [atm]
V_A = approximate molar air volume 20.1 cm^3/mol
V_B = pesticide molar volume [cm^3/mol]

Pesticide application

Subsequently, information on the pesticide application in the growing area was added, for which the following was considered:

- Supplied amount of pesticide to the crop 1.7 (kg/ha) for endosulfan and 3.4 kg for aldrin, as mentioned in the Rotterdam Convention, 2011 and ATSDR, 2002 respectively.
- According to the research with the people of the site, the corn sowing season is between April and October; therefore, the estimated date of the pesticide application is proposed to be in the month of May, so the approximate days after the sampling date (23/09/2018) are 180.
- In addition, the surface type application was considered and according to US EPA type application, 2016 is mentioned to be 0.99, while the load fraction (drift/T) is 0.064 for drinking water and of 0.01 for ecological risk.
- It was also noted that the application is carried out every year during the 10 years considered in the weather archive.

Cultivation/Soil type

The meteorological file is added in this section, and it consists of information of the last years collected from the study area or, as in this case, what is closer to it. For this reason, the data from the monitoring station located in the "Escuela Nacional Preparatoria N° 1 "Gabino Barreda" of the Universidad Nacional Autónoma de México, in Av. de la Noria and Calle Prolongación de Aldama s/n Xochimilco, Santa María Tepepan, was used, which belongs to the Red Universitaria de Observatorios Atmosféricos (México). To complete the file, rainfall data (cm/day), temperature (°C), wind speed (cm/s), solar radiation (langley or cal/cm2) were obtained, and the evaporation factor was also calculated from the Meyer equation (1944):

$$E = C(e_a - e)\left(1 + \frac{V}{16}\right) \quad (3)$$

Where:

E = evaporation factor [mm/day]
C = 0.5 this factor depends on the water mass
e_a = water steam pressure [mm Hg]
e = air steam pressure [mm Hg]
Vis = wind speed [cm/h]

To calculate air steam pressure, temperature variation was recorded daily, considering the relative humidity, which was obtained hourly from the same weather station. The water temperature was kept constant at 15°C.

The information was gathered and settled for 10 years, from January 2009 to October 2018, the file was arranged according to the program requirements, which is a format style fortran: 1X, 3I2, 5F10.0 and was arranged in the following order: MM, MD, MY, PRECIP, PEVP, TEMP, WIND SOLRAD.

Where:

MM = meteorological month
MD = meteorological day
MY = meteorological year
PRECIP = precipitation [cm/day]
PEVP = evaporation factor [cm/day]
TEMP = temperature [°C]
WIND = wind [cm/s]
SOLRAD = solar radiation [Langley]

This section also includes crop growth factors such as emergence, maturity, and harvesting days, as well as root depth, crop coverage, height, and water retention, based on data from the growing season. Field data established that corn crops are planted annually on April 15th, and, according to Nafziger (2009), DuPont (2015), and Ciampitti *et al.* (2016), the maturation period is approximately four months. Therefore, the crop reaches maturity around August 15th each year, with harvest taking place the following month, as also indicated by DuPont (2015).

Additional parameters include root depth (60 cm), crop coverage (350 %), height (300 cm), and water retention (0.15 cm), as referenced from the previously mentioned authors and Via rural Agro y Construcción (2019).

Other hydrological factors considered in the model include the evaporation factor, snowmelt factor, and minimum evaporation depth, as recommended by the US EPA (2016a) manual.

Irrigation data is also taken into account, including potential excess irrigation, the allowed loss in available water, the maximum rate of water supplied, and the piezometric depth level. Finally, the soil profiles at the study site are incorporated, as reported in Table 8.

Another important parameter that this section considers is the lower limit temperature and the albedo of the surface which the manual recommends being 0.2.

Table 8. Information of body of water

Parameter	Value
Photolysis	1.19
Suspended solids concentration (mg/L)	18.6
Chlorophyll concentration (mg/L)	0.8
Organic Carbon Fraction (foc)	0.6
Dissolved Organic Carbon (mg/L)	10
Biosmass concentration (mg7L)	15.65

Runoff

In the next PWC section, the runoff calculation was made in the study site, identifying the days that contributed with a visible effect, for this, the flow calculation was performed from precipitation.

$$Q=\begin{cases} 0, & P\le 0.2S \\ \dfrac{(P-0.2S)^2}{P+0.8S}, & P>0.2S \end{cases} \tag{4}$$

Where:

Q = runoff (cm)
P = precipitation (cm)
S = maximum potential retention (cm)

To get the maximum potential the calculation was made from the curve number:

$$S\frac{2540}{CN}-25.4 \tag{5}$$

Where CN is the curve number, for the case study site is of 78 according to (Gaspari *et al*., 2007).

This identified the days that followed with the greatest run-off during the simulated years which are reported in Table 9 and can be seen in Figure 2.

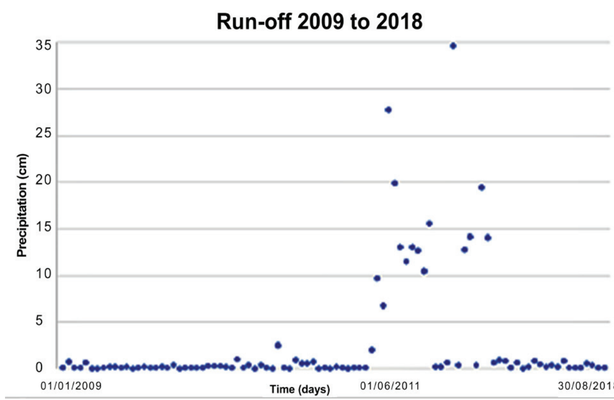

Figure 2. Run-off dates from 2009 to 2018

In addition, values for USLE C, USLE K, USLE LS, USLE P and IREG were determined, being 0.59, 0.21, 0.1, 0.6 and 1, respectively and according to US EPA (2005) recommendations, where:

- USLE–C:Specify the universal soil loss cover management factor.
- USLE K: Specify the universal soil loss equation of soil erodibility.
- USLE LS: Specify the universal soil loss equation topographic factor.
- USLE P: Specify the universal soil loss equation practice factor.
- IREG: Specify location of NRCS 24-hour hyetograph.

Water body

In order to characterize the basin, it was necessary to define the type of surface for the simulation. It was determined that the canals have a constant volume, and

Table 9. Comparison of detected pesticides and PWC

Sample	Detected pesticide	Quantity detected (µg/L)	Calculated value (µg/L)
APA2	Endosulfan II	55.02	8.79
AMP2	Dieldrin	48.42	0.0047
	Aldrin	9.54	0.036
APA1	Endosulfan I	29.91	8.79
	Endosulfan II	63.97	8.79

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although there is a small flow, it was considered negligible, as this is a lentic system. Additionally, the pesticide runoff rate (0.5) entering the water body due to erosion was defined and distributed between the water column and the benthic layer, as recommended by US EPA (2005).

The dimensions of the water body and basin were also determined. The cultivation area covers 400 m², based on observations made during exploration visits and the sampling day. The surface area of the water body is 2,400 m², considering the canals as an isolated body, with a depth ranging from 1 m to 1.3 m and a hydraulic length of 100 m, in relation to the canal's downstream connection. The volume of the site remains constant, with a maximum increase of 10 cm during the rainy season, as confirmed by local residents.

These values were also added to the benthic zone section and some others were obtained as recommended by the manual (US EPA, 2005).

Results

Figure 3 shows data from the PWC calculations, indicating that the concentration of endosulfan in the water column is 8.79 μg/L, while no concentration is reported in the benthic zone. This calculation was made for the period from January 2009 to October 2018, where Year 1 corresponds to 2009.

Figure 4 presents the PWC concentration report for aldrin. The concentration in the water column is 0.036 μg/L, with the application considered only until 2012, as SEMARNAT (2014) indicated it was the last year it should be applied. Afterward, no pesticide influence is observed in the water body for the subsequent years. Like endosulfan, the simulated years for aldrin were from 2009 to 2018.

Finally, Figure 5 shows the concentration of dieldrin, which follows the same application timeline as aldrin, up to 2012. However, in this case, the concentra-

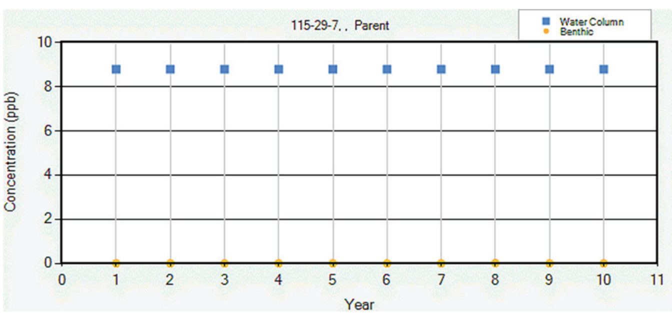

Figure 3. Concentration of endosulfan in PWC

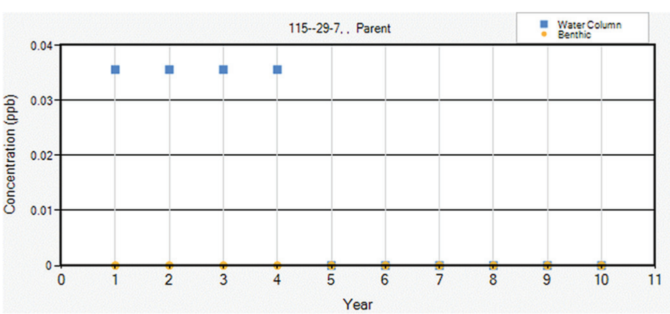

Figure 4. Concentration of aldrin in PWC

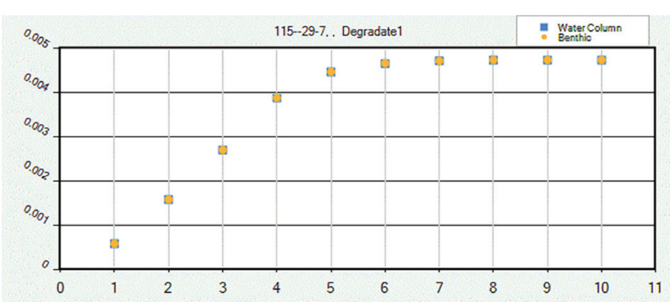

Figure 5. Concentration of dieldrin in PWC

tion of dieldrin, 0.0047 μg/L, persists and does not degrade over time.

The average values obtained during the simulations were 8.79 μg/L for endosulfan, 0.036 μg/L for aldrin, and 0.0047 μg/L for dieldrin. Although aldrin and dieldrin are no longer used due to CICOPLAFEST restrictions, and they were reportedly no longer applied nationwide after 2012 (Bojorquez, 2017), traces are still detected.

In the Ampampilco canal area, where endosulfan (APA2) was identified, a nearby soil sample (MS4) revealed a concentration of 55.02 μg/L. This may be due to pesticide use in multiple cultivation areas and/or application amounts exceeding allowed standards.

For aldrin and dieldrin near the soil sample (MS1), these compounds were found, though they were not detected in the water body. This could be because the amounts used in the growing area were very low and remained in the soil. Conversely, dieldrin (AMP2) was detected in the water body at a concentration of 48.42 μg/L, though no soil sample was taken at this location. Similarly, for the sampling point where aldrin (9.54 μg/L), endosulfan I (29.91 μg/L), and endosulfan II (63.97 μg/L) were detected (APA1), no soil sample was collected. All detected values in the water body are higher than those calculated with the PWC.

Conclusions

1. For the pesticides aldrin and dieldrin, although their use by various organisms in Mexico has been banned, dieldrin continues to persist in the water bodies. This suggests that it is still being applied, creating a serious problem for aquatic biota as well as for people who come into contact with the water at the site.
2. The concentrations calculated for aldrin and dieldrin exceed the limits set by the CCME, but for the EPA, both are below the standard. For the CE, it can be observed that dieldrin is within acceptable limits, while aldrin exceeds them. Therefore, we need to monitor and control the usage of these pesticides.
3. As for endosulfan, it can be said that it is also persistent. Although its application rate is lower (1.7 kg/ha) compared to aldrin (3.4 kg/ha), its concentration in the water column is higher. This might be because the pesticide is still being used in cultivation areas.
4. The concentrations calculated for endosulfan exceed all three international standards (CCME, EPA, and CE). Therefore, the application of this pesticide should be avoided, as it shows higher levels in both the PWC calculations and field detections. This will undoubtedly affect the population in contact with the site's water and potentially harm the aquatic biota.
5. The reason the values obtained from the PWC pesticide calculations are lower than those observed in the field may be due to the presence of several surrounding cultivation areas where these pesticides were and are still being applied. Additionally, the calculations only estimate pesticide use during the corn cultivation period and do not account for their use during other seasons or in different types of crops.

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References

ATSDR. (2002). Toxicological profile for aldrin/dieldrin. Atlanta: U.S. Department of health and human services.

ATSDR. (2015). Toxicological profile for endosulfan. Atlanta: ATSDR.

Betancur, L., Ocampo, R., & Ríos, A. (2015). La problemática del endosulfán: Aspectos químicos, analíticos y ambientales. *Luna Azul,* 40, 293-313. https://doi.org/10.17151/10.17151/luaz.2015.40.19

Bojórquez, L. (2017). C*ontaminación química y biológica en la zona lacustre de Xochimilco*. Ciudad de México, UAM.

Borja, A. (2017). *Influencia de la materia orgánica en la extracción en fase sólida de la atrazina y dos de sus metabolitos de degradación en muestras acuosas: Caso de estudio canales de Xochimilco.* (Tesis de maestría). Ciudad de México, UNAM.

Centro Ecoturístico Olintlalli. (2018). OLINTLALLI. Retrieved November 28 on https://www.olintlalli.com.mx/

Céondo GmbH. (2019). Cheméo. Retrieved March 27 on https://www.chemeo.com/cid/39-717-3/Endosulfan%20sulfate

Ciampitti, I., Elmore, R., & Lauer, J. (2016). Crecimiento y desarrollo del maíz. E U. En: How a Corn Plant Develops, Special Report No. 48, 1986 and Corn Growth and Development, PMR 1009, 2011. Iowa State University Extension.

DuPont. (2015). *Maíz. Crecimiento y desarrollo*. EU.

FAO. (1997). Depósito de documentos de la FAO. Retrieved April 2017 on http://www.fao.org/docrep/W2598S/w2598s06.htm

Gaspari, F., Senisterra, G., & Marlats, R. (2007). Relación precipitación-escorrentía y número de curva bajo diferentes condiciones de uso de suelo. Cuenca modal del sistema serrano de la Venta, Argentina. *Revista de la Facultad de Ciencias Agrarias*, XXXIX(1). 21-28.

Gil, K. M. (2015). *Identificación y cartografía del peligro por fenómenos de remoción en masa que afectan los poblados de la delegación Xochimilco*. (Tesis de ingeniería). Ciudad de México, UNAM.

Guevara, B., Ortega, H., Ríos, R., Solano, E., & Vanegas, J. (2015). Morfología y geoquímica de los suelos de Xochimilco. *Terra*

Latinoamericana, 33(4), 263-273. Retrieved on https://www.terralatinoamericana.org.mx/index.php/terra/article/view/65

Hernández, A., & Hansen, A. (2011). Uso de plaguicidas en dos zonas agrícolas de México y evaluación de la contaminación de agua y sedimentos. *Revista Internacional de Contaminación Ambiental*, 27(2), 115-127.

Hernández, I. (2005). *Pesticidas organoclorados en el agua de los canales de Xochimilco*. (Tesis de licenciatura). Ciudad de México, Facultad de Química, UNAM.

Ikkonen, E., García, N., Stephan, E., Fuentes, E., Ibáñez, A., Martínez, A., & Krasilnikov, P. (2012). CO2 production in the anthropogenic Chinampas soils in Mexico City. *Spanish Journal of Soil Science*, 2(1), 62-73. http://dx.doi.org/10.3232/SJSS.2012.V2.N2.04

Instituto Nacional de Estadística, Geografía e Informática (INEGI). (2005). Prontuario de información geográfica delegacional de los Estados Unidos Mexicanos, Xochimilco.

López, Z., Tavera, R., & Novelo, E. (2015). El fitoplancton de un canal de Xochimilco y la importancia de estudiar ecosistemas acuáticos urbanos. TIP. *Revista especializada en ciencias químico-biológicas*, 18(1), 13-28. Retrieved on http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1405-888X2015000100002&lng=es&tlng=es

Nafziger, E. (2009). Nitrogen management for corn. En college of agricultural, consumer & environmental sciences. Illinios Agronomy Handbook, 13-26. University of Illinois at Urbana-Champaign.

O´Sullivan, G., & Megson, D. (2017). Brief overview: discovery, regultaion, properties, and fate of POPs. Capítulo 1. En Environmental forensics for persistent organic pollutants (1-20). Elsevier. Retrieved on https://doi.org/10.1016/B978-0-444-59424-2.00001-3

Ortiz, I., Avila, M., & Torres, L. (2017). Plaguicidas en México: Usos, riesgos y marco regulatorio. *Revista Latinoamericana de Biotecnología Ambiental y Algal*, 4(1), 26-46. Retrieved on https://www.solabiaa.org/ojs3/index.php/RELBAA/article/view/42>

Pérez, P., Charli, L., Valiente, E., & Mazari, M. (2018). Oikos. Retrieved April 23 on http://web.ecologia.unam.mx/oikos3.0/index.php/articulos/xochimilco?tmpl=component&print=1&page=

Pérez, R., Rodrigo, J., & Cassiraga, E. (2018). Análisis del comportamiento de pesticidas en el suelo y aguas subterráneas. En Simposio Becarios CONACYT en Europa, Estrasburgo, Francia.

Ramos, R., Lenom, J., Flores, R., García, D., & E., N. (2001). Metales pesados, sales y sodio en suelos de Chinampa en México. *Agrociencia*, 35(4), 385-395. Retrieved on https://www.redalyc.org/articulo.oa?id=30235402

RAMSAR. (2004). Ficha informativa de los humedales de Ramsar (FIR). Convención relativa a los humedales de importancia internacional especialmente como habitat de aves acuáticas.

SAGARPA. (2018). Retrieved July 24 on https://www.gob.mx/sagarpa/articulos/plantas-y-alimentos-que-se-producen-en-las-chinampas?idiom=es

University of Hertfordshire. (2019). PPDB: Pesticide Propierties DataBase. Retrieved March 11 on http://sitem.herts.ac.uk/aeru/footprint/es/atoz.htm

US EPA. (2016a). Pesticide in water calculator user manual for versions 1.50 and 1.52. Washington, EU.

US EPA. (2005). PRZM-3 A model for predicting pesticide and nitrogen fate in the crop root and unsaturated soil zones: User manual for realese 3.12.2. Washington, DC.

US EPA. (2016b). PRMZ5 A model for predicting pesticides in runoff, erosion, and leachate. Washington DC.

US EPA. (2016c). The variable volume water model. Washington, EU.

Via rural agro y construcción. (2019). Agua y riego. Densidades de cosecha. Retrieved March 13 on https://www.viarural.com.ar/viarural.com.ar/insumosagropecuarios/agricolas/semillashibridas/cargill/manualmaiz/manualmaizcargill44.htm

Zambrano, L., Tovar, A., Sumano, C., Ayala, C., Rubio, M., & Trejo, M. (2014). *Rehabilitación de la red chinampera y del hábitat de especies nativas de Xochimilco*. Ciudad de México. Instituto de Biología, UNAM.

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