Water quality monitoring in the Xochimilco peri-urban wetland: experiences engaging in citizen science

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Abstract: Citizen science schemes for environmental monitoring generate benefits for scientists by increasing the capacity of scientists to gather information. Citizen scientist monitoring also benefits the citizens involved because they acquire a deeper knowledge and understanding of the benefits of ecosystems and the ways that anthropogenic activities affect them. This study details the efforts of a local non-government organization (Restauración Ecológica y Desarrollo A. C.), the Earthwatch Institute, and the Hongkong and Shanghai Banking Corporation's Water Program to monitor the water quality in the Xochimilco peri-urban wetland, which is threatened by accelerated urbanization. The Xochimilco wetland includes agricultural areas in which raised beds called chinampas are surrounded by canals and small lakes. These chinampas have been managed for hundreds of years. The water in the canals is mainly used for agricultural irrigation, but it is also the habitat of a variety of aquatic species. In this study, we analyze the water quality of 7 canals and 1 lake located in areas with chinampas that have different uses such as housing, tourism, semi-intensive agriculture, agroecological farming, and abandoned agricultural land. Water samples from these sites were collected by citizen scientists over the course of 4 y. Our aim was to determine how the water quality varies across areas with management differences and between dry and rainy seasons. We found significant differences in pH, temperature, dissolved oxygen, *Escherichia coli*, and conductivity between seasons. We expected to find suitable water quality for irrigation (based on national and international guidelines) in canals near low-impact activities in the chinampas (such as agroecological farming or chinampas without human activities). Instead, we found that the water in those canals exceeded the recommendations for pH values (>9), total coliforms (>240 CFU/ 100 mL), conductivity (>2000 μS/cm), and dissolved oxygen concentrations (<6.5 mg/L). However, nutrient concentrations were low. The structure of the canals near agroecological farming areas are narrow, shallow, and have low water flow, so alterations in the depth and width of these canals might result in improved water quality. The only sampling site that met most of the international and national guidelines for irrigation use was located in an area with many abandoned chinampas. Volunteers that participated in this study gained insights regarding the importance of being aware of anthropogenic impacts on ecosystems like the Xochimilco wetland, a place that is important to preserve because of its agricultural, ecological, and cultural significance.
Key words: citizen science, freshwater, Xochimilco, water quality, management practices, peri-urban wetland

Citizen science is a process that involves citizens in real-world scientific activities at different levels, from 'citizens collecting data' to full-scale 'citizen science' (Conrad and Hilchey 2010). Citizens that work with scientists have the opportunity to observe the relationships between ecological processes and human activities, and thereby gain an awareness of human impacts on natural systems (Bonney et al. 2014). The research community can also benefit from

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citizen science because citizen scientists can collect large amounts of data efficiently over short time periods and broad spatial scales. The participation of citizen scientists can also democratizes the process of knowledge production (Silvertown 2009, Gardiner et al. 2012, Thornhill et al. 2016). Successful citizen science programs are those with a good match between project goals, local priorities, and scientific methods. In the case of water quality monitoring, citizen science programs face challenges like intensive training and quantitative measurements skills (Cunha et al. 2017). In Mexico, citizen science has mostly focused on wildlife observations in natural protected areas and has not been used to monitor water quality at large spatial scales. However, involving citizen scientists in monitoring freshwater ecosystems allows both researchers and citizens to understand how human activities affect water quality, identify local pollution sources and threats, and understand the effects of management intervention on ecosystems (Danielsen et al. 2005).

Citizen scientists collected the data we present in this paper through the FreshWater Watch (FWW) program in Mexico City, which is led by the Earthwatch Institute (https://freshwaterwatch.thewaterhub.org) as part of the Global Water Program of the Hongkong and Shanghai Banking Corporation (HSBC). The aim of FWW is to understand and compare freshwater ecosystem dynamics under different anthropogenic pressures and to support local monitoring efforts (Thornhill et al. 2016). Mexico City participates in FWW along with other 35 countries. Since 2012, the FWW initiative has gathered almost 20,000 water-quality data points across the world (Earthwatch Institute 2017). Training for the FWW project in Mexico was done in the Xochimilco peri-urban wetland. The project was led by the local NGO Restauración Ecológica y Desarrollo A. C. (REDES) and a team of expert researchers in aquatic ecology.

The Xochimilco peri-urban wetland was formerly part of a 150,000 ha lake that was modified during pre-Hispanic times to irrigate artificially-raised beds, called chinampas, which were built inside the lake for cultivation. Chinampas are surrounded by a network of canals and small lakes (Ezcurra et al. 1999, González-Pozo 2010). The Xochimilco wetland and chinampas are ecologically and culturally important, and this wetland is internationally recognized as a Ramsar site, a World Heritage site by UNESCO, and a Globally Important Agricultural Heritage System by the Food and Agriculture Organization (FAO). The Xochimilco wetland has now shrunk to 2659 ha and 200 km of canals (GODF 2006), and it is located in the peri-urban area of Mexico City. Xochimilco faces urban encroachment because of high urbanization rates, population growth, and resource demands. In particular, the land use of the chinampas has changed from traditional agriculture to greenhouses, recreational facilities, and even informal settlements built on filled-in areas of wetland (Merlín-Uribe et al. 2012). Such changes in land use can lead to ecological impacts on aquatic ecosystems, particularly water pollution from tourist litter and agriculture, and the wastewater discharge from the informal settlements lacking drainage systems (FAO 2017). Some local NGOs and academics are now working with local farmers to recover traditional agricultural production to improve the environmental conditions in this wetland through agroecological farming. Agroecological techniques are practices that preserve and optimize natural resources through the use of local ecological knowledge to enhance pest resistance and nutrient conservation (Wezel et al. 2009, TWN and SOCLA 2015).

Xochimilco is located in an area with pronounced seasonal variation in temperature and precipitation (Romero-Lankao 2010). This variation, along with the anthropogenic activities in the wetland, affects the chemical characteristics of water, which in turn can affect food web structure, the proliferation of invasive species, and eutrophication (Zambrano et al. 2010, Nandini et al. 2015). The Xochimilco wetland used to receive water from aquifer-fed springs, but the aquifers are now diverted to fulfill water demands from Mexico City. Thus, the water in the canals is now filled mostly with water from city water treatment plants, which do not remove all of the nutrients and pollutants (Narchi 2013). The Xochimilco peri-urban wetland has persisted for 700 y since the chinampa-canal system was created, and in spite of the impact of urban encroachment and water overexploitation, it remains an important historical testimony to Mexican culture while continuing to provide ecosystem services for the 20 million inhabitants of Mexico City (Aguilar et al. 2013). Consequently, it is imperative that city residents are aware of the issues affecting the wetland and how its health affects their well-being, especially since Mexico City faces severe water supply issues.

The primary goal of this study was to test how water quality changes under different precipitation regimes and land management practices. This question is particularly important in this system because the water from the canals is used for irrigation. We used data collected by citizen scientists to assess water quality based on both physicochemical and microbiological parameters in Xochimilco canals that are adjacent to chinampas and have different land management practices. We also tested whether the season (rainy or dry) in which samples were collected influenced water quality.

METHODS

Citizen scientists collected physicochemical and microbiological data to assess water quality at sites with different land-management practices in the Xochimilco peri-urban wetland. Citizen scientists took samples over a 4-y period during both rainy and dry seasons with the help of professional scientists. The dry season occurs from December to April (2–47 mm monthly average precipitation), and the rainy season occurs from May to November (70–130 mm monthly average precipitation).

We used PERMANOVA and a post-hoc Hotelling T^2 test to relate water quality to land management practices in the surrounding chinampas. We compared the within-site measurements between seasons with the Kruskal–Wallis and Levene tests to understand how season affects water quality.

Sampling site selection

We selected sampling sites based on Zambrano et al. (2009) classification of broad areas of the Xochimilco wetland into 4 land use types: urban, tourism, chinampa, and urban-chinampa (a transition state). Here, we studied the urban and chinampa areas in the core zone of the wetland because they are 2 distinct areas with a diversity of land management practices. We selected 8 sampling sites in 7 canals and in 1 small lake in areas of the wetland with different land management practices. The sampling sites in the canals included Apantle 1, Apantle 2, Ampampilco, Apatlaco, Paso del Águila, Toscano, Sabino, and the small lake Tlilac (Fig. 1).

Volunteer training and data collection

A total of 486 volunteers (all HSBC staff) were trained to monitor water quality on 25 days from May 2013 to June 2016. The local HSBC office selected and coordinated the volunteers, and an average of 20 participants attended each training day. A team of professional scientists from REDES (www.redesmx.org) trained volunteers to collect data, sample water, and take measurements of nutrients, turbidity, coliform bacteria, and other physicochemical parameters at the REDES base camp on a chinampa in the center zone of the wetland. The team of professional scientists accompanied the volunteers during sampling to ensure high-quality data. Additionally, trainers provided information about freshwater issues and threats to water quality and quantity throughout the world and in Mexico. As a feedback exercise after the training session, the citizen scientists reflected on water issues, how meaningful it was for them to become citizen scientists, and how they felt about the opportunity to take more water samples.

Citizen scientists were trained so they could collect their own samples in different water bodies in Mexico City and thereby contribute to the global objectives of the FWW program. Here, however, we use the data collected from only the training sessions, which occurred over both the rainy (December to April) and dry seasons (May to November) over a 38-mo period (2013–2016).

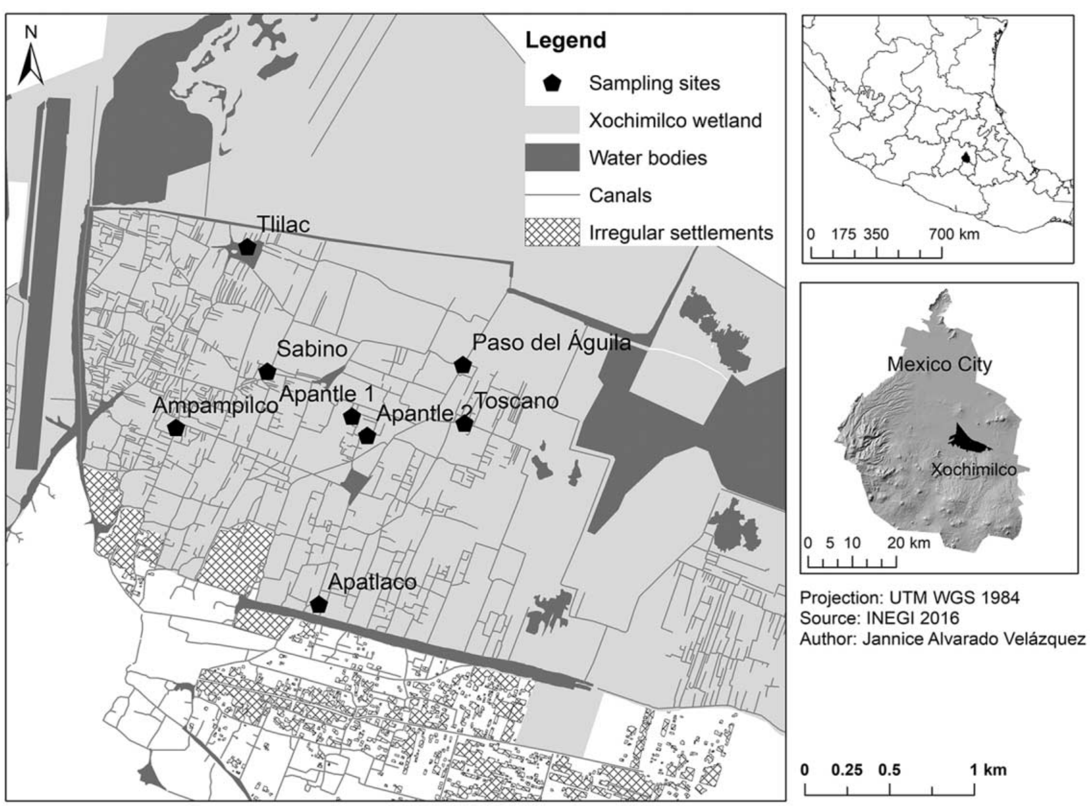

Figure 1. Study area and sampling sites location in the Xochimilco wetland, Mexico City.

Water quality variables

Volunteers used the FWW kit developed by Earthwatch Institute (Loiselle et al. 2016) to measure turbidity and nutrient variables. Turbidity was measured with a calibrated 0.5 m Secchi turbidity tube that had a Secchi disc drawn at the bottom and included a graduated, non-linear scale from 12 to 240 NTU (Nephelometric Turbidity Units). Volunteers used a colorimetric technique to quantify nitrate (NO_3-N) and phosphate (PO_4-P) concentrations in the water. The kit included a plastic cell to take unfiltered samples in situ, reagent tubes (Kyoritsu Chemical-check Lab. Corp.), and a color chart. The N-(1-naphthyl) ethylenediamine reaction measured the quantity of NO_3-N in mg/L in increments of <0.2, 0.2–0.5, 0.5–1, 1–2, 2–5, 5–10, and >10 (Ellis et al. 2011). The enzymatic 4-aminoantipyrine reaction measured the quantity of PO_4-P in mg/L in increments of 0.02, 0.02–0.05, 0.05–1, 0.1–0.2, 0.2–0.5, 0.5–1, and >1 (Berti et al. 1988). Volunteers compared the final reaction color of both nutrients with the color chart from the kit to determine the concentration range in the water sample.

Volunteers also obtained samples to grow fecal coliforms—both *Escherichia coli* and total coliforms. Bacteria were cultivated in 3M™ Petrifilm Plates containing Violet Red Bile (VRB) nutrients, an indicator of glucuronidase activity that facilitates colony enumeration. The samples were incubated in a compact microbiological laboratory incubator (Heratherm 50125590, Model IMC18; Thermo Scientific, Waltham, Massachusetts) at 35 ± 1°C. Total coliforms were counted after a 24-hr incubation period, and *E. coli* colonies were counted after a 48-hr incubation period. After the incubation period, REDES staff identified colonies by color (*E. coli* colonies are a blue color and coliforms are a dark red color) and counted gas-producing colonies following manufacturer instructions. Colonies with an adjacent bubble are lactose fermenting colonies, which indicates viable colonies.

The REDES staff collected additional data on physicochemical variables including temperature (°C), pH, conductivity (μS/cm), and dissolved oxygen (DO; mg/L) with a multi-parametric probe HANNA HI9828 (HANNA Instruments Co., Jackson, Mississippi). The probe was lowered to $^1/_3$ of the water depth in the middle of the canal or lake, continuous measurements were taken for 10 min, and variable means were used in analysis.

There are different optimal water characteristics for water bodies, depending on how their water will be used. In Xochimilco, canal water is mostly used for crop irrigation, boat navigation, and aquatic life. We used a combination of national and international guidelines to assess water quality at each site because none of the guidelines included all the variables assessed in this study. We determined whether water quality in a site was suitable for crop irrigation based on the following criteria: conductivity <2000 μS/cm (Mexican guideline NOM-CCA-032; NORMA Oficial Mexicana 1993), pH between 6.0–9 (USEPA 2012), *E. coli* counts between 25–75 CFU/100mL (USEPA 2012), and total coliforms between 23–240 CFU/100 mL (USEPA 2012). We also consider water quality to be suitable for aquatic life if DO was >6.5 mg/L (USEPA 1986).

Data analysis

The team of professional scientists that accompanied the volunteers during data collection analyzed the data. Measures of central tendency and dispersion were used to describe the water quality variables in each season. We used Kruskal–Wallis and Levene tests to determine whether significant differences in water quality measurements occurred between seasons (precipitation). Subsequently we used a multivariate permutation analysis of the variance (PERMANOVA) and the Hotelling T^2 post-hoc test, with a Bonferroni correction, to determine if there were significant differences in water quality among the sampling sites in both seasons. All the statistical analyses were done with R (version 3.3.0; R Core Development Team, Vienna, Austria).

RESULTS

Volunteers took 177 samples at 8 sampling sites (Table 1) in different water bodies in the Xochimilco peri-urban wetland. In total, they took 128 samples in the rainy season and 49 samples in the dry season.

Water quality varied substantially within and among sampling sites, especially for total coliforms, *E. coli*, and conductivity (Table 2). The median of NO_3-N ranged between 0 and 2.5 mg/L at all sites for both seasons except at Ampampilco for both seasons (Fig. 2A). The median P-PO_4 was 1.2 mg/L, the maximum detectable value, during both seasons except at Toscano (<0.5 mg/L; dry season), Apantle 1 (0.75 mg/L; rainy season), and Apantle 2 (<1 mg/L; rainy season) (Fig. 2B). At all sampling sites, the bacterial counts were highest during the rainy season (Fig. 2C, D). All sites had median pH values >7 in both seasons, and the highest values were >10 at A1 and A2 during the rainy season (Fig. 3A). The temperature medians ranged between 16°C and 20°C during the dry season and between 18°C and 22.5°C during the rainy season (Fig. 3B). Median DO levels generally were higher during the dry season (Fig. 3C). Turbidity was most variable during the rainy season. Apantle 1 and Apantle 2 had the lowest turbidity in the dry season (<25 NTU) and some values of 100 NTU were detected at Apantle 1 and Apatlaco during the rainy season (Fig. 3D). Conductivity values ranged from 500–1000 μS/cm at most sites during most seasons except at A1 and A2, where conductivity medians were >1500 μS/cm during the rainy season (Fig. 3E).

The statistical tests showed that water quality varied among sites and that some variables differed across sea-

Table 1. Sampling site descriptions. Housing = houses in chinampa land with no drainage system, constructions are prohibited in the wetland. Tourism = canals and lakes are used for traditional tourist boats (*trajineras*); some chinampas have small grocery shops and bathrooms for tourists with no drainage system. Semi-intensive agriculture = use of agrochemicals. Abandoned land = without use, covered with grass and shrubs.

Name	Coordinates (lat, long)	Width	Land management practices
Apantle 1 (A1)	19.275, 99.088	Narrow canal (1.5 m)	Agroecological farming
			This canal is also used to harbor the endemic axolotl; it has a mesh to exclude invasive species.
Apantle 2 (A2)	19.275, 99.087	Narrow canal (1.8 m)	Agroecological farming
			This canal is also used to harbor the endemic axolotl; it has a mesh to exclude invasive species.
Tlilac lake (TL)	19.284, 99.093	Small lake (2.2 ha; 118 × 188 m)	Housing + tourism + semi-intensive agriculture
Ampampilco (AM)	19.274552, 99.097201	Very wide canal (45 m)	Housing + tourism + semi-intensive agriculture
Apatlaco (AP)	19.265183, 99.089633	Very wide canal (15 m)	Housing + greenhouses
Paso del Águila (PA)	19.276, 99.083	Very wide canal (19 m)	Abandoned land + cattle grazing
Toscano (TO)	19.275, 99.082	Wide canal (9 m)	Abandoned land + cattle grazing
			Some land in this area is also susceptible to flooding events.
Sabino (SA)	19.278, 99.092	Wide canal (14 m)	Semi-intensive agriculture + cattle grazing

sons. The Kruskal–Wallis test showed that significant ($\alpha \leq 0.05$) differences existed between the rainy and dry seasons for pH ($p = 0.005$), temperature ($p < 0.001$), DO ($p < 0.001$), and *E. coli* ($p = 0.018$) (Table 2). Additionally, the variability in conductivity levels and *E. coli* counts differed significantly between seasons at each site (Levene test, $\alpha \leq 0.05$; Table 2). The PERMANOVA test ($\alpha = 0.01$) showed that significant differences in overall water quality existed between study sites for both seasons, and the Hotelling T^2 post-hoc test (Bonferroni corrected) revealed that the pairs of sites that were not significantly different were: Ampampilco with Apatlaco, Paso del Águila, Sabino, and Toscano; Tlilac and Apatlaco; Toscano with all sites except Apantle 1 and Apantle 2. Apantles 1 and 2 were not significantly different from each other, but each was significantly different from all other sites (Table 3).

Water quality in many of the canals was inadequate for either irrigation or aquatic life based on one or more water quality criteria. Apantles 1 and 2 surpassed the acceptable conductivity levels for irrigation in both seasons, as did SA

Table 2. Descriptive statistics and results of the Kruskal–Wallis and Levene's tests to compare water quality parameters across rainy and dry seasons (2013–2016). Total samples = 177. Rainy: 2013 ($n = 41$), 2014 ($n = 40$), 2015 ($n = 33$), 2016 ($n = 14$); Dry: 2014 ($n = 23$), 2015 ($n = 14$), 2016 ($n = 12$). *E. coli* = *Escherichia coli*. CFU = Colony Forming Unit, NTU = Nephelometric Turbidity Units. * indicates statistically significant value ($p \leq 0.05$).

Parameter	Season	NO_3-N (mg/L)	P-PO_4 (mg/L)	Total coliforms (CFU/100 mL)	*E. coli* (CFU/100 mL)	Turbidity (NTU)	Temperature (°C)	pH	Conductivity (µS/cm)	DO (mg/L)
Min	Rainy	0.1	0.01	0	0	12	16.8	5.7	389	0
	Dry	0.1	0.01	0	0	12	12.4	7.4	116	0.34
Max	Rainy	12	1.2	11,100	3200	100	25	10.4	3000	15
	Dry	12	1.2	6400	3400	75	23.8	9.7	2124	14.5
Median	Rainy	0.75	1.2	1000	200	30	21.1	8.1	814	4.8
	Dry	0.75	1.2	1450	100	30	17.8	8.6	809	7
SD	Rainy	2.69	0.39	2122	680	17	1.9	0.8	584.3	3.5
	Dry	2.53	0.36	1593	589	13	2.2	0.6	301.3	4
Kruskal–Wallis	*p*-value	0.429	0.199	0.101	0.018*	0.222	<0.001*	0.005*	0.656	*0.001
Levene's Test	*p*-value	0.475	0.260	0.646	0.074*	0.253	0.14	0.338	0.002*	0.19

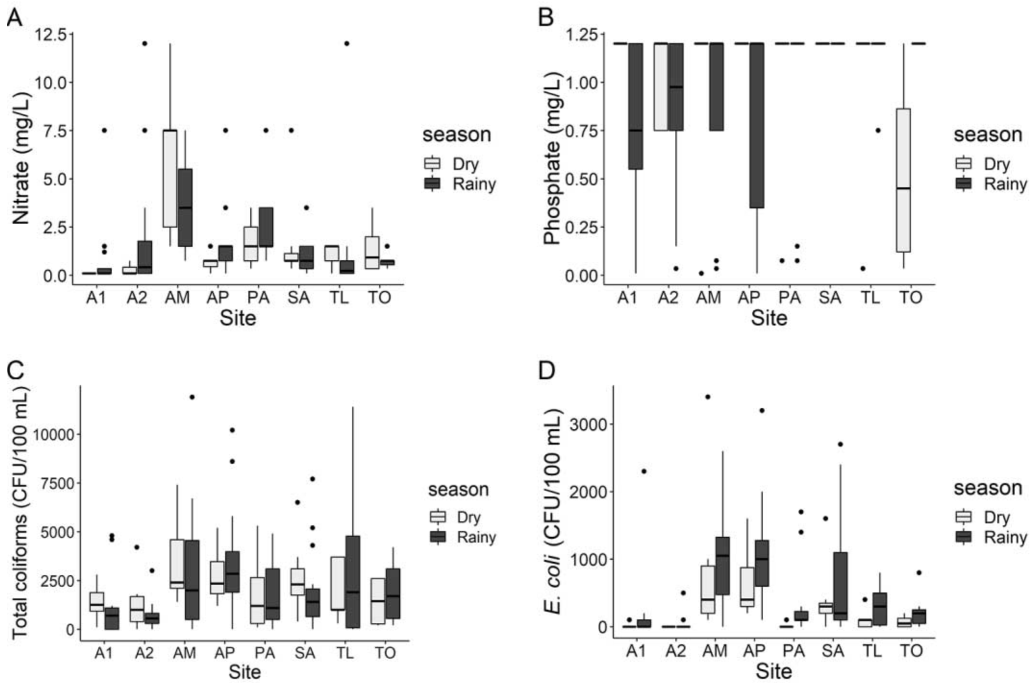

Figure 2. Box-and-whisker plots showing variation in water-quality variables between the rainy and dry seasons across the 8 sampling sites in the Xochimilco peri-urban wetland. The bar in each box shows the median measured value, box ends indicate the 25th and 75th percentiles. Whiskers show 1.5× the inter-quartile range (IQR). Points are outliers. Variation in nitrate concentrations (A), phosphate concentrations (B), total coliform counts (C), and *Escherichia coli* counts (D). See Table 1 for site names and descriptions.

in rainy season (Fig. 3E). A2, AM, AP, and PA had maximum pH values >9, and TL had a median pH >9 (Fig. 3A), indicating that in some parts of the year they were not suitable for irrigation. Median *E. coli* exceeded the optimum value for crop irrigation at AM, AP, SA, TL, and TO during the dry season, and also at all sites during the rainy season except for A1 and A2 (Fig. 3D). Total coliforms were higher than the maximum limit for irrigation at all sites in both seasons (Fig. 3C). Median DO was lower than recommended for aquatic life at A2 in the dry season and at A1, A2, SA, and TO in the rainy season. PA was the only site at which most of the water quality variables were below the maximum limits referenced in the international and national guidelines with the exception of total coliforms in both seasons and *E. coli* in the rainy season. PA is located in the flooded area of Xochimilco that has the most abandoned land, and hence, lowest human activity.

DISCUSSION

Water quality studies can improve understanding of the general threats that adversely affect the Xochimilco peri-urban wetland. We found that seasonality influenced pH, temperature, DO, *E. coli*, and conductivity. For example, conductivity values were clearly higher during the rainy season, suggesting an influence of precipitation on water quality. In general, during the dry season, DO, conductivity, and *E. coli* tended toward those values suggested by the international and national guidelines for irrigation water. However, none of the studied sampling sites met the international and national guidelines of suitable water for irrigation, even the sites located near to agroecological farming chinampas, at which we expected to observe better water quality. The citizen monitoring not only allowed us to document water quality patterns among sites, but also increase awareness among the volunteers about the need to regulate human activities as they have a high impact on ecosystems like wetlands, particularly those in peri-urban areas.

Values of most of the variables differed between the dry and rainy seasons during the nearly 4-y study. The seasonal differences in temperature, DO, pH, *E. coli*, and conductivity were statistically significant. This variability is consistent with other studies that concluded the water quality in Xochimilco is highly heterogeneous (Zambrano et al. 2009, 2010). Our results suggest that precipitation events affect the water quality of the canals by increasing water runoff, and therefore the input of nutrients and pollutants, from the chinampas into the canals. The increase in temperature we observed happened during the rainy season (Fig. 3B), which occurs during summer when temperatures in Mexico City are high. The increase in water temperature may promote bacterial growth and reduce DO concentrations, which can negatively affect aquatic biodiversity, es-

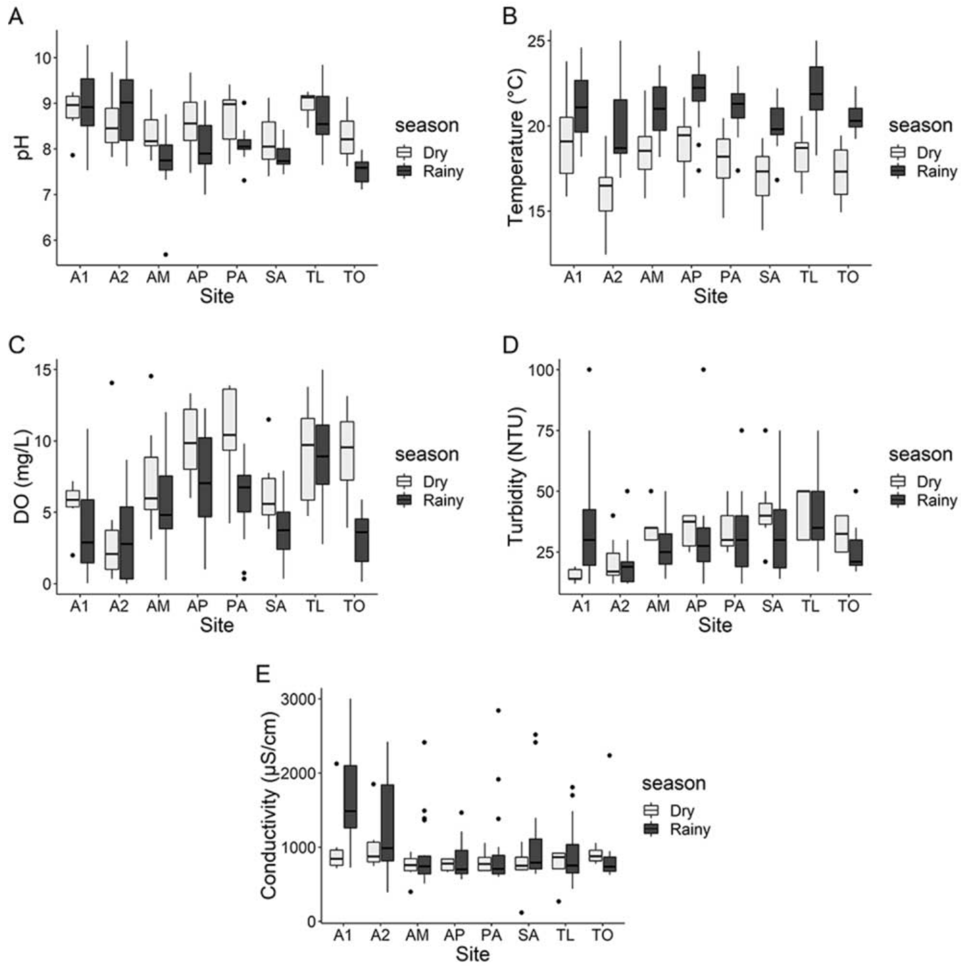

Figure 3. Box-and-whisker plots showing variation in water-quality variables between the rainy and dry seasons across the 8 sampling sites in the Xochimilco peri-urban wetland. The bar in each box shows the median measured value, box ends indicate the 25th and 75th percentiles. Whiskers show 1.5× the inter-quartile range (IQR). Points are outliers. Variation in pH (A), temperature (B), DO (C), turbidity (D), and conductivity (E). See Table 1 for site names and descriptions.

pecially small native fish species and macroinvertebrates (Latha and Mohan 2013). In addition to changes in water temperature, bacterial growth at our study sites could be related to nearby anthropogenic sources (Hill et al. 2006, Farnham et al. 2017), especially because there was clear evidence of housing wastewater discharge at these sites. Therefore, as the agricultural land use of the chinampas is converted into other uses such as housing, there is a constant threat of increased microbiological contamination in the water of the canals that could affect the health of users or visitors to the site (Aguilar 2008).

We did not find significant differences in NO_3-N or PO_4-P concentrations between either sampling sites or seasons based on either the Kruskal–Wallis or Levene's tests. However, one of the main input of nutrients in the water canals in the Xochimilco wetland is the inorganic fertilizers that are applied in semi-intensive or intensive agriculture, which is a common practice in most of the croplands in Xochimilco such as at the TL, AM, AP, and SA sites. In addition to fertilizers, the treated wastewater used to fill the canals is a source of P in the canal system (López-Hernández et al. 2010). Soil nutrients from inorganic fertilizer that have built up in the soil can mobilize and enter waterbodies, leading to eutrophication (López-López et al. 2010). This pattern occurred at most of our sampling sites, where the maximum NO_3-N concentration measurements were taken during the rainy season (Fig. 2A). In the AM canal site, which has a mixture of housing, tourism, and semi-intensive agriculture in the surrounding chinampas, the NO_3-N concentration was persistently higher than in the rest of the sampling sites (Fig. 2A). PO_4-P concentrations were often higher than the test detection limit (Fig. 2B), which may be why we saw no differences among sites.

Previous studies have shown that agroecological farming in chinampas is a more sustainable land use than inten-

Table 3. Results of post-hoc Hotelling's T^2 test for each pair of sampling locations, including NO_3-N (mg/L), PO_4-P (mg/L), total coliforms (CFU), *Escherichia coli* (CFU), temperature (°C), pH, conductivity (μS/cm), and dissolved oxygen (DO mg/L). Adjusted *p*-value ≤ 0.05 (Bonferroni correction) indicates statistically significant differences.

Site	Ampampilco	Apatlaco	Paso del Águila	Apantle 1	Apantle 2	Sabino	Tlilac	Toscano
Ampampilco	–	1	0.212	0	<0.001	0.097	0.006	1
Apatlaco		–	<0.001	0	<0.001	0.014	0.364	0.169
Paso del Águila			–	0	0	0.022	0.047	0.567
Apantle 1				–	1	0	0.008	0.018
Apantle 2					–	<0.001	0.013	0.036
Sabino						–	0.011	0.223
Tlilac							–	0.235
Toscano								–

sive agriculture and greenhouses, because local and natural resources are used more efficiently, reducing the impact on the ecosystem and enhancing productivity (Labrador 1996, Merlín-Uribe et al. 2012). Two of the canals we studied were located between chinampas with agroecological farming, which included the application of organic fertilizers, crop rotation, and biological pest control. We expected these canals to have better water quality than the other sampled canals because of the nearby agroecological farming. These canals (Apantles 1 and 2) are shallow and narrow with very low or stagnant flow. They are also used for conservation of an endemic and endangered species of salamander, the axolotl (*Ambystoma mexicanum).* For this reason, Apantles 1 and 2 are isolated with mesh at their entrances to prevent tilapia and carp, which are invasive species, from entering the canals. Our results showed that Apantles 1 and 2 did not differ from each other, but they both differed in water quality from other sampling sites (Hotelling T^2 test; Table 3), particularly because of their lowest *E. coli* counts and their highest conductivity values. However, the water quality in Apantles 1 and 2 sites did not meet the guidelines for crop irrigation and aquatic life because they had low DO concentrations (<6.5 mg/L), high total coliform counts (median >1000 CFU/100mL), and high conductivity levels (mean >1500 μS/cm). The low flow and shallowness of both Apantle 1 and Apantle 2 probably contributed to all of these values exceeding irrigation and aquatic life criteria (Fig. 3C). One of the implications of the use of high-conductivity water for crop irrigation is soil salinization and low crop growth (Ayers and Westcott 1985). A potential solution could be to dredge the canals to increase their depth and water flow and then monitor temperature, conductivity, and DO to determine whether dredging can improve water quality.

Citizen science, lessons learned

The conservation of peri-urban wetlands requires a social capacity to guide the interactions between humans and nature for sustainable management, which is one of the sustainability goals mentioned by Kates et al. (2001). To achieve sustainability in peri-urban wetlands, it is necessary that social actors including government agencies, the private sector, universities, local institutions, and civil society get involved. The citizen science approach shows that collaboration between scientists, NGOs, and citizens can generate valuable data. However, it can be difficult to get citizens involved, so training needs to be dynamic, inclusive, and attractive to get full commitment from volunteers. One of the advantages of this FWW effort was that this activity was part of the jobs of the volunteers, and their employer provided the means for them to become citizen scientists.

The scientific objectives of citizen science programs are important to pursue, but the societal impact is also a key goal of citizen science programs (Bonney et al. 2014). Societal impacts can be achieved by making citizens more observant of their environment (Dickinson et al. 2010, Dickinson et al. 2012) and more aware of the impact that human activities have on natural resources (Farnham et al. 2017). To gain insight into the volunteer experience, we asked how the program participants felt after being trained as citizen scientists and what new information was most impactful. One volunteer answered, with regard to becoming a citizen scientist, that *"thanks to the knowledge I now have, I can influence my family and friends to become aware of the implications of every individual decision we make in terms of water scarcity and water quality, and how it is affected at a local and global scale"*. Another volunteer said that he *"felt honored to have had the opportunity to contribute to scientific knowledge and data"* and mentioned a greater appreciation for *"the accuracy that is needed to have reliable information on freshwater systems"*. Another volunteer mentioned that *"the most shocking thing that I experienced today was that I realized the ignorance in which most of the population lives, by not knowing our history and our present, and not caring about our future, or the environment and water issues"*. Some volunteers have continued to participate in other monitoring programs and some have started to support agroecological farming in Xochimilco by buying fair trade products.

Citizen science can also be a powerful tool for stakeholders and policymakers to make more accurate decisions and allow stakeholders and managers to facilitate better planning and policies (Jordan et al. 2011). This study was a first step toward collaboration between citizen scientists and researchers, but it will be necessary to find paths to communicate the results to politicians and empower society to keep monitoring the environment and find solutions.

CONCLUSIONS

Our study was an example of how a citizen science scheme can create awareness of the impact of human activities on the environment and generate data to inform decisions on ecosystem management. The role of citizens in participatory monitoring was crucial not only for data collection but for increasing the recognition of the current ecological state of one of the most important ecosystem services providers in Mexico City, the Xochimilco periurban wetland. Xochimilco is a eutrophic wetland, and the current water quality is a result of several conditions such as seasonality, land management practices, climate conditions, and the water quality of the water treatment plants, which provide water to the system. It is necessary to highlight how sustainable management practices such as agroecological farming can improve canal conditions including eutrophication. Additionally, other changes to canal maintenance, such as dredging it to increase water flow and depth, could improve canal conditions.

Ultimately, this study demonstrated that, it is important to regulate and supervise the use of inorganic fertilizers and pesticides, the wastewater discharge from homes and tourism sites, the implementation of innovative and local processes of water treatment, and the treatment processes of wastewater treatment plants that supply water to the Xochimilco canals. Further, the citizen science efforts helped create awareness of environmental problems; bring together citizens, scientists, and NGOs; make scientific resources more efficient; and assist in the continuous monitoring of water quality.

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