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Quantifying the pollutant load into the Southern California Bight from Mexican sewage discharges from 2011 to 2020

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Sewage discharges into the ocean are one of the main sources of pollutant load on the coasts, resulting in health risks and ecological deterioration. The Southern California Bight runs from Point Conception in California (USA) to Punta Colonet in Baja California (Mexico). The impact of U.S. sewage discharges on the bay is well-documented, much less exist about the Mexican discharges. Official wastewater quality results for 17 wastewater treatment plants (WWTP) in Tijuana-Rosarito, Baja California from 2011 to 2020 are presented for the first time. The average wastewater flow during these years was 3,421 L s^{-1}, covering the discharge of 2,049,413 people. Water quality was compared with the current Mexican Norm for the discharge of wastewater to the ocean. It was found that only 53% of the samples complied with all the normed parameters, while 88% complied specifically with trace metal concentrations. Among the parameters above the norm were fecal coliforms, total suspended solids, and chemical and biochemical oxygen demand (COD and BOD). The San Antonio de Los Buenos WWTP accounts for the discharge of 80% of the BOD for all Tijuana-Rosarito WWTPs, 76% of COD, 84% of total suspended solids (TSS), 54% of total nitrogen (TN), and 55% of total phosphorous (TP) to the ocean. These represent mean yearly discharges from 2011 to 2020 of 150 tons of TN, 27 tons of TP, 528 tons of TSS, 401 tons of BOD and 1,191 tons of COD. Immediate action is needed to stop these high loads into the Pacific coast.

KEYWORDS

Southern California Bight, Rosarito, Tijuana, wastewater treatment, wastewater quality

Introduction

Good water quality is essential to human health, socio-economic development, and a healthy environment (UNESCO, 2015). However, the growth of water demands and the degradation of natural resources of safe water put supplies at risk. Intensive agriculture, industrial activity, and rapid urbanization have increased water demand and the release of pollutants like pesticides, trace metals, pathogens, and plastics (amongst others). Additionally, large volumes of partially treated or untreated wastewater are still discharged into surface water and groundwater, causing water pollution, health risks, and ecosystems deterioration (Flörke et al., 2013). According to the UN Water (2017), only 20% of the wastewater worldwide that flows back into the ecosystems is treated.

Official records by the Mexican National Water Commission [Comisión Nacional del Agua (CONAGUA, 2018)] establish that only 63% of the wastewater generated by urban use in Mexico receives some sort of treatment. There are 2,540 wastewater treatment plants (WWTP) across the country with a total treatment capacity of 181,152 liters per second (Ls^{-1}) treating 137,698 L s^{-1} (CONAGUA, 2018). However, mainly due to financial restrictions or design flaws, many are not operated properly, and the quality of the treatment is poor.

The Southern California Bight is a 685 km stretch of coastline that runs from Point Conception in California (USA) to Punta Colonet in Baja California (Mexico). There is a great deal of information regarding the impact of sewage discharges from the USA into the bight, much less so studies from Mexican discharges. This is the first study that quantifies the load of pollutants into the Bight from the cities of Tijuana and Rosarito from 2011 to 2020. Tijuana and Rosarito, with a combined population of 2,049,413 people, produces ~242,076 cubic meters of wastewater per day (CEABC, 2018; INEGI, 2020). Rosarito and Tijuana are, from a political and administrative point of view, two separate cities. However, their potable water and wastewater collection and treatment are both undertaken by the Tijuana's Water Public Commission (CESPT) and thus, in the present study will be discussed as a combined area named Tijuana-Rosarito.

From a hydrological point of view, the Tijuana-Rosarito region does not have important rivers and creeks and the rainy season lasts from September to March. The average annual precipitation is 200–400 mm. Therefore, Tijuana-Rosarito is highly dependent on the Colorado River; 99% of the available water comes from this source through the Rio Colorado-Tijuana Aqueduct (CEABC, 2018). Tijuana-Rosarito has followed a traditional linear model focused on water supply-demand; moreover, inequality in the spatial distribution of the water services is common, and currently treated wastewater is not reused (Navarro-Chaparro et al., 2016).

In Tijuana-Rosarito there are 13 WWTP operated by CESPT, three by the private company SUEZ and one binational plant operated by the International Boundary and Water Commission (IBWC), that treats wastewater from Tijuana but operates in the USA and discharges into the Tijuana River Estuary. The 16 WWTP operated in Mexico need to comply with the Mexican norm NOM-001-SEMARNAT-1996 that establishes the maximum levels of contaminants discharged into national waters, including coastal waters (SEMARNAT, 1996). Tijuana is the Mexican city with the second-largest economic growth in the USA-Mexico border. Before the 1960s, wastewater was directly discharged to the Tijuana River and eventually reached the USA coast. At the beginning of the 1960's, the first sewage collection system was built, and it would discharge the wastewater into the ocean, near Rosarito (IBWC, 2022). The system had frequent problems due to the fast growth of the city plus an inadequate operation. In 1965 there was an agreement between the USA and Mexico to send part of Tijuana's wastewater to the Point Loma WWTP in San Diego for treatment during emergencies. However, due to the fact that Tijuana was using the interconnection permanently, San Diego canceled the agreement in 1986 (Sánchez, 1988). In 1987 the San Antonio de los Buenos (SAB) (also known as Punta Banderas) WWTP started operation, having a treatment capacity of 1,100 L s^{-1} and discharging to the ocean. In 1999, the South Bay International (SBI) wastewater treatment plant was built with a total capacity of 1,100 Ls^{-1}. In 1989 the Rosarito 1 WWTP started operations (60 Ls^{-1}), followed by Rosarito Norte (210 L s^{-1}) in 2004 and El Prado (56 L s^{-1}) in 2007, Monte de los Olivos (460 L s^{-1}) in 2009 and La Morita (250 Ls^{-1}) in 2010. Most of the WWTP discharge directly to the ocean at the coastline. There are no ocean outfalls for the discharge of the treated wastewater. Worldwide, municipalities located near coastlines discharge treated or untreated effluent directly into the ocean (Howarth, 2008).

In Mexico, sewage pollution is one of the major threats to coastal ecosystems in the Yucatan Peninsula (Pacheco et al., 2000; Hernández-Terrones et al., 2015). The ecosystems are impacted by faulty septic tanks, untreated wastewater spills, and untreated wastewater injection, affecting aquifers and, eventually, groundwater discharges directly into the ocean affecting coral reefs (Hernández-Terrones et al., 2015). Hernández-Terrones et al. (2015) quantified nutrient fluxes [Soluble Reactive Phosphorus (SRP), Soluble Reactive Silica (SRSi), and Dissolved inorganic nitrogen (DIN)] associated with submarine springs along the coast near Akumal (Yucatán) demonstrating significant nutrient delivery to the reef lagoon.

The direct discharges of domestic wastewater are recognized as major source of phosphorus and nitrogen to the Mediterranean Sea, contributing to eutrophication (Powley et al., 2016). Powley et al. (2016) estimated the spatially distribution of annual inputs of phosphorus and nitrogen associated with direct domestic wastewater discharges from coastal cities to the Mediterranean Sea (MS). The inputs showed that direct discharges of treated and untreated domestic wastewater are the principal pathway for transporting nutrients to the Mediterranean Sea.

Sewage wastewater is a major nitrogen inputs to several coastal marine ecosystems in the northeastern United States (Howarth, 2008). Also, in the Southern California Bight (SCB), a baseline of direct point, non-point source and natural sources of freshwater discharge and nitrogen, phosphorus, carbon, iron, and silica loads to the SCB was constructed (Sutula et al., 2021). Direct point sources were the dominant nitrogen source, contributing with 70% of the total annual freshwater discharge and 95% of nitrogen loads (Sutula et al., 2021).

In the present study, the wastewater quality results for the 13 WWTP operated by the CESPT and the three by the private company SUEZ in Tijuana and Rosarito from 2011 to 2020 are reported and the contaminant load into the Pacific Ocean is discussed in terms of the Mexican Official Norm for wastewater discharges to coastal water used for recreational uses. In the case of the South Bay International wastewater treatment plant, the IBWC has resolutions for discharge and its possible effects on the coastal water are discussed. The data are the official results from CESPT and this is the first time they are presented anywhere.

Materials and methods

CESPT's wastewater quality quarterly reports (January, April, July, October) from 2011 to 2020 were located in a storage facility at the main offices of the CESPT in Tijuana; however, it was not possible to locate all reports for the time period and some data is missing. The average percent of missing data for all Tijuana-Rosarito WWTPs was 25%. There is no available data for none of Tijuana's plants during 2014, which represents 56% of the total missing data, which could indicate administrative changes or loss of the physical document. In the reports, wastewater quality analysis was undertaken according to Mexican norms, which are the equivalent to Standard Methods (APHA, AWWA, WEF, 2012). BOD was estimated using the dilution method (5-day incubation); TSS with gravimetric analysis, TN with Kjeldahl method, TP with UV-Vis spectrophotometry, oils and grease with Soxhlet method, and fecal coliforms with the multiple tube (most probable number-MPN) method. For more details about the sampling and procedure of the different analytes see NOM-001-SEMARNAT-1996.

The results were captured in an electronic database in Excel^{TM}, where descriptive statistics (arithmetic mean, minimum, maximum, and standard deviation) were performed. For fecal coliforms the geometric average was determined.

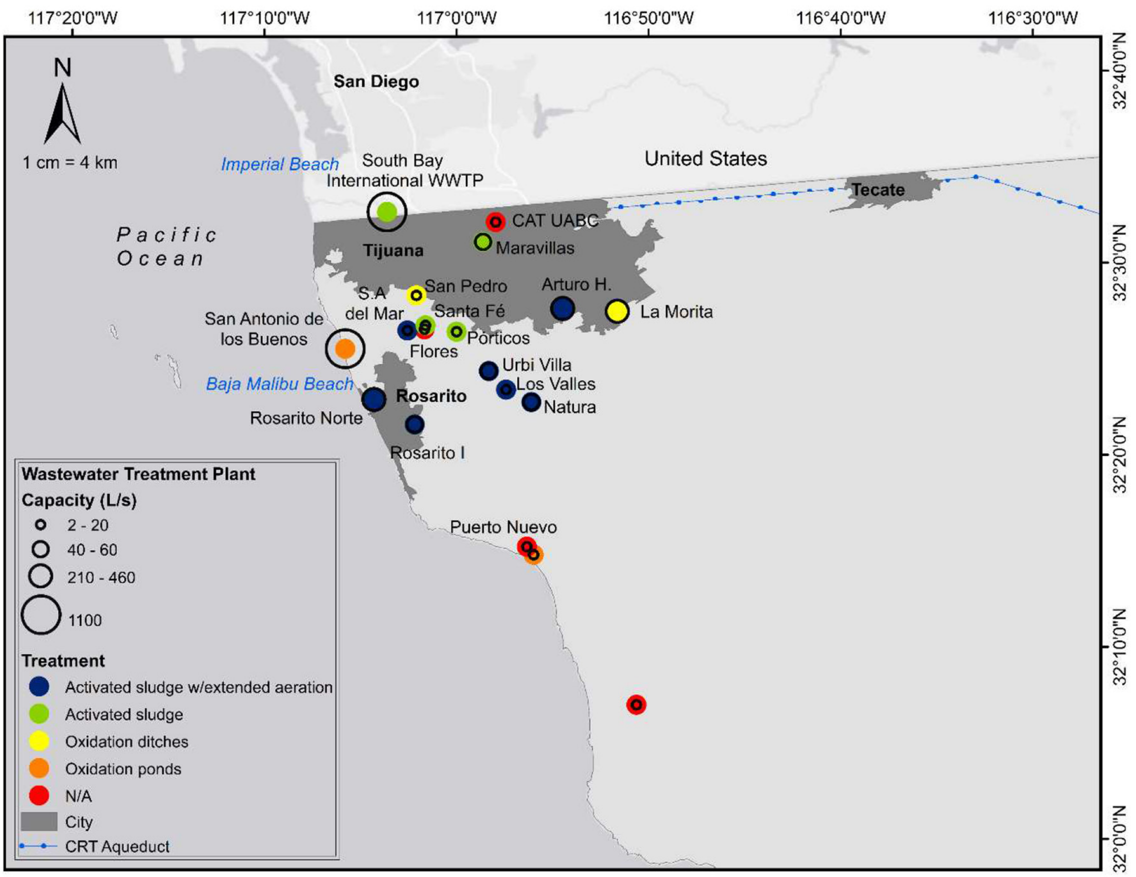

FIGURE 1
Names and location of Tijuana's wastewater treatment plants.

TABLE 1 Average constituent concentration of all wastewater treatment plants in Tijuana, Baja California for 2011–2020 (numbers in bold indicate those exceeding the maximum permitted concentrations by the NOM-001-SEMARNAT-1996).

Wastewater treatment plant	*n*	BOD (mg L^{-1})	COD (mg L^{-1})	TSS (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})	Oils & greases (mg L^{-1})	Fecal coliforms (MPN 100 mL^{-1})	pH	T (°C)
NOM Maximum Level*		75	200	75	–	–	15	1,000	–	40
South Bay International	17	22 (21)	70 (41)	17 (13)	29 (53)	3 (3)	7 (4)	**8,086**	7.2 (0.4)	21.8 (3)
San Antonio de los Buenos	34	**149 (71)**	**442 (162)**	**196 (113)**	56 (20)	10 (10)	**34 (14)**	**2,998**	7.5 (0.4)	21.6 (4)
Arturo Herrera	39	6 (6)	46 (29)	10 (5)	17 (17)	6 (3)	6 (2)	55	7.2 (0.4)	23.5 (3)
La Morita	34	6 (6)	57 (30)	9 (3)	19 (10)	5 (2)	6 (2)	87	7.3 (0.3)	23.2 (3)
Rosarito Norte	37	13 (27)	56 (80)	20 (34)	18 (17)	7 (7)	6 (4)	141	7.3 (0.3)	21.7 (3)
Rosarito I	38	19 (20)	78 (71)	19 (20)	42 (21)	6 (5)	6 (3)	128	7.7 (0.3)	21.0 (3)
Natura	8	4 (4)	60 (30)	11 (3)	14 (18)	7 (8)	5 (5)	6	7.5 (0.3)	21.7 (5)
Urbi Villa	24	22 (22)	122 (159)	73 (73)	17 (16)	7 (16)	7 (6)	38	7.3 (0.2)	22.8 (3)
Los Valles	13	68 (60)	174 (115)	51 (31)	35 (19)	8 (3)	10 (9)	295	7.0 (0.2)	19.0 (3)
Las Flores	11	**197 (129)**	**299 (161)**	**122 (80)**	44 (17)	8 (4)	**27 (26)**	**1,309**	7.6 (0.2)	20.2 (4)
Pórticos	34	24 (29)	89 (74)	46 (98)	28 (16)	7 (4)	6 (3)	24	7.6 (0.4)	21.1 (3)
Puerto Nuevo	18	73 (76)	**307 (441)**	**225 (386)**	45 (46)	14 (5)	14 (5)	16	7.5 (0.6)	22.2 (3)
San Antonio del Mar	26	41 (56)	**181 (274)**	**158 (362)**	29 (23)	4 (2)	16 (31)	58	7.4 (0.4)	22.3 (3)
Santa Fe	30 (78%)	15 (21)	54 (50)	18 (17)	25 (19)	5 (2)	6 (3)	30	7.4 (0.3)	22.7 (3)
San Pedro	25	22 (35)	66 (105)	19 (18)	20 (4)	6 (3)	7 (3)	40	8.0 (0.3)	20.0 (4)
Maravillas	10	73 (72)	**264 (136)**	**169 (72)**	40 (32)	8 (4)	**14 (12)**	487	7.6 (0.6)	22 (4)
CAR UABC	8	35 (30)	NA	30 (11)	NA	NA	9 (7)	**2,166**	NA	NA

[*] Maximum permissible limits corresponding to the Coastal Waters used for Recreation category.

n = number of reports available in the period, ( ) = Standard Deviation.

Official data on the design treatment capacity of each WWTP was obtained from CESPT website (CESPT, 2020). Results were then compared to the maximum levels established by the Mexican quality norm for wastewater discharge NOM-001-SEMARNAT-1996. The average concentrations were compared with the permissible limits corresponding to the Coastal Waters—Recreation category. The non-parametric Mann-Whitney test was applied to determine if the average concentrations were significantly above the limit ($\alpha = 0.05$). Previous analysis of the normal distribution of the data was done by Shapiro-Wilk normality test. Both tests were performed using the statistical toolbox of OriginPro^{TM} software. The location, type of treatment, and capacity of 17 WWTPs in Tijuana-Rosarito are presented in Figure 1. The total load into the ocean of total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), chemical oxygen demand (COD), and biological oxygen demand (BOD) were estimated as:

$$Load_P \; : C_P \; x \; FR_{WWTP} \qquad (1)$$

Where C_P is the concentration of each pollutant (P) and FR_{WWTP} is the average flow rate for each WWTP. Quantifying anthropogenic discharges of nutrients to the coastal oceans has become a priority since they are recognized as eutrophication drivers (Howarth, 2008; Wurtsbaugh et al., 2019). Deoxygenation and acidification co-occur in many coastal ecosystems (Breitburg et al., 2019; Boco et al., 2020). Nutrient enrichment produces excess organic matter that intensifies aerobic respiration during decomposition, depleting O_2, increasing CO_2 and lowering pH (Boco et al., 2020). Despite the successes in North America and Europe in reducing eutrophication, many eutrophication-related problems remain in coastal oceans, particularly in developing countries (Wurtsbaugh et al., 2019).

Results

The average concentration for basic pollutants of all wastewater treatment plants in Tijuana, Baja California are presented in Table 1. All Tijuana-Rosarito WWTP are secondary treatment plants: 14 are activated sludge, two are oxidation ditches, and one is an aerated lagoon. The 17 plants treat about 85 Mm^3 of wastewater per year of domestic/commercial (93%) and industrial (7%) nature.

The efficiency of the WWTP concerning basic pollutants can be considered poor since only 53% comply with regulations. Main quality parameters above the norm include fecal coliforms, TSS, COD and BOD. The WWTP that do not comply with the norm are: San Antonio de los Buenos, Los Valles, Las Flores, Puerto Nuevo, San Antonio del Mar, Santa Fe, and San Pedro. Trace metal concentrations rarely exceed the maximum levels allowed by Mexican norms, despite that the Tijuana-Rosarito area has a large industrial activity. The Hg and Pb concentrations exceeded the norm (0.012 and 0.881 mg L^{-1}, respectively) only in two occasions between 2011 and 2020. These are abnormal values for Arturo Herrera (Hg), and Santa Fe (Pb) WWTP receiving water from industrial parks. The WWTP operated and maintained by the private company SUEZ (Arturo Herrera, La Morita, and Natura) are more efficient than those operated by CESPT; all three comply with the regulations and present the lowest concentrations for the quality parameters.

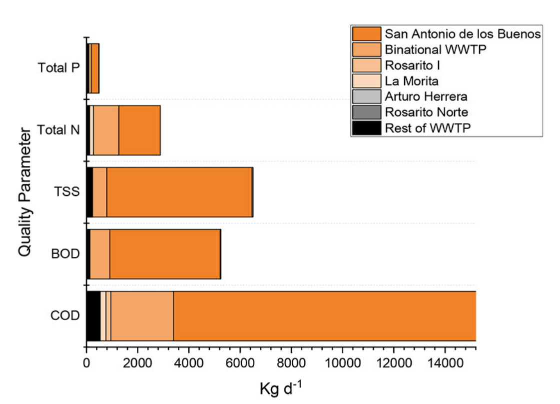

FIGURE 2
Average pollutant loads per day of the wastewater treatment plants.

In contrast to the previously mentioned WWTP, the SBI and the SAB WWTP exceed eight and three times the maximum level by the norm for fecal coliforms, respectively. The SAB WWTP (built-in 1985) exceeded by 2-fold the most basic pollutants' maximum levels. The effluent quality results of the WWTP are resumed in Figure 2. The SAB plant discharged 24,675 kg d^{-1} (76% of the total of all 16 WWTP) to the Pacific Ocean, followed by the SBI plant, 4,913 kg d^{-1} (15%) to Tijuana River Estuary, and the rest of WWTP 2,912 kg d^{-1} (9%) to creeks, Pacific Ocean, and Tijuana River. The SAB WWTP accounts for the discharge of 80% of the BOD for all Tijuana-Rosarito WWTP, 76% of COD, 84% of TSS, 54% of TN, and 55% of TP to the ocean.

The SAB WWTP is a secondary treatment plant with oxidation ponds and is currently out of operation and in anoxic conditions. Considering that all the effluents from this plant are discharged directly to the ocean and the implication for coastal eutrophication, the temporal variation of N, P, and organic loads were quantified (Figure 3). The mean yearly discharges from 2011 to 2020 were 4,730 × 105 m^3 of effluent, comprising 150 tons of TN, 27 tons of TP, 528 tons of TSS, 401 tons of BOD, and 1,191 tons of COD.

Discussion

As mentioned previously, 94% of Tijuana-Rosarito's wastewater goes through a wastewater treatment plant and is

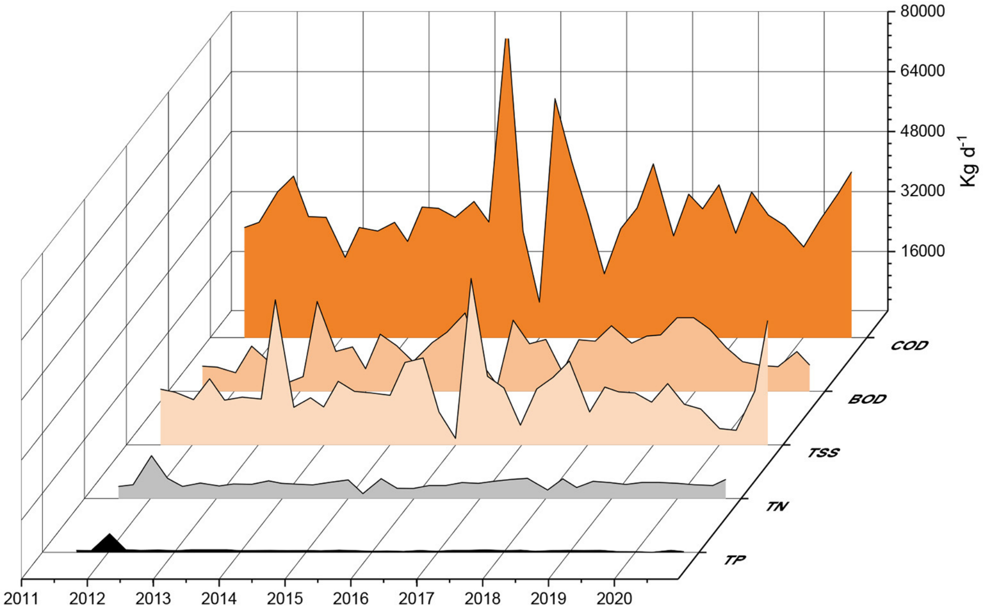

FIGURE 3
Monthly time series from 2011 to 2020 of total phosphorus (TP), total nitrogen (TN), total suspended solids (TSS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) of the San Antonio de los Buenos (SAB) wastewater treatment plant.

officially treated. There is no relationship between the pollutant load and the location of the WWTPs; however, higher pollutant loads correspond to the older plants, such as SAB plant (started in 1987), SIB (1999), and Puerto Nuevo (2000). In contrast, lower pollutant concentrations are present in La Morita (2010) and Arturo Herrera (2009). In reality, the SAB WWTP, the largest wastewater treatment plant in the region, is not working and does not provide any treatment at all.

According to Thulsiraj et al. (2017), fecal indicator bacteria in beaches near the SAB discharge are twelve to 270 times higher in comparison to beaches free from discharge inputs and both dog and human fecal contamination were important sources and frequently detected at and near the SAB effluent discharge. Moreover, Thulsiraj et al. (2017) investigated the extent of contamination associated with the SAB outfall and found that human-associated markers and high levels of fecal indicators bacteria were detected at the outfall and 2.05 km upcoast from the discharge point.

Although the SAB effluent has been mentioned as an occasional source of northbound pollution (San Diego beaches) (Kim et al., 2009) and even southbound sites (Baja Malibu beach, Figure 1) (Sassoubre et al., 2012), transport depends on coastal currents, which are very variable, depending on weather, wind and other local conditions.

A model by Feddersen et al. (2021) combined for the first time hydrodynamic, pathogen, and human illness models to predict human health and beach impacts in the California Bight, impacted by untreated or poorly treated wastewater in Tijuana. In the Baseline, the percentage of swimmers becoming ill was 3.8% over the year, increasing to 4.5% for the tourist season (Memorial to Labor Day) due to south-swell driven SAB discharge.

Zimmer-Faust et al. (2021) used multiple microbial source tracking tools to characterize the impact and reach of the SAB WWTP effluent along the coast. They found evidence of a gradient in human fecal pollution that extended up to 20 km north from the wastewater discharge across the United States-Mexico border from the point source was observed using human-associated genetic markers and microbial community analysis. The spatial extent of fecal contamination observed was largely dependent on swell and ocean conditions. Therefore, it is necessary to add to this study one in which the Point Loma WWTP effluent, that discharges *via* an ocean outfall north of San Diego, is tracked on swell and ocean conditions heading southbound to discharge the hypothesis that it may also be a source of pollution to San Diego beaches. The high levels of fecal coliforms in both SAB and the SBI WWTP, under high-flow regimes, impacts the waters of the Pacific Ocean. Regarding total coliforms from the SIB WWTP, there is an international standard established in IBWC Minute 270 entitled "Recommendations for the Stage I Disposal and Treatment Works for the Solution of the Border Sanitation Problem at San Diego, California. Tijuana, Baja California," dated April 30, 1985. Resolution number 4 in Minute 270 stipulates "...that the quality of the coastal receiving waters at the international boundary shall comply with the water quality criteria established for primary contact recreation uses, in the sense that the most probable number of coliform bacteria will be <1,000 organisms per 100 mL, provided that not more than 20% of the total monthly samples (at least 5) exceed 1,000 per 100 mL". This criterion should be applicable to the SIB. According to the results presented here, the SBI WWTP had an average fecal coliform concentration of 8,086 per 100 mL, hence, eight times above the aforementioned criterion. Therefore, PCR DNA studies to track this effluent, like the study by Zimmer-Faust et al. (2021), are also needed.

In addition to SAB, the Las Flores and Los Valles WWTPs are not operating. There are several plans to stop the SAB WWTP pollution. One is to redesign and rebuild the WWTP. A credit for 26,561,576 USD has been approved for this project, yet no concrete steps have been taken. It is intended to consist of three modules of oxidation ditches, each with a capacity of 400 L s^{-1}. According to Proyectos México (2021), its construction would start in 2024. Once the new WWTP is built, the effluent could be sent southeast to the Guadalupe Valley wine growing region, for the irrigation of vineyards (Mendoza-Espinosa et al., 2019). Although this project has been awarded to a private company, it is unclear if the reclaimed water would be delivered through new pipelines running from west to east or south along the coastline until La Mision and then east toward the Guadalupe valley. The cost of reclaimed water to farmers is one limiting factor and no agreement on a suitable water cost between the company and farmers has been reached.

In addition to pathogens, high discharges of carbon and nitrogen to the ocean affect aquatic habitats and marine ecosystems. Increased nitrogen flux from terrestrial runoff is considered one of the leading causes of coastal eutrophication (Howarth, 2008). Mexican transboundary inputs to US waters *via* the SBI WWTP and the Tijuana River represent 35% of total dissolved inorganic nitrogen loads to the south San Diego region (Sutula et al., 2021). Moreover, SAB discharge to the ocean is one of the main ways Tijuana sewage pollutes the North American coast, accounting for 54% of the total nitrogen of Tijuana's wastewater. According to Sutula et al. (2021), the median annual load of TN in the south San Diego region (1997–2017) coming from the largest USA WWTP is 8,390 tons. The SAB WWTP plant discharges an average annual load of 1,618 tons of TN (2011–2020), thus, representing 19% of the USA mean annual discharge.

TSS was another quality parameter above the norm (>75 mg L^{-1}). The SAB WWTP accounts for 84% of TSS discharge for all Tijuana-Rosarito plants. TSS are major contributors to the deterioration of water quality, adding higher costs for water treatment, decreases in fish resources, and the organoleptic characteristics of water (Bilotta and Brazier, 2008). The occurrence of TSS in water bodies in Mexico has been recognized in other coastal zones from Colima to Guerrero, in the south of Veracruz, and Tabasco (Arreguín-Cortéz et al., 2011). In addition, excess TSS depletes the dissolved oxygen (DO) in the effluent water (Verma et al., 2013). Biochemical oxygen demand (BOD) and total suspended solids (TSS) are related (Gerardi, 2015). A portion of the TSS, the volatile suspended solids, is degradable and exerts an oxygen demand (Gerardi, 2015). As seen in Figure 3, the peaks of TSS concentration in SAB WWTP follow the same pattern as COD and BOD peaks. In general, the lowest concentrations were observed for TSS, COD, and BOD for 2011–2020 in the first quarterly reports (January) of each year. COD and BOD parameters, both above the norm (>200 and >75 mg L^{-1}, respectively), are indicators of organic pollution due to the untreated water from SAB WWTP. A maximum in COD (84,510 kg d^{-1}) and BOD (2,109 kg d^{-1}) was observed for July 2015, which could be associated with an operative failure in the WWTP, discarding rain events as contributory factor (rainy season is during November-April) (Servicio Metereológico Nacional, 2022).

At the SAB plant, an average of 149 of BOD mg L^{-1} and more than 440 mg L^{-1} of COD were observed. There is no definite trend of increase or decrease in the concentration of the pollutant in the last 9 years, which evidences the lack of improvements at the wastewater plant. Peaks of higher concentration are distinguished in April-July 2012, 2015, and 2016 for COD and BOD. On the other hand, the IBWC monitored the influent at the SBI WWTP from December 2018 to October 2019; the wastewater averaged 378 mg L^{-1} for BOD and over 700 mg L^{-1} for COD (IBWC, 2020). The high levels of organic matter in Tijuana wastewater may be associated to the prevalence of water conservation due to the shortage of potable water in the region (IBWC, 2020). There are many types of treatments such as sequencing batch reactor (SBR), chemical coagulation and electrocoagulation that can be used as an alternative to aerobic and biological systems (Bazrafshan et al., 2012) such as activated sludge in Tijuana's WWTP. However, according to an evaluation by North American Development Bank - Arcadis (2019), the main problem with Tijuana's WWTP is its faulty operation and maintenance due to the limited personnel, limited operation and maintenance budget, limited preventive maintenance practices, and high-risk physical and performance conditions.

The Tijuana-San Diego region is not the only example of transboundary river quality conflict between Mexico and the USA. The Rio Nuevo in the city of Mexicali, Baja California, has been causing pollution since the 1950s. The Rio Nuevo is currently considered one of the most polluted waterways in the United States and flows into the Salton Sea. This river carries water from agricultural and industrial runoff generated in Mexicali, as well as highly polluted water (Amidon et al., 2018).

Deficiencies in Tijuana-Rosarito wastewater treatment must be addressed as soon as possible due to the environmental and health impacts that are being generated. CESPT has begun the construction of a coastal collector intended to eliminate discharges to the sea by capturing water from Tijuana to

Ensenada for final disposal and treatment. The collector is a large pipeline that will run from Tijuana to Ensenada along the coast. If this project is completed, it will benefit the coastal corridor by eliminating ∼100 L s^{-1} of sewage from 14 housing developments along the road (De León, 2020). This project is expected to partially resolve the constant complaints from the United States to Mexico about the discharge of wastewater from Tijuana and Playas de Rosarito that affects the Imperial Beach and Coronado counties.

These initiatives represent significant progress, but there is still much to be done. The WWTP that are not in compliance with regulations require urgent maintenance and, in some cases, new infrastructure. These challenges are also observed in Middle Eastern countries, like Baja California, this area has a dry and semi-dry weather (Moghaddam et al., 2017), water resources are limited, and wastewater reuse represents an attractive strategy. However, the lack of proper operation of well-designed wastewater treatment plants in Middle Eastern prevents the wastewater reuse (Moghaddam et al., 2017).

A program to evaluate the WWTP efficiency and the information generated in this study could address the specific needs of each plant. In addition to scientific evidence, citizen participation can improve the quality of government decisions, increase the quality of the products generated by the government, incorporate different resources and capacities, and develop learning among the political community (Villada-Canela et al., 2019).

Conclusions

The efficiency of the WWTP analyzed in this study can be considered poor concerning basic pollutants since only 53% of the plants comply with regulations. In the case of trace metals, it can be regarded as acceptable since 88% of the plants comply with the regulations. All Tijuana-Rosarito WWTP are secondary treatment plants; 82% are activated sludge, 12% are oxidation ditches, and 6% are aerated lagoons. For the maximum limits for basic contaminants established in NOM-001-SEMARNAT-1996, it was found that the WWTP operated and maintained by SUEZ (Arturo Herrera, La Morita, and Natura) are more efficient than those operated by CESPT, since all three comply with the regulations. The San Antonio de Los Buenos WWTP accounts for the discharge of 80% of the BOD for all Tijuana-Rosarito WWTPs, 76% of COD, 84% of TSS, 54% of TN, and 55% of TP to the ocean. The need for the construction, rehabilitation, and proper operation of sewage, pumping, and wastewater treatment systems in Tijuana-Rosarito is urgent. A program to evaluate the WWTP efficiency could address the specific needs of each plant. Moreover, citizen participation and develop learning among the political community is necessary to embrace the water management process. The public availability of water quality results is a big step toward the democratization of data. By making data available to the scientific community and the general public, citizens will be able to participate in a more knowledgeable way in the decision-making process related to water management in the region.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

AA-S: investigation and writing—original draft. LM-E: conceptualization, writing—review and editing, and supervision. AH-C: formal analysis and data curation. LD and MV-C: writing—review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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