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Health risks and cross-border environmental exposure: A binational study of the San Diego-Tijuana-Rosarito Pacific Ocean coastline

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ABSTRACT

The Pacific coastline along the US-Mexico border is increasingly contaminated by the binational Tijuana River. The topic has garnered significant political interest in both countries, but little is known about the binational health implications of this pollution. This mixed methods study explored self-reported health risks associated with interactions with specific beach sites across the San Diego-Tijuana-Playas de Rosarito region, among residents, workers, and coastal visitors in 2024–2025. A non-probability online survey was distributed at beaches and among coastal communities, and completed by $n = 390$ participants. Associations between coastal interactions and self-reported health conditions were assessed using adjusted and unadjusted odds ratios. Additional in-depth qualitative interviews were conducted with three local health professionals. Ethnographic field notes were collected by study staff during survey recruitment and coastal site field work. Triangulating these information sources, we find that coastal visitors encounter substantial environmental hazards, including high enterococci levels at specific coastal water sites. The most prevalent self-reported health issues were respiratory conditions (47 % of participants), eye allergies (16 %), gastrointestinal conditions (15 %), and ear infections (11 %). Multivariate analysis showed higher odds of these outcomes among residents and visitors of certain coastal sites, as well as those who practiced aquatic sports, and those who reported encountering unpleasant conditions at local beaches (e.g. trash or human feces). Findings suggest that recreational activities, contact with polluted water, and passive environmental exposure—via air and sand contact—may contribute to the region's health burden. These results support the implementation of planetary health approach and increased binational collaboration to improve infrastructure and environmental monitoring.

1. Introduction

Consistent with 'Blue Space' literature, coastal proximity often correlates with improved mental and general health (Gascon et al., 2017; Geiger et al., 2023; Wheeler et al., 2012; White et al., 2013). However, evidence suggests that localized pollution may erode these typical protective effects. Beyond the 1.36 million global deaths from water pollution annually (Fuller et al., 2022), recreational contact with contaminated surface waters drives significant health burden, causing over 90 million annual illnesses in the United States (US) alone (DeFlorio-Barker et al., 2018). These risks can extend further inland through sea spray aerosol (Pendergraft et al., 2021). Wastewater discharges, stormwater, and industrial and touristic activities are significant, well-documented contributors to water pollution in coastal areas (Pendergraft et al., 2023; de J. Piñon-Colin et al., 2018). Environmental protection can be increasingly challenging when international borders divide these shared ecosystems.

The US-Mexico border of Tijuana-San Diego shares two

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interconnected bodies of water with great significance for both cities and countries – the binational Tijuana River, and the Pacific Ocean, which receives this river's discharge. The Pacific coastal environment of the US-Mexico border region has a history of growing population, migration, and socioeconomic disparities (Mendoza and Dupeyron, 2020; Tenorio et al., 2024). The Pacific Ocean serves as a primary landmark for those in Tijuana, Playas de Rosarito, and San Diego due to the environmental, cultural, and economic resource it provides for coastal populations.

In this transboundary context, the Tijuana River serves as a conduit for contaminants originating upstream in Mexico and discharged downstream into the Pacific Ocean in the US. In the last decades, coastal waters at the US-Mexico border have been affected by persistent pollution from urban, industrial, wastewater and stormwater runoff (Pendergraft et al., 2023; Musegaas, 2024; Stigler Granados et al., 2024). These discharges often contain high loads of pollutants, posing direct risks to coastal water quality and public health on both sides of the border. Exposure to contaminated coastal waters has been associated with gastrointestinal, dermatological, and respiratory illnesses, disproportionately affecting marginalized populations in border communities. Moreover, differences in environmental regulations, wastewater infrastructure, and institutional capacity between the US and Mexico complicate effective management and mitigation efforts. Consequently, understanding coastal water pollution in this binational region is essential for protecting ecosystem health, sustaining economic activities, and reducing public health risks.

The Tijuana River watershed covers more than 4400 Km^2 across the US and Mexico. The river crosses the US-Mexico border multiple times and flows through the city of Tijuana before it reaches the ocean in San Diego. During its natural flow – which occurs mostly in rainy season – the river enters the US through the Tijuana River Estuary and reaches the Pacific Ocean in Imperial Beach at San Diego County, California in the US. In the dry season, its flow is mostly diverted to *Punta Bandera,* a wastewater treatment plant south of Tijuana, where the water is partially treated and discharged into the ocean through an open canal. Despite existing infrastructure on both sides of the border—including treatment plants in Mexico and the International Boundary Wastewater Treatment Plant operated by the US—capacity overload and failures result in ongoing discharges that do not meet water-quality standards (Stigler Granados et al., 2024; Arreola-Serrano et al., 2022; Calderón--Villarreal et al., 2022). Reflecting the severity of the contamination, local and federal governments in both the US and Mexico have formally declared states of emergency regarding the river's water pollution (San Diego County 2023; Estado de Baja California 2020).

The Tijuana River contains a complex mixture of treated wastewater, including effluent from *La* Morita treatment plant (~254 liters per second [lps]), Arturo Herrera treatment plant (~460 lps) which flows downstream towards the South Bay International Wastewater treatment plant. As the river reaches this region, it converges with multiple additional sources of contamination, including solid waste and wastewater flows from unregulated urban settlements and industrial pollutants such as oils, pesticides, and heavy metals; and microplastics (de J. Piñon-Colin et al., 2018; Stigler Granados et al., 2024; Calderón-Villarreal et al., 2022; Gladstone et al., 2021; San Diego Regional Water Quality Control Board 2020; Villaverde, 2012; Alvarez-Andrade et al., 2023; Piñon-Colin et al., 2024).

Concentrations of fecal indicator bacteria are high at surfing beaches in San Diego, particularly during storm events. Stormwater discharges near San Diego surfing beaches contain human fecal markers in all samples and human norovirus in up to 96 % of samples, with fecal indicator bacteria concentrations ten-fold higher than adjacent beach waters (Steele et al., 2018). These indicators were associated with gastrointestinal illness among swimmers and surfers in the San Diego coastal area (Soller et al., 2017; Steele et al., 2017). Similarly, a prospective cohort of San Diego surfers reported that seawater exposure considerably increased ear and wound infections especially during wet weather (Arnold et al., 2017). Furthermore, Hepatitis A virus, enteroviruses and adenoviruses were detected on coastal waters and beaches in Southern California and Baja California (Pendergraft et al., 2023; L.M. Sassoubre et al., 2012). In the Pacific Ocean coast in Baja California, bacterial contamination has been reported at multiple sites from the US border to *Punta Bandera* (Orozco-Borbón et al., 2006), but no study–to our knowledge–has explored health risk associations among Mexican coastal communities in this region. Given that this is a joint health and environmental issue, a simultaneous evaluation of both countries is warranted. Current research lacks a binational perspective, focusing primarily on US-based impacts.

This hypothesis-generating, community-based assessment aimed to explore health risks associated with proximity and interactions with the binational San Diego-Tijuana-Rosarito Pacific Ocean coastline. This mixed-methods study was conducted among adults residing, working, or visiting this binational coastal region, as well as among healthcare professionals serving these populations. Additionally, this study investigates coastal interactions, public awareness, and potential mitigation strategies, thereby addressing a gap in the environmental health literature concerning this transboundary issue.

2. Methods

2.1. Study design

We employed mixed-methods non-probability study design, integrating quantitative, qualitative data, and secondary water quality data to assess health risks associated with proximity and interactions with the Pacific Ocean coastline. The study population included individuals who lived, worked, or spent time in San Diego, Tijuana and Playas de Rosarito coastal region. This study is a research component of the *One Coastal Community* initiative, a collaborative effort led by the community organizations *Proyecto Fronterizo de Educación Ambiental* (PFEA) located in Tijuana, in Baja California, Mexico and *San Diego Coastkeeper,* located in San Diego in California, US. This study is also part of the *Socio Environmental Tijuana River Project,* a participatory action research collective that aims to assess the impacts of transboundary river pollution on human health from environmental justice and human right perspectives. This research was partially funded by the Border Resilience Initiative launched by the San Diego Foundation and by California State University San Marcos (CSUSM).

The area of interest covered 102.4 Km^2 on the coastline, with 59.3 Km^2 in Mexico and 43 Km^2 in the US. The US portion includes the coastal cities of Coronado and Imperial Beach, connected by the Silver Strand sand bar. In Mexico, it covered 24 Km of coastline in Tijuana and Playas de Rosarito. About 137,770 people reside in the area of interest of this study, comprising 85,746 people in Mexico and 52,024 people in the US. The study area was delineated according to the Binational Resilience Initiative (BRI) criteria and was defined through an assessment conducted by PFEA in 2024, during a previous BRI-funded project. These assessments examined physical and social coastal characteristics, with a focus on erosion processes and water quality conditions. The same study area was used for the present analysis.

2.2. Study participants

The survey included adults (18+) who lived, worked, or visited the study area in San Diego in California, US, and Tijuana and Playas de Rosarito in Baja California, Mexico in 2024–2025. Participants in qualitative interviews included health professionals with clinical experience serving coastal communities in San Diego and Tijuana, and who consented to participate. The Institutional Review Board of CSUSM reviewed and approved this study (2260,867).

2.3. Quantitative data

The quantitative component included an online survey available on the CSUSM Qualtrics platform in English and Spanish. We employed a multi-channel recruitment strategy including community-based organizations, coastal-themed social media groups, and the distribution of flyers and posters in public coastal areas, schools, and community events. Furthermore, we utilized targeted social media advertising in both languages tailored to reach individuals based on their geographic proximity to the coast and interest in coastal activities. This purposive sampling approach was designed to ensure that respondents had a direct, lived connection to the study area. The survey included demographic information, interactions with the Pacific Ocean coastline, body contact with ocean water and beach sand, perception on infrastructure and environment, and health-related questions.

Demographic information included age, gender, education, disability status, housing status, race/ethnicity, nationality, and place of residence (at county or municipality level). Interactions with the coastline were categorized by type (recreational use, residence, work/study or practice sports), and frequency (e.g., visits per week, visits during the last month, hours expended at the coastline and typical visit duration). Body contact with ocean water and coastal sand were assessed separately for various parts of the body. We assessed if participants observed unpleasant situations during their last visit to the coastline, including garbage and unhygienic risks, discharges, behavioral, and infrastructure. Perceptions of environmental quality included overall assessments of environmental, air and water quality.

Eight groups of health conditions were included: respiratory, gastrointestinal, ocular, otic, dermatological, urogenital, and injuries or accidents. Five health outcomes were selected for detailed reporting: respiratory allergies, eye allergies, ear infections, respiratory infections and diarrhea. Selected exposure variables include demographics, coastline interactions, body contact with water/sand, water quality reports, and observed unpleasant situations during participant's visit to the coastline.

2.4. Qualitative data

The qualitative component included open-ended survey questions, ethnographic insights from field visits, and semi-structured interviews with local healthcare providers, to better understand the scope and magnitude of public health issues. Open-ended and ethnographic field notes were included to document unexplored health risk patterns, environmental conditions and potential pollution sources. We conducted confidential semi-structured interviews with $n = 3$ health professionals who provided services to coastal communities. Interviews were recorded and transcribed to generate qualitative data.

Ethnographic field notes were taken by team members during fieldwork. Team members were given brief training in ethnographic observation methods and were instructed to take notes regarding the coastal environment (e.g. visible pollution, contamination, or trash) and public practices (e.g., surfing, hiking, or beach sports). These observations were used to contextualize quantitative insights.

2.5. Secondary water quality data

Coastal water quality data were obtained from official government surveillance programs in the United States and Mexico for the period of November 2024 to July 2025. Data were reported as the most probable number (MPN), colony-forming units (CFU), or copies of *Enterococcus* per 100 mL of water. Enterococci are fecal indicator bacteria commonly used to assess microbial contamination and potential health risks in recreational marine waters.

Water quality data for the US coastline were obtained from historical Beach and Bay Program conducted by the Environmental Health & Quality Department, which utilize Enterolert, membrane filtration, and droplet digital PCR (ddPCR) methods. In Mexico, surveillance data were obtained from the *Comisión Federal para la Protección contra Riesgos Sanitarios* (COFEPRIS) water quality monitoring program, under the Federal Ministry of Health, which uses the Enterolert method for routine assessment of *Enterococcus* concentrations.

2.6. Data analysis

Demographic composition, coastline interactions, contact with water and sand, health outcomes and perceptions were described with means and frequencies. Given the exploratory and descriptive nature of this study, our statistical approach aimed to identify potential associations and generate hypotheses regarding coastal exposure and health outcomes. We calculated unadjusted and adjusted odds ratios (OR and AdjOR) and 95 % confidence intervals (95 %CI), using regression models for selected health outcomes and exposure variables to describe associations. Covariates used in adjusted models included variables with a significant relationship (at the $p \leq 0.05$ level) in unadjusted models. We report both p-values and 95 % CIs to allow for a transparent assessment of effect magnitude and precision. We interpret associations with wide confidence intervals with caution, as they may indicate instability due to small subgroup sizes (particularly with geographic data). Missing values are reported in Supplementary Table 1.

Qualitative data were codified and analyzed using Atlas.ti. Responses were organized thematically, using a codebook created with categories chosen *a priori* and re-evaluated throughout the coding process. Methodological triangulation was conducted in weekly research meetings, combining qualitative and quantitative methods, comparing results for confirmation or contradiction, until saturation was reached.

Secondary water quality data from official monitoring systems were divided into three periods: November 2024 to January 2025, February to April 2025, and May to July 2025. We calculated the average enterococci level per period using available government data and calculated the overall average enterococci level per the whole period. Most available data were reported in MPN/100 mL, however, in sites where MPN data were unavailable, alternative units were reported. To address this lack of uniform reporting and measurement methods across the border, we aggregated these disparate data points into a standardized water contamination scale. This standardization was a methodological necessity to allow for a consistent binational comparison; at the same time, we acknowledge that this aggregation inherently obscures the fine-scale spatiotemporal variability of microbial concentrations. An average Enterococci contamination scale was developed with the following levels: 0=zero MPN/100 mL, 1 = 1–99 MPN/100 mL, 2 = 100–199 MPN/100 mL, 3 = 200–499 MPN/100 mL, 4 = 500–999 MPN/100 mL, and 5=>1000 MPN/100 mL.

3. Results

This study included survey responses from $n = 390$ participants, alongside qualitative data from three semi-structured interviews (health professionals and lifeguards) and eight ethnographic field notes. Participants residency included Tijuana (45 %), San Diego (38 %), and Playas de Rosarito (13 %), with 2 % residing in multiple locations (Table 1). The sample was predominantly female (67 %) and highly educated (15.4 [standard deviation ±2.4] years of school), with a mean age of 38.9 (±15.5) years. Demographic distributions were consistent across study locations. By nationality, 65 % were Mexican, 42 % US citizens, 10 % both Mexican and US citizens, and 8 % of other nationalities. Notably, 8 % of participants identified as having a disability and 3 % reported experiencing housing instability.

3.1. Coastal contact and interactions

More than half of the participants (53 %) visited the coastline area for recreational purposes; 49 % resided <2.5 km or 1.55 miles from the

Table 1
Demographic characteristics of study participants and their interactions with the Pacific Ocean coastline.

Variable	Value			
	Rosarito (n = 44)	Tijuana (n = 149)	San Diego (n = 128)	Total (n = 390)
Demographic characteristics				
Age (mean, SD)	38.8 (13.7)	37.9 (14.8)	40.2 (16.3)	38.9 (15.5)
Gender (%)				
Cis woman	28 (63.6 %)	93 (63.3 %)	93 (72.7 %)	242 (67.0 %)
Cis man	15 (34.1 %)	52 (35.4 %)	34 (26.6 %)	114 (31.6 %)
Trans woman, trans men or non-binary	1 (2.3 %)	2 (1.4 %)	1 (0.8 %)	5 (1.4 %)
Schooling (mean, SD)	15.0 (2.70)	15.4 (2.2)	15.8 (2.0)	15.4 (2.4)
Having a disability (%)	15.0 (2.70)	6 (4.3 %)	16 (13.7 %)	26 (8.4 %)
Experiencing housing instability (%)	0 (0 %)	1 (0.7 %)	7 (5.8 %)	8 (2.5 %)
Race/ethnicity (%)				
Hispanic, Latino, or Spanish Origin	37 (84.1 %)	118 (79.2 %)	51 (39.8 %)	239 (66.0 %)
White	3 (6.8 %)	9 (6.0 %)	73 (57.0 %)	94 (26.0 %)
Mestizo, 2+ races	7 (15.9 %)	20 (13.4 %)	11 (8.6 %)	37 (10.2 %)
Indigneous, Native American, Alaska Native, Hawaiian Native, Pacific Islander	0 (0 %)	3 (2.0 %)	9 (7.1 %)	12 (3.3 %)
Asian or Asian American	0 (0 %)	2 (1.3 %)	6 (4.7 %)	8 (2.2 %)
Afro Mexican, African American or Black	0 (0 %)	3 (2.0 %)	3 (2.3 %)	7 (1.9 %)
Nationality (%)				
Mexico & US	2 (4.5 %)	12 (8.1 %)	20 (15.7 %)	36 (10.0 %)
Mexico	37 (84.1 %)	143 (96.0 %)	28 (22.0 %)	233 (64.5 %)
US	7 (15.9 %)	15 (10.1 %)	113 (89.0 %)	152 (42.1 %)
Other	3 (6.8 %)	4 (2.7 %)	18 (14.2 %)	29 (8.0 %)
Residency (%)				
Municipality of Playas de Rosarito	44 (100 %)	2 (1.3 %)	0 (0 %)	44 (13.1 %)
Municipality of Tijuana	2 (4.5 %)	149 (100 %)	3 (2.3 %)	149 (44.5 %)
San Diego County	0 (0 %)	3 (2.0 %)	128 (100 %)	128 (38.2 %)
Interactions with the Pacific Ocean coastline				
Type of interaction (%)				
Recreational use	14 (31.8 %)	72 (50.0 %)	81 (64.8 %)	187 (53.4 %)
Residence	38 (86.4 %)	60 (41.7 %)	64 (51.2 %)	171 (48.9 %)
Work/study	14 (31.8 %)	23 (16.0 %)	42 (33.6 %)	84 (24.0 %)
Practice sports	9 (20.5 %)	19 (13.2 %)	23 (18.4 %)	60 (17.1 %)
Visiting once per week (%)	30 (68.2 %)	59 (40.4 %)	78 (62.4 %)	178 (50.3 %)
Visited in the last month (%)	38 (88.4 %)	111 (76.0 %)	113 (90.4 %)	287 (81.8 %)
Number of hours usually spend in the area (mean, SD)	4.1 (5.2)	4.6 (5.4)	3.6 (5.7)	4.0 (5.3)
Most common visit time (%)				
Day hours	11 (25.0 %)	51 (34.9 %)	36 (29.0 %)	121 (34.3 %)
Most of the day/night	11 (25.0 %)	22 (15.1 %)	25 (20.2 %)	61 (17.3 %)
In the afternoon	4 (9.1 %)	24 (16.4 %)	17 (13.7 %)	50 (14.2 %)
In the mornings/sunrise	4 (9.1 %)	10 (6.8 %)	7 (5.6 %)	23 (6.5 %)
In the evening/sunset	4 (9.1 %)	8 (5.5 %)	12 (9.7 %)	23 (6.5 %)
Beaches/coastal areas visited in the last 6 months (%)				
South Rosarito, Muelle and Popotla	26 (59.1 %)	43 (29.9 %)	6 (4.9 %)	85 (24.4 %)
Playas Santa Monica, El Bebe, and La Bardita	7 (15.9 %)	8 (5.6 %)	1 (0.8 %)	18 (5.2 %)
Playas de Rosarito	35 (79.5 %)	71 (49.3 %)	9 (7.4 %)	125 (35.9 %)
Baja Malibu	5 (11.4 %)	8 (5.6 %)	1 (0.8 %)	17 (4.9 %)
Playa Blanca	6 (13.6 %)	15 (10.4 %)	0 (0 %)	22 (6.3 %)
San Antonio de Mar	2 (4.5 %)	9 (6.3 %)	2 (1.6 %)	15 (4.3 %)
Rocky Area Southern Playas de Tijuana	1 (2.3 %)	24 (16.7 %)	3 (2.5 %)	28 (8.0 %)
Parque Azteca/Unidad Deportiva Parque Azteca (Playas de Tijuana)	0 (0 %)	41 (28.5 %)	1 (0.8 %)	45 (12.9 %)
Parque Mexico (Playas de Tijuana)	2 (4.5 %)	51 (35.4 %)	0 (0 %)	59 (17.0 %)
Playas de Tijuana, Malecon/Faro, or Parque los Sauces	12 (27.3 %)	114 (79.2 %)	17 (13.9 %)	161 (46.3 %)
Border Field State Park Beach	1 (2.3 %)	4 (2.8 %)	11 (9.0 %)	18 (5.2 %)
Tijuana River Valley	0 (0 %)	13 (9.0 %)	33 (27.0 %)	53 (15.2 %)
Imperial Beach	2 (4.5 %)	11 (7.6 %)	67 (54.9 %)	95 (27.3 %)
San Diego Bay National Wildlife Refuge	1 (2.3 %)	1 (0.7 %)	31 (25.4 %)	36 (10.3 %)
Coronado Cays Park	7 (15.9 %)	9 (6.3 %)	38 (31.1 %)	65 (18.7 %)
Silver Strand State Beach	0 (0 %)	0 (0 %)	30 (24.6 %)	35 (10.1 %)
Coronado Beach	6 (13.6 %)	4 (2.8 %)	65 (53.3 %)	86 (24.7 %)

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Table 1 (*continued*)

Variable	Value			
	Rosarito (n = 44)	Tijuana (n = 149)	San Diego (n = 128)	Total (n = 390)
San Diego Bay	4 (9.1 %)	15 (10.4 %)	80 (65.6 %)	113 (32.5 %)
Point Loma and Sunset Cliffs Natural Park	1 (2.3 %)	4 (2.8 %)	76 (62.3 %)	92 (26.4 %)
Who typically accompany participants (%)				
Family	18 (40.9 %)	84 (57.9 %)	40 (32.3 %)	168 (47.7 %)
Partner	18 (40.9 %)	49 (33.8 %)	63 (50.8 %)	144 (40.9 %)
Go by themselves	17 (38.6 %)	41 (28.3 %)	64 (51.6 %)	134 (38.1 %)
Friends	13 (29.5 %)	31 (21.4 %)	66 (53.2 %)	125 (35.5 %)
Clients, coworkers or classmates	6 (13.6 %)	7 (4.8 %)	16 (12.9 %)	36 (10.2 %)
Outdoor activities during the last month (%)				
Walking/hiking and running with/without dogs	38 (88.4 %)	113 (79.6 %)	109 (87.9 %)	289 (83.5 %)
Eating (picnicking, barbeque, dining in private business patios/food trucks/carts)	9 (20.9 %)	41 (28.9 %)	49 (39.5 %)	105 (30.3 %)
Sitting in public spaces or sunbathing (tanning, relaxing on the beaches)	10 (23.3 %)	24 (16.9 %)	46 (37.1 %)	87 (25.1 %)
Practicing aquatic sports (swimming, surfing, etc.)	3 (7.0 %)	9 (6.3 %)	23 (18.5 %)	42 (12.1 %)
Nautical/water-dependent activities	1 (2.3 %)	7 (4.9 %)	17 (13.7 %)	30 (8.7 %)
Practicing beachsports (volleyball, biking, rock climbing, etc.)	1 (2.3 %)	2 (1.4 %)	13 (10.5 %)	18 (5.2 %)

This table describes demographic characteristics among study participants who lived, worked or spent time at the binational Pacific Ocean coastline in 2024–2025. Demographic characteristics and self—reported interactions listed are reported by the city of residency and as a total number of participants. Participants can have more than one city of residency. Values are presented as mean and standard deviation (SD), or as n and percentage (%), indicated in each row.

ocean, and 24 % worked or studied on the coastline (Table 1). Coastal interaction was frequent, with 82 % of participants visiting the area in the month preceding the survey. Daytime visits were more common and weekly visits averaging four hours in duration predominated. San Diego residents were more likely to visit alone or with friends, whereas Tijuana and Rosarito residents primarily visited with family.

In the last month, nearly all participants (92 %) engaged in outdoor coastal activities, like walking or running (84 %), eating (30 %), and sitting in public spaces or sunbathing (25 %). San Diego residents practiced water-based activities (19 %) at more than double the rate of those in Tijuana (6 %) or Rosarito (8 %). Physical contact with the coastal environment was widespread: 78 % of participants reported contact with beach sand and 59 % with ocean water, primarily on lower extremities and face (Table 2). Less common activities also include beach sports, fishing, biking, rock climbing, activities in boats, beach combing, watching nature, and wind foiling.

Additionally, study participants reported 1058 visits in the last six months, revealing significant binational mobility. One in eight visits (12

Table 2
Health outcomes, contact with ocean water and beach sand, and participants perceptions.

Variable	n (%)	Variable	n (%)
Health conditions in the last month		*Body contact with the Pacific Ocean in last month*	
Respiratory conditions	163 (47.4 %)	Any contact with ocean water	204 (58.8 %)
Respiratory allergies (e.g., rhinitis, sinusitis, pharyngitis)	129 (37.5 %)	Legs and feet	193 (55.6 %)
Respiratory infections (e.g., flu, influenza, pneumonia)	74 (21.5 %)	Head (face, eyes, ears and mouth)	143 (41.2 %)
Gastrointestinal conditions	92 (26.7 %)	Whole body	115 (33.1 %)
Nausea	52 (15.1 %)	Any contact with coastal sand	269 (77.5 %)
Stomach pain	37 (10.8 %)	Legs and feet	259 (74.6 %)
Bloating	31 (9.0 %)	Head (face, eyes, ears and mouth)	169 (48.7 %)
Diarrhea (3+ loose stools/day)	22 (6.4 %)	Whole body	145 (41.8 %)
Vomiting	11 (3.2 %)	*Observed unpleasant situations during last visit*	
Blood in stool	2 (0.6 %)	Garbage and unygienic risks	
Parasitic diseases (e.g., amebiasis)	3 (0.9 %)	Urban garbage or littering	237 (69.7 %)
Eye conditions	64 (18.6 %)	Sharp objects (broken glass, needles)	142 (41.8 %)
Eye irritation/allergies	56 (16.3 %)	Decomposing animals	108 (31.8 %)
Eye infection (e.g., conjunctivitis)	15 (4.4 %)	Burning of garbage	100 (29.4 %)
Weather related conditions	44 (12.8 %)	Animal or insect pests (rats, cockroaches)	53 (15.6 %)
Dehydration	30 (8.7 %)	Discharges	
Heat exhaustion/stroke	14 (4.1 %)	Wastewater or sludge discharges	211 (62.1 %)
Hypothermia	3 (0.9 %)	Industrial or fats discharges	170 (50.0 %)
Swimmer's Ear (ear infection)	36 (10.5 %)	Industrial discharges	148 (43.5 %)
Skin conditions	32 (9.3 %)	Fat or oil discharges	99 (29.1 %)
Sunburn	22 (6.4 %)	Behavioral	
Skin reaction/irritation (e.g., dermatitis)	8 (2.3 %)	Unleashed dogs	152 (44.7 %)
Skin and soft tissue infections (e.g., abscess)	5 (1.5 %)	Tobacco smoke	73 (21.5 %)
Urogenital conditions	6 (1.8 %)	Drug dealing and/or drug consumption	45 (13.2 %)
Urinary tract infections	4 (1.2 %)	Drunk people	31 (9.1 %)

(*continued on next page*)

Table 2 (*continued*)

Variable	n (%)	Variable	n (%)
Genital irritation/ infection (e.g., vaginal infection)	2 (0.6 %)	Violence or people fighting	1 (0.3 %)
Injuries/accidents due to erosion of the coast	3 (0.9 %)	Infrastructure	
Behavioral risks		Drinking water not available	163 (41.8 %)
Smoking status		Sanitation facilities not available	143 (36.7 %)
Smoking risk (smokes/ used to/live with someone who smokes)	79 (23.5 %)	Insufficient shaded spaces for sun protection	120 (35.3 %)
Active smoker	43 (12.8 %)	Unhealthy food stalls	104 (30.6 %)
Chronic conditions diagnosed on household members in the last year		Hand hygiene facilities not available	97 (28.5 %)
Asthma	25 (7.6 %)	Insufficient security or lifeguards	76 (22.4 %)
Diabetes	21 (6.4 %)	*Perceptions of environmental quality at coastal areas visited in the last month**	
Hypertension	15 (4.6 %)	Bad air quality	190 (57.6 %)
Cancer	10 (3.0 %)	Bad water quality	130 (39.2 %)
Autoimmune diseases	5 (1.5 %)	Bad overall environmental quality	171 (50.9 %)
COPD	5 (1.5 %)		

*Bad air quality includes unhealthy for sesitive groups or the general public, very unhealthy and hazardous; bad water quality includes poor and very poor; and bad overall environmental quality includes poor and very poor.
This table describes self-reported outcomes of health, environmental exposure, observing unpleasant situations at the coastline and perceptions of environmental quality, spanning from last visit to last year (stated on each variable). Results are shown as number (n) and percentages of the total available responses per variable. Multiple selection was allowed, so percentages may not sum to 100 %. Chronic conditions diagnosed with household members are reported diagnoses, not clinically verified. Observed unpleasant situations during the last visit included sightings of any of the listed situations at the coastlines in the last month.

%) involved crossing the US-Mexico border. Nine percent of the visits reported by residents of San Diego were in Tijuana or Rosarito. Thirteen percent of the visits by residents of Tijuana and 20 % of the visits by residents of Rosarito were in the San Diego coastline. Regardless of their residency, the most frequented sites were concentrated around *Playas de Tijuana, Playas de Rosarito*, and the *San Diego Bay* (Fig. 1).

3.2. Water and environmental quality

Analysis of official governmental reports across 21 study sites revealed substantial *Enterococcus* contamination between November 2024 and July 2025. No site reported zero enterococci during the study period. The highest contamination levels were concentrated in *Imperial Beach, Silver Strand State Beach*, and the *Playas de Tijuana* area (Malecon/ Faro). Notably, 76 % of monitored sites (16/21) exceeded the water contamination threshold of 200 MPN/100 mL (Scale $\geq$ 3) (Table 3).

Quantitative findings were corroborated by qualitative data, with participants and health professionals expressing significant concern regarding the binational coastal environment.

> *'We've learned or observed that the water –especially in the Playas de Tijuana area- is contaminated and it doesn't comply with some of the regulations that exist in Mexico to adequately conserve the environment… Rosarito and Playas de Tijuana are beaches that every year are still shown as generally very contaminated…"* (Male medical doctor, City of Tijuana [translated from Spanish])

This concern aligned with broader participant awareness: 39 % rated water quality as "poor" or "very poor," and 58 % perceived coastal air quality as harmful or hazardous. Overall, more than half of the participants (51 %) held a negative perception of the general environmental quality at the sites they visited, suggesting that public awareness of the contamination is high.

3.3. Health conditions

Participants reported a high burden of acute health issues in the preceding month, primarily allergic (44 %) and infectious (40 %) conditions. Respiratory symptoms were the most prevalent (47 %), comprising of both allergies (37 %) and infections (22 %). These conditions were more frequently reported by San Diego residents (46 % allergies; 30 % infections) compared to those in Tijuana (33 %; 15 %) and Rosarito (37 %; 28 %) (Table 2).

Qualitative insights linked mirrored these findings. A lifeguard in Coronado noted a perceived longitudinal increase in respiratory illness among staff, attributing it to both direct water contact and the inhalation of "polluted sea spray". This was echoed by a Tijuana-based physician who observed a clinical rise in cases among residents after they moved to coastal neighborhoods:

> *"…as the water quality has gotten worse over the past several years, more [lifeguards] are becoming ill from exposure to the water and even the air… whether it's congestion or mild infections… you're going to be exposed to polluted water and polluted sea spray hundreds, if not thousands of times."* — Male Lifeguard, Coronado

> *"I have noticed that many people who move [to Playas de Tijuana] start having many respiratory illnesses and allergies… it's half and half [viral and allergic]. There is a lot of moisture inside the houses; you can feel it, the clothes smell damp."* — Female Physician, Playas de Tijuana

Gastrointestinal (GI) conditions were reported by 27 % of participants. Diarrheal diseases were reported nearly twice as often in San Diego (12 %) compared to Rosarito (7 %) and four times more often than in Tijuana (3 %). Residents and clinicians consistently linked these spikes to water quality. A Tijuana physician noted a seasonal rise in rotavirus cases coinciding with peak beach tourism, while a Rosarito resident observed that illnesses frequently followed exposure to "fecal bacteria above the maximum permitted level."

Sensory conditions included eye allergies (16 %) and ear infections (10 %). The latter was significantly more common among San Diego residents (16 % vs. 6–9 % in Mexico). While skin conditions and injuries from coastal erosion were less frequent, they represented a shared concern for both human and animal health. Health professionals suggested these patterns reflect broader ecological shifts, linking illness to polluted coastal waters, sea spray, and high indoor humidity. This environmental connection is underscored by a case of a resident splitting time between coastal Playas de Tijuana and inland San Diego; she reported that respiratory allergies appeared immediately upon arriving at the coast and resolved upon returning inland.

Beyond acute conditions, participants reported a variety of chronic diagnoses within their families over the past year. The most frequent were asthma (8 %), diabetes (6 %), hypertension (5 %), and cancer (3 %).

3.4. Perceptions and coastal infrastructure

On average, participants observed five ($\pm$4) unpleasant conditions

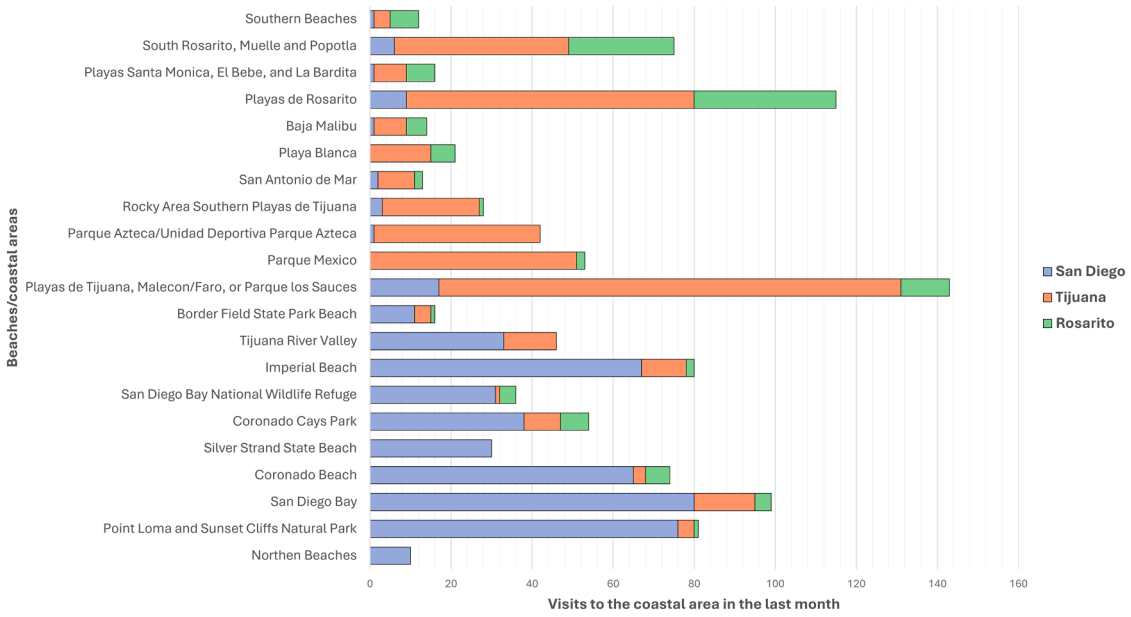


Fig. 1. Most visited beaches and coastal areas in the last month by place of residency.
This figure describes the frequency of visits in the last month to every beach or coastal area in the binational Pacific Ocean coastline, by participant's place of residency. Residency for San Diego, Tijuana and Rosarito included San Diego County, and the Municipalities of Tijuana and Playas de Rosarito respectively. Beaches are organized from northernmost to southernmost. Visits from San Diego residents are shown in blue, visits from Tijuana residents are shown in orange and visits from Rosarito residents are shown in green. "Southern beaches" and "Northern beaches" are beyond the scope of the study. Multiple selections were allowed.

during their visits to the coastline in the previous month. The most common issues related to pollution and waste management, including urban garbage or littering (70 %), wastewater or sludge discharges (62 %), industrial or oil/fat discharges (50 %) (Table 2).

The lack of basic infrastructure was also reported; participants identified deficits in drinking water (42 %), sanitation facilities (37 %), and shaded areas for sun protection (35 %). Other concerns included unleashed pets (45 %), dangerous or sharp objects (42 %), noise pollution, sargassum, and a pervasive "sewage odor". These conditions hindered the use of public spaces, with 46 % of participants considering not returning to specific beaches due to perceived health and safety risks. This avoidance is reflected in the lived experiences of residents on both sides of the border:

> *"We haven't been able to practice our exercises on the beach for more than two years due to sewage pollution"* — 72-year-old female, San Diego

> *"I have seen sewage waste from a building next to the beach, which is about to collapse [due to erosion]."* — 33-year-old male, Tijuana

3.5. Health risk associations

3.5.1. Geographic and demographic associations

Analysis identified several variables associated with reported health conditions. Coastal residency was associated with a higher frequency of reported health conditions, including a three-fold higher odds of diarrheal illness [OR (95 %CI): 3.0 (1.2–8.4), $p = 0.028$], 2.6 times higher odds of ear infections [2.6 (1.3–5.6), $p = 0.013$], and elevated reports of respiratory [1.85 (1.2–2.9), $p = 0.007$] and eye allergies [1.85 (1.0–3.4), $p = 0.042$] compared to those who visit, work, or study in the area. Regionally, San Diego County residents reported 4.2 times higher odds of diarrhea [4.2 (1.6–12.1), $p = 0.004$], 2.6 times higher odds of ear infections [2.6 (1.3–5.7), $p = 0.011$], 1.97 times higher odds of respiratory infections [1.97 (1.2–3.4), $p = 0.013$], and 1.67 times higher odds of respiratory allergies [1.67 (1.1–2.7), $p = 0.031$] compared to those in Tijuana or Rosarito. In multivariable models, residency in San Diego County remained significantly associated with ear infections [AdjOR (95 %CI): 5.1 (1.3–22.3), $p = 0.023$] and diarrheal diseases [9.7 (2.4–48.2), $p = 0.003$] (Fig. 2).

3.5.2. Site-specific health clusters

Visiting specific coastal areas was linked to various health outcomes. In Mexico, visiting the beaches of *La Bardita, El Bebe, or Santa Monica* was associated with elevated odds across three categories: diarrheal conditions [OR (95 %CI): 6.9 (2.0–20.7), $p = 0.001$], ear infections [4.8 (1.6–13.4), $p = 0.003$], and respiratory infections [3.9 (1.5–10.5), $p = 0.005$]. The association with respiratory infections remained in the adjusted model [AdjOR (95 %CI): 3.2 (1.0–9.8), $p = 0.038$]. Participants visiting *Muelle or Southern Rosarito* reported 2.6 times the odds of ear infections [2.6 (1.2–5.2), $p = 0.010$]. Visits to *San Antonio del Mar* and *Baja Malibu* were linked to eye allergies [4.1 (1.3–12.4), $p = 0.012$ and 3.0 (1.0–8.2), $p = 0.040$, respectively] and ear infections [3.7 (1.0–11.6), $p = 0.037$ and 3.9 (1.2–11.3), $p = 0.016$, respectively], although these associations did not reach significance after adjustment (Table 4).

In Southern San Diego, visiting *Imperial Beach* was linked to respiratory allergies [2.3 (1.4–3.8), $p = 0.001$], respiratory infections [1.9 (1.1–3.2), $p = 0.025$], eye allergies [2.8 (1.5–5.1), $p = 0.001$], and ear infections [2.1 (1.0–4.2), $p = 0.048$], with eye allergies remaining significant after adjustment [AdjOR (95 %CI): 2.5 (1.3–4.9), $p = 0.007$]. *Border Field State Park* showed the strongest associations; visitors reported 9.1 times the odds of respiratory allergies [9.1 (2.9–39.8), $p = 0.001$] and 3.1 times the odds of respiratory infections [3.1 (1.1–8.1), $p = 0.022$]. The association with respiratory allergies remained significant in the final model [AdjOR (95 %CI): 6.8 (1.9–32.3), $p = 0.006$].

3.5.3. Respiratory conditions

Respiratory allergies were linked to female gender [OR (95 %CI): 1.7 (1.1–2.8), $p = 0.030$], visiting beaches with high enterococci levels [2.7 (1.4–5.6), $p = 0.004$], observations of wastewater [2.0 (1.3–3.3), $p = 0.003$] and tobacco smoke [1.8 (1.1–3.1), $p = 0.027$] at the coastline, eating outdoors [1.8 (1.1–2.7), $p = 0.014$], and weekly coastal visits [1.6 (1.0–2.5), $p = 0.031$]. After adjustment, female gender [AdjOR (95 % CI): 2.4 (1.4–4.3), $p = 0.004$] and observation of tobacco smoke [1.9

Table 3
Pacific Ocean coastline locations and enterococci level average by official government agencies in the US and Mexico from November 2024 to July 2025.

Site name	Site name in monitoring program	North latitude coordinates	West longitude coordinates	Mean enterococcus MPN/100 ml per period/site (Nov-Jan 2024–25)	Mean enterococcus MPN/100 ml per period/site (Feb-Apr 2025)	Mean enterococcus MPN/100 ml per period/site (May-Jul 2025)	Mean enterococcus MPN/100 ml per site (all period)	Water contamination scale level by site[a]
Rosarito								
Muelle Rosarito	Rosarito I	32° 20′ 08.0″N	117° 03′ 28.2″W	197	301	42	180	2
Playas de Rosarito	Rosarito II	32° 20′ 47.2″N	117° 03′ 49.2″W	237	185	78	155	2
	Hotel Rivera	32°2026.2″N	117°0337.3″W	93	232	101		
Playa La Bardita/ Playa El Bebé/Playa Santa Monica	Rosarito III	32° 21′ 40.8″N	117° 04′ 12.3″W	298	722	43	354	3
Tijuana								
Baja Malibú	Baja Malibú	32°25′01.99″N	117°05′48.8″W	3609	1291	623	1841	5
Playa Blanca	Playa Blanca	32°25′10.72″N	117°05′51.08″W	3324	534	590	2,432[d]	5
	BC-010[b]	32°25′08.8″N	117°05′50.3″W	3757	3664	2721		
San Antonio del Mar	Tijuana I (San Antonio del Mar)	32°25′59.07″N	117°06′05.12″W	1284	609	741	878	4
Rocky Area Southern Playas de Tijuana	El Vigía	32°30′09.53″N	117°07′26.50″W	1354	1590	19	1,092[d]	5
	BC-020[b]	32°29′55.3″N	117°07′22.8″W	2113	1059	418		
Parque Azteca/ Unidad Deportiva	Cañada Azteca	32°31′16.25″N	117°07′28.86″W	789	1795	13	866	4
Parque México	Tijuana II (Parque México)	32°31′39.6″N	117°07′28.0″W	216	14,136	18	3,081[d]	5
	BC-030[b]	32°31′32.5″N	117°07′26.4″W	1853	2004	259		
Malecón/ Faro/ Parque Los Sauces	Tijuana III (La Mojonera/ El Faro)	32°32′01.0″N	117°07′28.3″W	146	15,531	17	5231	5
San Diego								
Border Field State Park	IB-010	32°32′09.4″N	117°07′27.5″W	160	1550	141	617	4
Tijuana River Valley	IB-020	32°32′36.3″N	117°07′30.8″W	746	2545	259	1183	5
Imperial Beach	IB-060	32°35′08.4″N	117°07′59.0″W	57	614	168	34,567[c]	5
	EH-030	32°34′43.5″N	117°07′59.5″W	22,714[c]	159,490[c]	185,742[c]		
	EH- 010	32°34′21.6″N	117°07′59.5″W	23,925[c]	187,153[c]	220,157[c]		
	IB-050	32°33′59.7″N	117°07′59.5″W	279	1263	1353		
San Diego Bay National Wildlife Refuge	EH-120	32°37′43.7″N	117°06′29.1″W	no data	1,268[c]	492[c]	880[c]	4
Coronado Cays Park	EH-575	32°37′41.3″N	117°08′10.4″W	no data	no data	240[c]	240[c]	3
Silver Strand State Beach	IB-068	32°37′35.0″N	117°08′21.9″W	11,707[c]	39,391[c]	21,715[c]	24,271[c]	5
San Diego Bay	EH-090	32°38′10.7″N	117°08′28.0″W	297[c]	1,351[c]	641[c]	763[c]	4
Coronado Beach	IB-079	32°40′26.6″N	117°10′20.3″W	2,710[c]	13,070[c]	7,533[c]	7,771[c]	5
Point Loma	PL-050	32°40′49.7″N	117°14′55.7″W	3	2	2	2	1
	PL-040	32°39′55.1″N	117°14′35.5″W	2	2	2	2	1
Sunset Cliffs Natural Park	PL-070	32°43′09.6″N	117°15′25.0″W	2	6	4	4	1

Data source: Department of Environmental Health and Quality, Beach and Bay Monitoring Program, County of San Diego (US), and Comisión Federal para la Protección contra Riesgos Sanitarios (COFEPRIS), Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT), Secretaría de Salud & Red Nacional de Laboratorios de Salud Pública (Mexico).
a: Enterococci average contamination scale level by site, 0=zero MPN/100 mL, 1 = 1–99 MPN/100 mL, 2 = 100–199 MPN/100 mL, 3 = 200–499 MPN/100 mL, 4 = 500–999 MPN/100 mL, and 5=>1000 MPN/100mL.
b: Tijuana sites with measurments from San Diego.

c: Results in ddPCR (copies/100 ml).
d: Average of available measurements per site.
Data source: Department of Environmental Health and Quality, Beach and Bay Monitoring Program, County of San Diego (US), and Comisión Federal para la Protección contra Riesgos Sanitarios (COFEPRIS), Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT), Secretaría de Salud & Red Nacional de Laboratorios de Salud Pública (Mexico).
a: Enterococci average contamination scale level by site, 0=cero MPN/100 mL, 1 = 1–99 MPN/100 mL, 2 = 100–199 MPN/100 mL, 3 = 200–499 MPN/100 mL, 4 = 500–999 MPN/100 mL, and 5=>1000 MPN/100mL.
b: Tijuana sites with measurements from San Diego.
c: Results in ddPCR (copies/100 mL).
d: Average of available measurements per site.
This table describes secondary data measurements of the enterococci level average obtained from official governmental agencies public reports in the US and Mexico from November 2024 to July 2025. It includes data from the monitoring programs of COFEPRIS/SEMARNAT for Tijuana and Playas de Rosarito, and the Beach and Bay Monitoring Program of the County of San Diego for San Diego County's data and three Mexican sites in Tijuana (BC-030, BC-020 and BC-010).

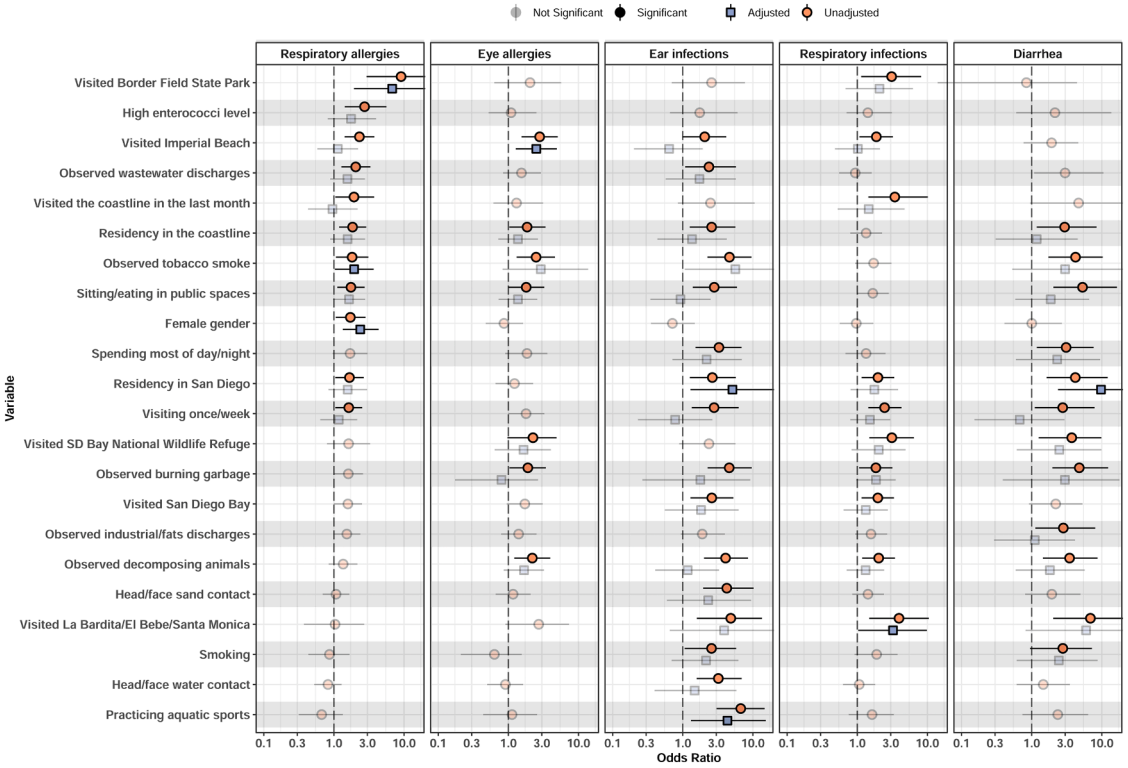


Fig. 2. Adjusted and unadjusted odds ratios of selected health outcomes and exposure/demographic variables.
This figure describes self-reported health outcomes experienced by study participants in the last month. Visiting beaches/coastal areas referred to any visit in the last month. Observed variables referred to unpleasant conditions observed by participants in the beach/coastal area visited in the last month. High enterococci level was an average level >200MPN/ml in the beaches between November 2024 and July 2025; Sitting/eating in public spaces referred to activities in the last month in the coastline, including picnicking, barbequing, tanning, among others. Residency on the coastline includes living <2.5 km or 1.55 miles from the Pacific Ocean. Residency in San Diego included any part of San Diego County. Smoking includes active tobacco smokers. Head/face water contact referred to Pacific Ocean water contact in the previous month; and practicing aquatic sports include swimming, surfing, kayaking and other sports practiced in the last month in the ocean.

(1.0–3.7), $p = 0.040$] remained significant. Respiratory infections were associated with weekly visits [2.5 (1.4–4.3), $p = 0.001$], observing decomposing animals [2.0 (1.2–3.5), $p = 0.010$], and observing burning garbage [1.8 (1.1–3.2), $p = 0.027$], with the latter remaining significant after adjustment [AdjOR (95 %CI): 1.9 (1.0–3.6), $p = 0.050$].

3.5.4. Eye and ear conditions

Eye allergies were associated with observations of tobacco smoke [OR (95 %CI): 2.5 (1.3–4.6), $p = 0.004$], decomposing animals [2.2 (1.2–3.9), $p = 0.009$], burning garbage [1.9 (1.0–3.4), $p = 0.035$], and eating outdoors [1.8 (1.0–3.2), $p = 0.050$]. Ear infections were linked to aquatic sports [6.7 (3.0–14.6), $p < 0.001$], head/face contact with sand [4.2 (2.0–10.2), $p = 0.001$] or water [3.2 (1.6–6.9), $p = 0.002$], and environmental observations including tobacco smoke, burning garbage, decomposed animals, and wastewater discharges. In the final model, aquatic sports remained the variable most significantly associated with ear infections [AdjOR (95 %CI): 4.3 (1.3–15.2), $p = 0.018$].

3.5.5. Gastrointestinal conditions

GI symptoms were associated with coastal visits [2.3 (1.1–5.2), $p = 0.029$], head/face contact with sand [2.1 (1.3–3.5), $p = 0.003$], and observing decomposed animals [2.4 (1.5–4.0), $p = 0.001$] or industrial discharges [1.8 (1.1–3.0), $p = 0.016$]. Reported diarrhea was linked to eating or sitting outdoors at the coastline [5.3 (2.0–16.5), $p = 0.001$], observing burning garbage [4.8 (2.0–12.3), $p = 0.001$], tobacco smoke [4.2 (1.7–10.3), $p = 0.000$], and decomposing animals [3.5 (1.4–8.7), $p = 0.006$]. Following multivariable adjustment, only geographic variables retained significant associations with GI and diarrheal conditions.

3.5.6. Summary of health risk patterns

The statistical associations reveal three consistent patterns. First, geographic location serves as a primary indicator of reported health

Table 4
Health outcomes by residency at the coastline, residency in Rosarito, Tijuana or San Diego, and coastal sites visited in the last month.

	Respiratory allergies			Eye allergies			Respiratory infections			Ear infections			Diarrhea		
Site of residence or visit in the last month	%	OR (95 %CI)	p value	%	OR (95 %CI)	p value	%	OR (95 %CI)	p value	%	OR (95 %CI)	p value	%	OR (95 %CI)	p value
Residency in the coastline	44.9	1.85 (1.19 - 2.89)	0.007**	20.4	1.85 (1.03 - 3.39)	0.042*	24.0	1.34 (0.80 - 2.26)	0.274	15.0	2.58 (1.25 - 5.63)	0.013*	9.6	2.95 (1.18 - 8.40)	0.028*
Rosarito															
Residency	37.2	0.97 (0.49 - 1.86)	0.916	14.0	0.86 (0.31 - 2.02)	0.739	27.9	1.42 (0.67 - 2.88)	0.340	9.3	0.90 (0.26 - 2.46)	0.859	7.0	1.14 (0.26 - 3.60)	0.837
Visiting in the last month															
Muelle Rosarito	37.8	0.99 (0.59 - 1.64)	0.958	23.2	1.79 (0.95 - 3.30)	0.065	26.8	1.45 (0.80 - 2.55)	0.210	18.5	2.55 (1.23 - 5.21)	0.010*	8.5	1.51 (0.56 - 3.71)	0.390
Playas de Rosarito	36.9	0.93 (0.58 - 1.46)	0.740	18.9	1.30 (0.71 - 2.32)	0.387	23.8	1.19 (0.70 - 2.02)	0.517	14.9	1.93 (0.96 - 3.89)	0.063	9.0	1.86 (0.77 - 4.47)	0.162
La Bardita/El Bebé/Santa Monica	38.9	1.04 (0.37 - 2.71)	0.940	33.3	2.71 (0.91 - 7.33)	0.057	50.0	3.94 (1.48 - 10.48)	0.005**	33.3	4.83 (1.59 - 13.43)	0.003**	27.8	6.88 (2.02 - 20.71)	0.001***
Tijuana															
Residency	32.6	0.66 (0.42 - 1.05)	0.083	14.2	0.82 (0.44 - 1.50)	0.515	14.9	0.45 (0.25 - 0.78)	0.006**	6.4	0.46 (0.20 - 1.00)	0.061	2.8	0.30 (0.08 - 0.83)	0.033*
Visiting in the last month															
Baja Malibú	47.1	1.48 (0.54 - 3.96)	0.435	35.3	2.97 (0.98 - 8.18)	0.040*	35.3	2.04 (0.68 - 5.56)	0.176	29.4	3.90 (1.18 - 11.29)	0.016*	11.8	2.01 (0.3 - 7.83)	0.374
Playa Blanca	47.6	1.52 (0.62 - 3.71)	0.354	23.8	1.64 (0.52 - 4.39)	0.357	19.0	0.83 (0.23 - 2.34)	0.750	19.0	2.10 (0.58 - 6.08)	0.207	0.0	NA	NA
San Antonio del Mar	42.9	1.23 (0.40 - 3.62)	0.706	42.9	4.12 (1.31 - 12.37)	0.012*	21.4	0.98 (0.22 - 3.22)	0.970	28.6	3.65 (0.96 - 11.62)	0.037*	0.0	NA	NA
Rocky Area Southern Playas de Tijuana	51.9	1.84 (0.83 - 4.11)	0.128	29.6	2.32 (0.91 - 5.43)	0.062	14.8	0.60 (0.17 - 1.63)	0.362	14.8	1.52 (0.42 - 4.25)	0.468	3.7	0.53 (0.03 - 2.71)	0.546
Parque Azteca/ Unidad Deportiva	45.5	1.42 (0.74 - 2.69)	0.280	20.5	1.36 (0.58 - 2.90)	0.452	18.2	0.77 (0.32 - 1.66)	0.531	11.6	1.12 (0.37 - 2.83)	0.824	2.3	0.30 (0.02 - 1.51)	0.250
Parque México	43.1	1.29 (0.72 - 2.28)	0.385	20.7	1.41 (0.67 - 2.80)	0.349	20.7	0.92 (0.44 - 1.80)	0.818	10.5	0.98 (0.36 - 2.34)	0.973	3.4	0.47 (0.07 - 1.66)	0.313
Malecón/ Faro/ Parque Los Sauces	40.3	1.19 (0.77 - 1.85)	0.433	13.8	0.69 (0.38 - 1.23)	0.213	15.7	0.50 (0.29 - 0.85)	0.011*	8.2	0.61 (0.29 - 1.24)	0.179	3.8	0.40 (0.14 - 1.01)	0.064
San Diego															
Residency	45.5	1.67 (1.05 - 2.65)	0.031*	17.4	1.22 (0.66 - 2.25)	0.519	29.8	1.97 (1.16 - 3.37)	0.013*	15.7	2.64 (1.26 - 5.68)	0.011*	11.6	4.19 (1.63 - 12.12)	0.004**
Visiting in the last month															
Border Field State Park	83.3	9.08 (2.92 - 39.79)	0.001***	27.8	2.04 (0.63 - 5.66)	0.194	44.4	3.09 (1.14 - 8.14)	0.022*	22.2	2.57 (0.70 - 7.68)	0.114	5.6	0.84 (0.05 - 4.42)	0.869
Tijuana River Valley	50.0	1.79 (0.98 - 3.25)	0.056	15.4	0.91 (0.38 - 1.95)	0.811	23.1	1.09 (0.52 - 2.15)	0.813	11.5	1.11 (0.40 - 2.66)	0.822	5.8	0.86 (0.20 - 2.66)	0.819
Imperial Beach	52.7	2.31 (1.42 - 3.77)	0.001***	28.0	2.79 (1.54 - 5.06)	0.001***	30.1	1.87 (1.08 - 3.23)	0.025*	16.1	2.05 (0.99 - 4.16)	0.048*	9.7	1.92 (0.77 - 4.62)	0.149
San Diego Bay National Wildlife Refuge	48.6	1.62 (0.80 - 3.28)	0.179	28.6	2.24 (0.97 - 4.86)	0.047*	42.9	3.11 (1.49 - 6.43)	0.002**	20.0	2.36 (0.89 - 5.64)	0.065	17.1	3.72 (1.26 - 9.86)	0.011*
Coronado Cays Park	44.6	1.4 (0.81 - 2.42)	0.227	21.5	1.52 (0.75 - 2.93)	0.228	18.5	0.77 (0.37 - 1.50)	0.466	12.3	1.23 (0.50 - 2.72)	0.630	7.7	1.26 (0.40 - 3.33)	0.662

(*continued on next page*)

Table 4 (*continued*)

Site of residence or visit in the last month	Respiratory allergies			Eye allergies			Respiratory infections			Ear infections			Diarrhea		
	%	OR (95 %CI)	p value	%	OR (95 %CI)	p value	%	OR (95 %CI)	p value	%	OR (95 %CI)	p value	%	OR (95 %CI)	p value
Silver Strand State Beach	54.3	2.09 (1.04 - 4.29)	0.040*	28.6	2.24 (0.97 - 4.86)	0.047*	25.7	1.27 (0.54 - 2.76)	0.558	11.4	1.09 (0.31 - 2.99)	0.875	5.7	0.86 (0.13 - 3.13)	0.844
San Diego Bay	45.5	1.58 (0.99 - 2.52)	0.052	21.8	1.72 (0.95 - 3.08)	0.071	30.0	1.97 (1.15 - 3.34)	0.012*	17.3	2.59 (1.29 - 5.26)	0.008**	10.0	2.20 (0.91 - 5.31)	0.075
Coronado Beach	48.8	1.81 (1.10 - 2.99)	0.020*	22.6	1.72 (0.91 - 3.17)	0.085	26.2	1.39 (0.77 - 2.44)	0.266	15.5	1.84 (0.87 - 3.77)	0.102	9.5	1.81 (0.70 - 4.40)	0.199
Point Loma & Sunset Cliffs Natural Park	38.6	1.03 (0.62 - 1.70)	0.896	17.0	1.05 (0.54 - 1.98)	0.877	25.0	1.28 (0.71 - 2.24)	0.403	18.2	2.56 (1.24 - 5.18)	0.009**	9.1	1.69 (0.65 - 4.10)	0.254

Signif. codes: 0 '***' 0.001 '**' 0.01 '*.'
Significant value $p < 0.05$: * 0.01, ** 0.001, *** <0.001.
This table describes associations of selected health outcomes with residency of the coastline (<2.5 Km or 1.55 miles), place of residency, and beach or coastal area visited in the last month among study participants. Each site of residence or visit in the last month contains a percentage prevalence (%), odds ratio (OR), 95 % confidence interval (CI) and p value associated with every health outcome. Participants could report more than one condition.

conditions, with San Diego residency and proximity to the coastline showing the most frequent associations with GI and respiratory conditions after multivariable adjustment. Second, certain beaches, such as *Border Field State Park* in San Diego and the *La Bardita/El Bebe* cluster in Rosarito, exhibit concentrated associations with respiratory and infectious symptoms, suggesting localized environmental factors. Finally, behavioral exposures —specifically aquatic sports and head-to-water contact—are consistently linked to elevated reports of ear infections. These patterns highlight a clear intersection between geographic residency, specific coastal sites, and recreational activities in the reporting of acute health issues within this border region.

4. Discussion

This study explored the binational coastal interactions and self-reported health outcomes in San Diego, Tijuana, and Rosarito. We described common activities, visit frequency, social contexts, and specific sites visited, including cross-border movement and contact with ocean water and sand. Our findings show a consistent pattern of respiratory symptoms, allergic reactions, GI symptoms, and eye and ear conditions specific coastal locations and behaviors. Health conditions explored may be related – but not limited – to the environmental risk factors.

4.1. Residency and regional factors

Coastal residency was associated with allergies (respiratory and eye), ear infections and diarrhea, though only in unadjusted models. This finding emphasizes the need for nuance regarding specific sites, exposure duration, and interactions that may represent health risks. In multiple contexts, residency near the ocean provides physical and mental health benefits (Gascon et al., 2017), which may counterbalance particular health risks in this binational coastline.

Selected health outcomes were more frequently reported by participants living in San Diego. Residency in San Diego County was associated with diarrhea diseases and ear infections; in unadjusted models, it also correlated with respiratory allergies and infections. This higher frequency requires further research to identify potential etiologies and risk factors. These findings should be interpreted through the lens of differential risk perception and health literacy across national contexts, which may relate with environmental, self-perception, aquatic activities, and cultural differences. National differences in public health messaging, media attention on water quality, and cultural thresholds for reporting symptoms may lead to higher reporting in certain populations, regardless of objective exposure levels.

Furthermore, participants' experiences are not strictly linked with their city of residence. Many participants work or recreate in coastal areas across the border. This cross-border flow increases the complexity of coastal usage patterns. For example, San Diego residents may dine in Rosarito, while Tijuana residents may surf in San Diego. This constant movement—connected with dual residency, nationality, work and recreational dynamics—highlights the necessity of a binational coastal community perspective in this region.

4.2. Site-specific associations

Visiting certain beaches and coastal areas in San Diego and Playas de Rosarito was associated specific health outcomes. The most notable associations occurred among those who visited *Border Field State Park, Imperial Beach, San Diego Bay National Wildlife Refuge,* and *San Diego Bay* in the last month. *Border Field State Park,* the area closest to the border, was associated with respiratory conditions. *Imperial Beach* visits were associated with respiratory conditions, ear infections, and—most strongly—with respiratory and eye allergies.

These associations align with the geographic proximity to the Tijuana River Estuary, suggesting this area should be prioritized for future exposure modeling. This source of environmental contamination is linked to an air quality crisis due to airborne exposure of wastewater-derived pollutants, including a wide range of industrial contaminants (B. Rico et al., 2025). Air pollutants can reach further inland compared to coastal water pollution, and may be related to our finding of more frequent eye allergies reported among *San Diego Bay National Wildlife Refuge* and *Silver Stand State Beach* visitors, and respiratory allergies among *Silver Stand State Beach* and *Coronado Beach* visitors.

Ear infections were significantly associated with visits to *Imperial Beach, San Diego Bay,* and *Point Loma.* This association could be related to frequent aquatic activities—such as swimming and surfing—which remained significant after adjusting for covariates. Existing literature indicates that swimmers face more than double the risk of GI conditions and 78 % higher risk of respiratory illness compared to non-swimmers (Russo et al., 2020). Likewise, beachgoers in England and Wales showed elevated odds of developing skin, respiratory and eye conditions compared to non-bathers (Leonard et al., 2020). While we did not find significant associations between aquatic sports and gastrointestinal or

respiratory conditions in our final models, the positive direction of these associations suggests they should be studied further in larger samples of swimmers and surfers.

Along the Mexican coast, this study contributes to management strategies by providing the first empirical data on health outcomes for Tijuana and Rosarito coastal users. Previously, such data were unavailable. Participants who visited *La Bardita/El Bebe/Santa Monica* beaches in Playas de Rosarito reported more frequent diarrhea, ear and respiratory infections, and respiratory infections remained significant after adjusting. These beaches are close to *Baja Malibu, Playa Blanca* and *San Antonio del Mar*. In these areas, a strong association with risk factors was expected due their proximity to the *San Antonio de los Buenos* water treatment plant, where a significant portion of the Tijuana River water is diverted to the ocean. Although unadjusted models associated visits to *Baja Malibu* and *San Antonio del Mar* with eye allergies and ear infections, only the associations for *La Bardita/El Bebe/Santa Monica* remained significant in the final models. This discrepancy is consistent with previous studies documenting critical exceedances of water quality standards at the *San Antonio de los Buenos* creek discharge (L.M. Sassoubre et al., 2012; Thulsiraj et al., 2017). It also aligns with Mexican surveillance systems that rank *Playa Blanca* and BC-010 among the most polluted sites. The lack of more robust final association at the immediate discharge sites may result from several factors: limited sample size at specific beaches, a greater perception of risk among local communities who avoid contaminated water, and the potential existence of additional diffuse pollution sources. While small sample sizes in these geographic strata may result in wider confidence intervals, identifying these tendencies remains a public health priority. From a preventative perspective, these findings serve as critical signals that help characterize geographic 'hot spots' of risk, and preliminary indicators to guide future research in these high-exposure binational zones.

The binational region of San Diego and Tijuana has experienced rapid urbanization with unmitigated environmental consequences (Cysneiros de Carvalho et al., 2025). The city of Tijuana faces challenges in meeting the demands for infrastructure and public services, including the sewage system (Calderón-Villarreal et al., 2022; Gladstone et al., 2021; Graizbord et al., 2006; Mumme, 2007). In the past 30 years, Tijuana has expanded by 7.4 acres of urbanization per day. This growth is driven by large-scale US-owned factories, immigration from Southern Mexico and other countries and deportees from the US (Calderón-Villarreal et al., 2022; Dirección de Obras e Infraestructura Urbana Municipal, 2026; Instituto Mentropolitano de Planeación de Tijuana, 2022). A 2022 study found that only 53 % of 17 Tijuana and Rosarito wastewater plants comply with the existing regulations, whith higher pollutant loads corresponding to older facilities (e.g., *San Antonio de los Buenos* plant) (Arreola-Serrano et al., 2022).

4.3. Environmental observations and health links

Data describing unpleasant situations observed by participants provides significant information about infrastructure, behavioral and environmental health. Urban garbage, wastewater discharges, industrial discharges, and lack of drinking water were commonly reported. Some of these conditions were found significantly associated with key health outcomes. Burning garbage, tobacco smoke, decomposing animals, and wastewater discharges (not limited to Tijuana River flow) and industrial discharges were associated with multiple self-reported health outcomes. Burning garbage is a public health concern as the burning of waste substances such as plastic or food release harmful chemical pollutants into the environment, which disproportionately affect the elderly, pregnant women, and children (Stec, 2017); while smoke exposure can cause headaches, eye irritation, and nausea (Jakhar et al., 2023). Decomposing animals also produce toxic metabolites that may harm nearby water sources and human health (Zhou et al., 2021). Notably, observing tobacco smoke at the coastline was associated with respiratory infections and remained significant in final models. Tobacco smoke contains over 9500 compounds, including tar and chemicals that can damage multiple human systems (Flor et al., 2024; Lu et al., 2024).

4.4. Exposure duration and pathways

Multiple associations found in unadjusted models suggest the need for future research, into visit frequency, duration of stay, specific behaviors like eating/sitting outdoors, and contact with ocean water or beach sand. Participants who visited the coastline once per week had significantly higher odds of reporting respiratory allergies and infections, ear infections and diarrhea diseases. We suggest two plausible, non-mutually exclusive pathways underlying the reported level of respiratory symptoms. One potential explanation involves exposure to sea spray aerosols (SSA) in coastal environments, which may contain microorganisms, endotoxins, and other biologically active components capable of activating inflammatory and immune responses in the respiratory tract (Li et al., 2024). Alternatively, symptoms may relate to indoor environmental conditions, such as elevated humidity or mold within coastal homes, which are well-established risk factors for allergic and respiratory symptoms. Distinguishing between outdoor coastal exposures and indoor household conditions is therefore critical for accurate interpretation. While this study lacks direct environmental sampling, the association between visit frequency and symptoms align with these hypothesized mechanisms.

To better differentiate between these pathways, future systematic assessments of symptoms and timing, environmental observations, wastewater odors, indoor humidity and mold in both coastal and inland households would help clarify whether symptoms may be driven by indoor environmental conditions.

Similarly, having visited the coastline during the last month was associated with respiratory allergies and diarrhea diseases; spending extended periods (day and night) was also associated with ear infections and diarrhea. These results highlight the relevance of visit frequency and duration as a valuable covariable for further research.

The most relevant activities performed on the coastline were aquatic sports and sitting or eating outdoors. Diarrheal diseases, ear infections and allergies (respiratory and eye) were significantly associated—in unadjusted models—with sitting and eating outdoors. These variables, along with visit frequency and duration, suggest a potential health risk increase with longer environmental exposure. Other coastal community studies show that eye and respiratory symptoms can be common, such as in villages along the Tanzanian coast (Said et al., 2018). According to a Centers for Disease Control and Prevention (CDC) assessment of the Tijuana River sewage crisis in San Diego County, 43 % of exposed individuals reported eye irritation and 47 % experienced respiratory symptoms (CDC, 2025). These findings support the plausibility of environmentally linked symptoms in coastal populations, consistent with the prevalence observed in our study. However, without concurrent air and water sampling during our study period, these comparisons remain associative rather than definitive evidence of specific exposure-response pathways.

4.5. Airborne pathways

While some people may avoid direct contact with coastal waters, health risks may persist through airborne pathways. Recent research has identified marine aerosols as a previously underestimated transmission pathway. The Tijuana River acts as a significant source of pollution that transfers from the aquatic to the atmospheric environment (Cysneiros de Carvalho et al., 2025; B. Rico et al., 2025). Concentrations of illicit drugs, pharmaceuticals, tire wear additivities and personal care products have been detected in sea spray aerosols near the river's mouth. Inhalation exposure is estimated to reach tens of nanograms per hour, representing a distinct public health challenge (Cooper et al., 2025). This issue is compounded by the presence of harmful gases. Air quality monitoring has recorded nighttime peaks of Hydrogen Sulfide (H_2S)

reaching 4500 ppb, levels that exceed environmental safety standards. Notably, these levels decrease by 95 % after controlled wastewater diversions are implemented (B. Rico et al., 2025). This suggests that improving water infrastructure is intrinsically linked to air quality solutions. Although our study did not provide direct measurements of these airborne contaminants, the temporal and geographic overlap of our survey with these documented pollution peaks support the hypothesis that airborne pathways contribute to the reported health outcomes.

The Tijuana-San Diego border is a high-traffic area affected by particulate matter (PM) pollution, concentrated at the border port of entry (Khanum et al., 2021; Quintana et al., 2015). Traffic-related pollution near the both sides of the border represents an environmental justice challenge, disproportionately affecting low-income minority communities (Quintana et al., 2015). Because traditional exposure-response data is often lacking in this marginalized border zone, our community-based empirical data provides a preliminary baseline for advocating for more equitable monitoring. In Tijuana, pollutants such as SO_2, NOx, ozone, carbon monoxide has been associated with long-term health conditions (Badilla et al., 2023). In San Diego, elevated PM 2.5 levels have been directly associated with higher rates of hospitalization for respiratory conditions and heart attacks (Mehta et al., 2021). Furthermore, emerging evidence on marine microplastics indicates that counties with higher levels of these pollutants show a greater prevalence of type 2 diabetes and coronary disease (Makwana et al., 2025).

4.6. Contact with beach sand

Our study also found that head or face contact with ocean water or beach sand increased the odds of ear infections. Although there is extensive literature on the risks of contaminated water, sand represents a potential threat to human health that is often unrecognized. The WHO recognizes the rationale that people spend more time on the sand than in the water (WHO 2003). Studies conducted on sand samples have found the presence of fecal indicator bacteria enterococci and fungi of medical relevance (Brandão et al., 2021; Brandão et al., 2023). Contamination in the supratidal zone (the strip of sand furthest from the water) may stem from animal shedding and organic matter accumulation, which serve as food source for opportunistic microorganisms (Brandão et al., 2023). Further research is required to assess the microbiological quality of beach sand and the specific risks among with direct contact.

4.7. Limitations

This study is the first effort—to our knowledge—to document self-reported health risks along this binational coastline. While this study offers valuable insights for hypothesis generation, some limitations require consideration. First, reliance on self-reported data introduces potential recall, desirability, non-response and risk perception bias. In highly publicized 'risk zones' like the San Diego-Tijuana border, residents' heightened awareness of environmental hazards can lead to an over-reporting of symptoms—a phenomenon well-documented in recreational water literature (Fleisher and Kay, 2006). Second, the study utilized a non-probability, purposive sampling design. While our recruitment strategy—which combined targeted social media advertising with physical outreach—effectively reached the intended target population of frequent coastal users and residents, it introduces selection bias. Consequently, the results may not be generalizable to the entire binational coastal community, particularly infrequent visitors. Also, the sociodemographic profile of the sample, with its high levels of education, may not fully capture the perceptions and experiences of individuals from more vulnerable socioeconomic backgrounds, such as those residing in unregulated settlements. Furthermore, it is possible that individuals with a higher baseline interest in coastal health or those experiencing more frequent symptoms were more likely to participate, which could lead to an overestimation of health outcome prevalence. This study implemented qualitative data through interviews with health professionals providing clinical insight; however, recruitment faced significant obstacles, particularly on the US side. The low response rate was influenced by restrictive institutional policies and technological barriers (email firewalls) that hindered communication, limiting the volume of interviewed obtained. Despite sending invitation emails to dozens of clinics, hospitals, and local organizations on both sides of the border, the overall sample size was low.

Moreover, the comparability of water quality data (Table 3) presented technical challenges due to the lack of uniformity across sites Measurement methods varied between most probable numbers (MPN), colony-forming unit (CFU) or copies of Enterococcus per 100 mL of water, depending on each country and specific site. The use of Enterococci as a proxy for exposure involves further inherent limitations, particularly regarding the spatiotemporal alignment between discrete water quality samples and individual coastal visits. Without personal monitoring, we cannot account for individual 'activity spaces' or the 'spatial polygamy' of participants—the various contexts where exposure may actually occur—which may lead to exposure misclassification (Matthews and Yang, 2013). Because monitoring is conducted at specific intervals, pulse-pollution events may be missed, leading to potential exposure misclassification. Additionally, the aggregation of water quality data into broad contamination scales—while necessary to harmonize binational datasets—may obscure meaningful localized variability in microbial concentrations. These discrepancies underscore the need to standardize governmental surveillance systems to obtain a coherent regional picture. Finally, although the cross-sectional design restricts causal interpretations and reporting remains subject to varying risk perceptions, the associations identified offer a potentially helpful roadmap. By utilizing a community-based approach similar to established neighborhood health assessments, these data provide an essential 'empirical signal' of population-level distress that clinical data alone—-which marginalized populations often lack access to—cannot capture.

4.8. Future directions

The convergence of survey data, health professional testimonies, and environmental context analysis provides a foundation for future research and informed public policies. These findings suggest that border environmental challenges are not isolated events but are symptomatic of broader ecosystem health disruptions. By documenting recurring health patterns in high-exposure zones, this research provides an empirical baseline that identifies the binational coast as a critical site for planetary health research. Future research may include planetary health or one health approach, including veterinary, marine biology, and environmental sciences. It is imperative to assess not only the risk to human health, but also the impact of pollutants on pets, wildlife, and the resilience of the terrestrial and aquatic ecosystems that sustain the region. Findings from this study can inform localized management strategies and cross-border policy dialogues. To ensure the public health protection, we suggest prioritize the following pillars: 1) Infrastructure, urgent improvements to sewage systems and wastewater treatment plants; 2) Surveillance and technology, implementation of real-time binational environmental monitoring systems and health alerts; 3) Education and behavior, public health strategies aimed to modifying risky behaviors and raising awareness about water, air and sand quality; and 4) Binational governance, strengthening US-Mexico collaboration to standardize indicators and response protocols for environmental challenges.

5. Conclusion

This hypothesis-generating, community-based assessment study underscores the critical public health challenges facing the binational coastal community within the US-Mexico border region of San Diego, Tijuana, and Rosarito. Our results indicate that frequent interactions

with the coastline are associated with a consistent pattern of respiratory, ocular, otic, and GI conditions. The findings highlight how proximity to environmental risk hotspots—particularly wastewater-derived pollutants—contributes to a complex risk profile. This profile transcends national borders through both water contact and emerging atmospheric transmission pathways, such as marine aerosols. While aquatic activities remain significantly associated with infections, our findings align with emerging research suggesting that even passive exposure–through inhalation of aerosols and sand contact– warrants further investigation as a potential contributor to the regional disease burden. Ultimately, the study supports a planetary health approach and the strengthening of binational collaboration. We suggest the utility of harmonizing monitoring systems and modernizing water infrastructure to protect the well-being of this interconnected cross-border population.

In conclusion, this study supports the notion that the health challenges in the San Diego-Tijuana region represent a multimodal exposure problem. Pollution in this context is not confined to direct contact with water. While associative, these results are consistent with studies suggesting that the disease burden is distributed through the air and sand, affecting even those who engage in passive recreation. These findings suggest a shift toward more robust binational climate and health governance. Protecting the health of this interconnected population requires not only infrastructure but also a vision of environmental justice that recognizes that pathogens and aerosols do not respect walls or jurisdictions. The well-being of one side of the border is inevitably dependent on the environmental integrity of the other.

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CRediT authorship contribution statement

Alhelí Calderón-Villarreal: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Ruben Alejandro Gonzalez-Garcia:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Alejandra Badillo:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Gurasees Bajwa:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Sara Alejandra Gonzalez-Olachea:** Writing – review & editing, Visualization, Validation, Funding acquisition, Conceptualization. **Joseph R. Friedman:** Writing – review & editing, Visualization, Validation, Methodology, Conceptualization. **Delia Castellanos Armendariz:** Writing – review & editing, Validation, Funding acquisition, Conceptualization. **Margarita Díaz:** Writing – review & editing, Validation, Supervision, Resources, Funding acquisition, Conceptualization. **Phillip Musegaas:** Writing – review & editing, Validation, Supervision, Funding acquisition. **Ietza Bojorquez:** Writing – review & editing, Validation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Phillip Musegaas reports financial support was provided by San Diego Foundation. Margarita Diaz reports financial support was provided by San Diego Foundation. Alhelí Calderón-Villarreal reports financial support was provided by San Diego Foundation. Sara Alejandra Gonzalez-Olachea reports financial support was provided by Secretaría de Ciencia, Humanidades, Tecnología e Innovación (SECIHTI). Joseph R. Friedman reports financial support was provided by National Institute on Drug Abuse. Alejandra Badillo reports financial support was provided by Steven Livesay Scholarship Fund. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envc.2026.101480.

Data availability

Data will be made available on request.

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