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Sanitation in Ensenada, Baja California, Mexico: bridging the gap between human rights and practice

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Access to water and sanitation remains a major global challenge and has been prioritized in international sustainable development agendas. In 2015, it was incorporated into the Sustainable Development Goals (Goal 6), aiming for universal and sustainable access by 2030. While water provision often receives more attention due to its immediate impact on quality of life, sanitation is equally relevant for public health and environmental protection. This study examines sanitation in Mexico, focusing on the urban area of Ensenada, Baja California. Despite significant progress in sewer coverage, persistent challenges remain, particularly discrepancies between local and national data that hinder accurate assessment and policy development. Adopting a human rights perspective, this research analyzes technical and social factors affecting access and quality of sanitation services, with a special emphasis on sustainability in wastewater management. A mixed-methods approach—combining documentary research, surveys, and stakeholder interviews—was employed. Results reveal low public awareness of sanitation as a human right, deficiencies in the cleanliness and maintenance of public sanitary facilities, and persistent accessibility barriers for vulnerable populations. Additionally, concerns about septic system failures, wastewater odors (reported daily by 20% of residents), and doubts about treatment effectiveness (expressed by over 65%) were prominent. Nevertheless, the study identifies opportunities for alternative sanitation solutions. Recommendations include infrastructure upgrades, community education initiatives, and continuous monitoring to ensure sustainable, equitable sanitation management, both locally and globally.

KEYWORDS

sanitation, human rights, sustainability, wastewater, public perception survey, urban areas

1 Introduction

Access to water and sanitation is fundamental for human survival, dignity, and well-being. Recognized as an basic human right (ECOSOC, 2010; UNGA, 2010), the human right to water and sanitation (HRWS) was formally acknowledged by the United Nations in 2010, derived from the right to an adequate standard of living and closely linked to the realization of other human rights (UN-CESCR, 2002; UNGA, 2010). Although water and sanitation are interconnected, in 2015, UN Resolution A/RES/70/169 emphasized the distinct features of each, advocating for their separate recognition to address specific challenges more effectively. This distinction is fundamental, as sanitation often remains overlooked unless treated as an

independent right, despite its vital role in human health and ecosystem protection (UNGA, 2015).

Globally, cities face difficulties in providing universal water and sanitation services (García-Searcy et al., 2022; Koop and van Leeuwen, 2017; UNESCO-UN-Water, 2020; UNICEF-WHO, 2020). However, the expansion of water services has generally outpaced that of sanitation, especially in developing countries (UNDP, 2006; Bautista Justo, 2013; Feris, 2015; Obani and Gupta, 2016; Winkler, 2016; Vélez-Ramírez et al., 2022). Since the adoption of the Millennium Development Goals (MDGs) and later the Sustainable Development Goals (SDGs) in 2015, progress in sanitation has improved, yet challenges persist. The initial MDG sanitation targets were criticized for their narrow focus on infrastructure, neglecting treatment and environmental impacts (UNGA, 2009; Zimmer et al., 2014). The SDGs addressed these gaps, particularly Goal 6, which seeks not only universal access to sanitation but also improvements in wastewater treatment and pollution reduction (UN, 2018).

Despite advancements, achieving universal access to safely managed sanitation services by 2030 remains an important challenge. To meet SDG targets, progress rates must at least quadruple, as global access to safely managed sanitation increased by only 1.27 percentage points annually between 2000 and 2020, with substantial regional disparities (WHO-UNICEF, 2021). By 2022, 43% of the global population still lacked access to safely managed sanitation and 42% of household wastewater remained untreated; in Mexico, similar patterns persisted, with approximately 37% of the population lacking such services and 36% of wastewater remaining untreated (UN-Water, 2024).

Within this national context, the urban region of Ensenada, Baja California, presents an interesting case. Historically, Ensenada was recognized for achieving full wastewater treatment compliance (Mendoza-Espinosa et al., 2004; Daesslé et al., 2005, 2014). However, over time, the city's sanitation system deteriorated, leading to critical infrastructure failures (Flores, 2023; Mercado, 2023). By 2021–2022, environmental crises emerged, such as Playa Hermosa being designated the most contaminated beach in Mexico (COFEPRIS, 2022; La Jornada, 2022), and ongoing pollution affecting streams, coastal areas, and surrounding localities like El Sauzal and Maneadero (El Mexicano, 2023; Lamas, 2023; Peñuelas, 2023; Portillo-Lopez and Hoyos-Salazar, 2021).

This alarming situation highlights broader issues: pollution of rivers, groundwater, and coastal ecosystems, driven by untreated urban wastewater, agricultural runoff, and industrial discharges (Bashir et al., 2020; CNDH-UNAM, 2019). Effective sanitation management depends not only on infrastructure availability but also on infrastructure quality, maintenance practices, sustainability, and community engagement (UNGA, 2009; Yamauchi et al., 2022).

Citizen perceptions are critical for understanding the real status of municipal services and for guiding improvements (Jiménez et al., 2019; Nelson et al., 2021; Tseklevs et al., 2022). Public opinion provides valuable insights into service adequacy and points to gaps often invisible to official metrics (Turrén-Cruz et al., 2019; Grasham et al., 2021). Consequently, examining perceptions regarding sanitation services can better inform planning and policymaking (Adugna, 2023; Anthonj et al., 2018; Turrén-Cruz et al., 2020).

The present study aims to examine the state of sanitation services in Ensenada through a comprehensive human rights and sustainability framework. By integrating technical and social perspectives, and

drawing from governmental data, local media, citizen surveys, and stakeholder interviews, this research identifies key barriers to service quality and accessibility and proposes pathways for improvement.

2 Study area

The Ensenada urban region is located in the northwestern part of the Municipality of Ensenada, in Baja California, Mexico. The primary urban center is the city of Ensenada, followed by the localities of Maneadero (officially Rodolfo Sánchez Taboada) and El Sauzal (El Sauzal de Rodríguez). This study focuses on these three settlements, as they are the most representative in terms of population in the region (Figure 1).

The city of Ensenada has a population of 330,652, Maneadero 27,969, and El Sauzal 11,371, totaling 369,992 inhabitants. Together, they account for 83.4% of the municipality's total population of 443,807 (INEGI, 2020).

The region has a semi-arid (Mediterranean) climate, characterized by dry, warm summers and wet, cold winter, with an average annual temperature to 18.1 °C (IMIP, 2024). Located in a state prone to droughts (CONAGUA, 2024) this region experiences most of its precipitation between November and April, frequently in short but intense episodes, which can create challenges for water management during the rainy season. The average annual rainfall for this region is recorded at 273 mm (Gámez-Balmaceda et al., 2020).

Water and wastewater services are managed by the Ensenada Public Services Commission (CESPE). While the National Census data reports sewer coverage rates of 99% in Ensenada and El Sauzal and 87% in Maneadero (INEGI, 2020), CESPE's 2023 report indicates that overall sewer coverage in the urban area is closer to 76% (CESPE, 2024b), highlighting discrepancies in service data.

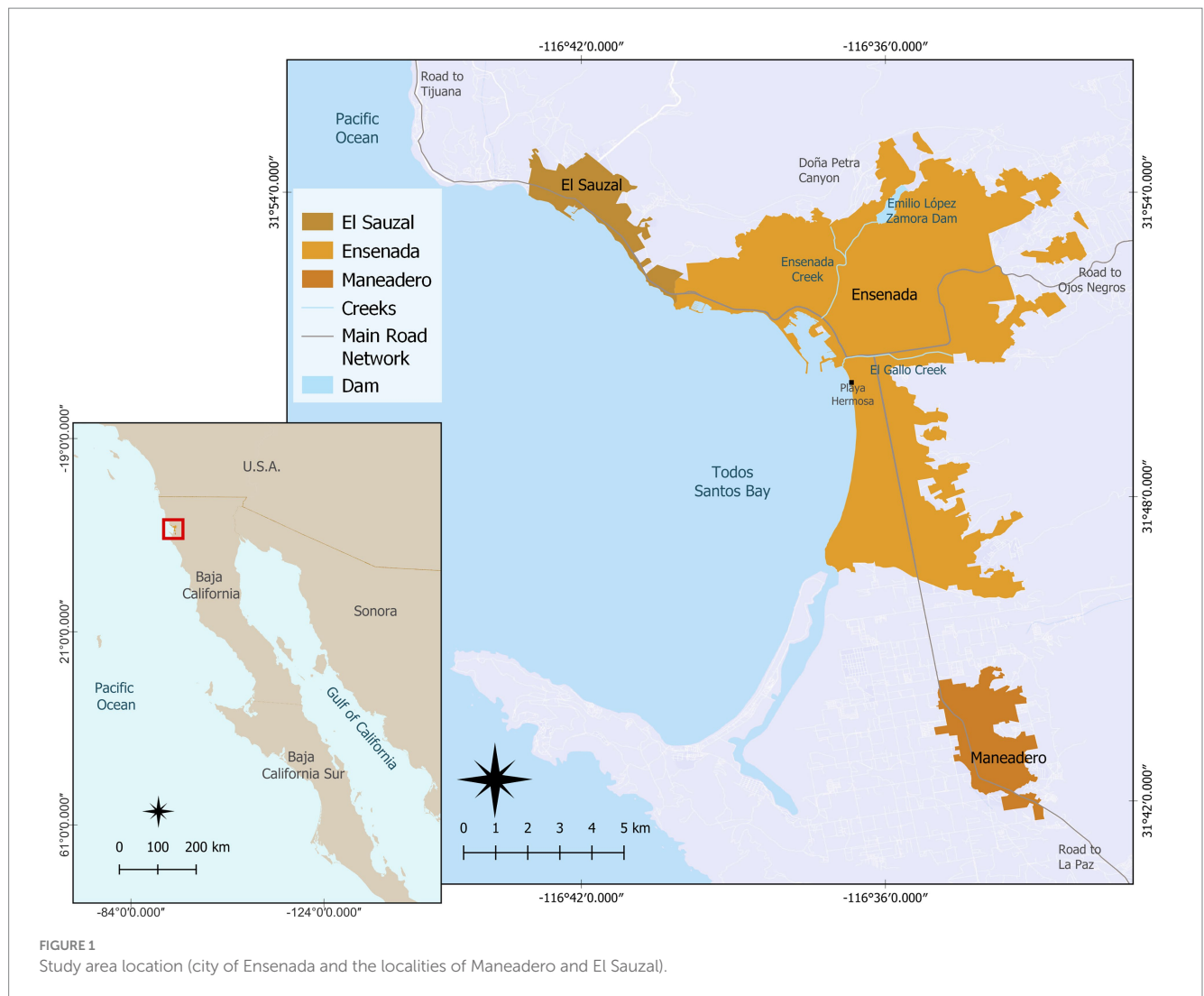
The region lacks a separate stormwater sewer system, leading to increased loads on wastewater treatment plants (WWTPs) during rainy periods, which reduces effluent quality (Mendoza-Espinosa et al., 2004). The sewer network, spanning 31.6 km, is aging: 55% of pipelines are between 15 and 25 years old, and 28% exceed 25 years, indicating urgent maintenance needs (IMIP, 2024).

Five WWTPs serve the region: El Naranjo, El Gallo, and Noreste in Ensenada, and additional facilities in El Sauzal and Maneadero (CESPE, 2024a). However, operational issues—including untreated wastewater discharges into coastal areas—have been widely reported (Buendía, 2022; Lamas, 2023; Mercado, 2023). In response, these plants have been targeted for rehabilitation under the State of Baja California Water Program 2022–2027 (SEPROA-CEABC, 2023).

Environmental impacts are increasingly evident, particularly the pollution of Todos Santos Bay. Rapid urban and industrial growth, combined with inadequate wastewater treatment, has led to organic and bacteriological contamination along the northwest coast (Orozco-Borbón et al., 2006). Moreover, recent studies have detected elevated concentrations of pollutants such as microplastics and pyrethroids in wastewater effluents (Hernández-Guzmán et al., 2017; Piñon-Colin et al., 2018; Ramírez-Álvarez et al., 2020; Tanahara et al., 2021), signaling broader ecological and public health risks.

3 Method

This study adopted a mixed-methods approach to strengthen the validity of findings through triangulation, acknowledging the biases



and limitations inherent in individual methods (Hernández Sampieri et al., 2014; Creswell, 2014; Dawadi et al., 2021). A concurrent design was implemented, combining data from three sources: (1) documentary research, (2) semi-structured interviews, and (3) a public opinion survey.

3.1 Documentary research

Official data were gathered from government agencies including the National Institute of Statistics and Geography (INEGI), the Baja California State Water Commission (CEABC), the Ensenada Public Services Commission (CESPE), and the National Water Commission (CONAGUA). Information not publicly accessible was requested via the National Transparency Platform (PNT). Additionally, an online search of news articles from local media (El Vigía, El Imparcial, Semanario Zeta, La Jornada BC, and El Mexicano) was conducted, covering the period 2021–2024—coinciding with peak pollution events at Ensenada's beaches. Search keywords included “wastewater,” “sewage,” “treatment plants,” and “pollution.” News reports served as indicators of public problem recognition (Rivera Salas and Curro Lau, 2021). A review of

academic sources was also conducted to provide context and support the analysis.

3.2 Semi-structured interviews

Six semi-structured interviews were conducted with key actors: three government officials and three academic researchers specializing in water and sanitation (see Supplementary Table S1). Participants were selected based on their expertise, institutional roles, and availability. A thematic guide was used, covering issues such as service availability, quality, accessibility, affordability, wastewater pollution, and local governance. The semi-structured format allowed flexibility for respondents to elaborate on topics, contributing both quantitative and qualitative insights. Data were organized and analyzed using Atlas.ti version 9 (Scientific Software Development GmbH, Berlin, Germany), which supported the thematic coding and categorization of interview content (see Supplementary Table S2).

Although the number of interviews was limited, in mixed-methods research, triangulation with other sources compensates for sample size constraints (Cobern and Adams, 2020; Creswell, 2014; Saunders and Townsend, 2016). This analysis contributed to the

identification of recurring patterns, key concerns, and stakeholder perspectives relevant to the governance of wastewater and sanitation in Ensenada urban region.

3.3 Public opinion survey

A self-administered online survey was designed to capture residents' perceptions of water and sanitation services across Ensenada, El Sauzal, and Maneadero. The questionnaire included sections on water, sanitation, public management, community participation, and sociodemographic information. For this analysis, only responses from the sanitation section were considered (see [Supplementary Table S3](#)). Prior to full deployment, the survey was pilot-tested with 20 participants to ensure clarity and reliability, leading to minor refinements. The final survey was distributed via Facebook, Instagram, and the authors' networks between April and May 2024. Eligibility criteria included being 18 years or older and residing in the study area. A total of 463 responses were received, with 456 validated after discarding inconsistent or out-of-area responses. The required sample size was calculated using the standard sampling formula for finite populations (95% confidence level and 5% margin of error). For a total adult population of 243,353 residents, the minimum sample size was 384; therefore, the validated responses exceeded this threshold. While the overall sample size was adequate, representation across the three subareas was not fully proportional: Maneadero was underrepresented, likely due to lower internet access rates (45.5% of households, compared to over 73% in Ensenada and El Sauzal). [Table 1](#) summarizes respondents' characteristics, which were compared against official census data, and chi-square tests showed statistically significant differences in most categories. Although internet-based surveys offer advantages such as anonymity, flexibility, cost-effectiveness, and broad reach, they also pose challenges related to sampling biases and limited participation ([Arundel, 2023](#); [Callegaro et al., 2015](#); [Creswell, 2014](#)). Despite these limitations, the online survey proved effective for reaching a diverse participant base and efficiently collecting data relevant to this study.

4 Results and discussion

4.1 What does sanitation include? Public perception from a human rights perspective

From a human rights perspective, sanitation must be understood as a comprehensive process. It involves four essential stages: (1) access to hygienic and safe sanitation facilities; (2) the collection and transport of wastewater through centralized or decentralized systems; (3) wastewater treatment; and (4) the safe disposal or reuse of treated wastewater ([ECOSOC, 2010](#); [WHO, 2018](#)).

However, the mere availability of these stages is not sufficient. Sanitation services must also meet fundamental criteria such as quality, accessibility, and acceptability, and must respect transversal principles including sustainability, equity, non-discrimination, and the rights to information and public participation ([UNGA, 2009](#)). In particular, access to information plays a key role in promoting

transparency, accountability, and empowering civic engagement in service management ([Fedorov et al., 2023](#); [Marciel, 2023](#)).

To assess public understanding of sanitation's scope, residents of Ensenada, Maneadero, and El Sauzal were surveyed with the question: "From a human rights perspective, what elements are considered part of sanitation?" Respondents could select more than one option ([Figure 2](#)).

Survey results indicate a strong recognition of the importance of treating wastewater, with 86% of participants identifying it as an essential element. Similarly, although 74% acknowledged the importance of wastewater collection and transport, a significant 26% did not associate this stage with the concept of sanitation.

Access to adequate and hygienic sanitation facilities received the lowest level of agreement: 34% of respondents did not recognize it as a fundamental part of sanitation. This suggests that while many individuals understand the necessity of proper wastewater management, there is a gap in recognizing the critical role of direct access to sanitary facilities. A chi-square test confirmed that these differences in response patterns were statistically significant ($p < 0.0001$).

These findings highlight a need for increased public education on the comprehensive nature of sanitation. Strengthening awareness around all stages—particularly access to facilities—would enhance understanding of sanitation as a human right, and support more effective advocacy for service improvements that safeguard health, dignity, and well-being.

4.2 Access to hygienic and safe sanitation facilities

Access to adequate sanitation facilities—such as toilets, improved latrines, or ecological alternatives—is fundamental to the human right to sanitation. It is essential for preventing disease, ensuring hygiene, safeguarding human dignity, enhancing productivity, reducing healthcare costs, supporting school attendance, and protecting the environment ([WHO, 2018](#)).

Official data show high household toilet access in Ensenada and El Sauzal, with coverage rates of 98%, while only 1% of households report using latrines. In contrast, Maneadero lags significantly, with 77% of households having toilet access and 21% relying on latrines ([INEGI, 2020](#)). This disparity is mirrored in sewer connections and indicates a need for targeted improvements in Maneadero's sanitary infrastructure.

The type of sanitation technology employed is also critical. Hygienic technologies can reduce diarrheal disease by up to 32% ([WHO, 2004](#)). Although flush toilets dominate, dry or ecological toilets represent viable alternatives, particularly in water-scarce areas ([Langergraber and Muellegger, 2005](#); [Ihalawatta et al., 2015](#); [Aburto-Medina et al., 2020](#)). Survey data reveal that 6.7% of El Sauzal respondents reported using ecological toilets, while participants from Ensenada and Maneadero predominantly used flush toilets ([Figure 3](#)). Statistical tests found no significant association between sanitation type and sociodemographic factors, suggesting that infrastructure availability, rather than personal characteristics, primarily determines facility types.

Beyond the type of technology, the cleanliness and hygiene of sanitation facilities are critical. Respondents rated the condition of

TABLE 1 Characteristics of respondents across Ensenada, Maneadero, and El Sauzal.

Characteristics	Category (survey)	No. of respondents survey (<i>n</i> = 456)	% survey	Population (census official data) (<i>n</i> = 270,485)	% Population (official data)
Residence location	Ensenada	382	83.8	243,353	90.0
	El Sauzal	45	9.9	8,483	3.1
	Maneadero [†]	29	6.4	18,649	6.9
Age	18–29	76	16.7	76,074	28.1
	30–39 [‡]	105	23.0	57,090	21.1
	40–49	105	23.0	50,598	18.7
	50–64	118	25.9	56,802	21.0
	65 and more [‡]	52	11.4	29,921	11.1
Educational level	No formal education ^a	1	0.2	-	-
	Elementary or middle school ^a	10	2.2	-	-
	High school ^b	59	12.9	151,395 ^b	56.0 ^b
	Higher education (university) ^b	241	52.9		
	Postgraduate (master, phd) ^b	145	31.8		
Income level ²	< \$10 K MXN/month	74	16.2	National average income \$22,437 MXN /month ^c	-
	\$10 K–\$20 K MXN/month	185	40.6		
	\$20 K–\$30 K MXN/month	86	18.9		
	\$30 K–\$40 K MXN/month	35	7.7		
	\$40 K–\$50 K MXN/month	32	7.0		
	> \$50 K MXN/month	31	6.8		
	Prefer not to answer	13	2.9		
Gender	Women	283	62.1	132,695	49.1
	Men	169	37.1	137,790	50.9
	Other	4	0.9	-	-

Chi-square tests were conducted for categories with available census population data. Significant differences ($p < 0.05$) were found in most categories, except those marked with [†].

^aOfficial data defines different age ranges for individuals with no formal education or up to middle school: it includes those aged 15 and older, whereas this survey includes only individuals aged 18 and older, making direct comparison unfeasible.

^bOfficial data does not disaggregate these education levels as in the survey. Instead, it consolidates high school, higher education, and postgraduate into a single group: "Population aged 18 and older with post-basic education".

^cOfficial income data is not disaggregated as in the survey. Nationally, the average quarterly income is \$67,311 MXN, equivalent to \$22,437 MXN per month (INEGI, 2020).

restrooms at workplaces and educational institutions: 62.3% found them generally clean or always very clean, while 22.6% reported occasional deficiencies, and 6.6% described frequent uncleanliness (Figure 4). While perceptions are largely positive, there remains room for improvement in facility maintenance and operations.

Accessibility for people with disabilities and other vulnerable groups is another fundamental dimension of the human rights perspective. Sanitation services must be available to all individuals at all times, whether at home or in public spaces (Cumming and Slaymaker, 2018; UNGA, 2009). Census data estimates that 3% of the study area's population has mobility or self-care limitations (INEGI, 2020).

Among survey participants, 10% reported either living with someone facing mobility challenges or experiencing such mobility limitations themselves (Figure 5A). Of these households, only 43% had made bathroom modifications, while 57% had not (Figure 5B). Public restrooms were perceived as largely inadequate for people with disabilities: 55% indicated major deficiencies, 32% reported minor issues, and only 13% found no problems (Figure 5C).

These results underscore the urgent need to improve both private and public sanitation infrastructure to ensure accessibility. Economic constraints, lack of information, outdated designs, and maintenance gaps may contribute to these deficiencies. Similar challenges have been documented in other studies, which emphasize that without inclusive planning, sanitation infrastructure often fails to meet the needs of vulnerable populations (Noga and Wolbring, 2012; Kayoka et al., 2019; Moreira et al., 2021).

4.3 Collection and transport of wastewater

Over recent decades, Mexico has made substantial progress in sewer coverage, with Ensenada and El Sauzal consistently surpassing state and national averages. According to the 2020 Population Census, sewer coverage reached 98.8% in both Ensenada and El Sauzal, compared to the national average of 96.3%, while Maneadero lagged behind at 87.3% (Figure 6A). However, alternative indicators reveal different trends. The Ensenada Public Services Commission (CESPE),

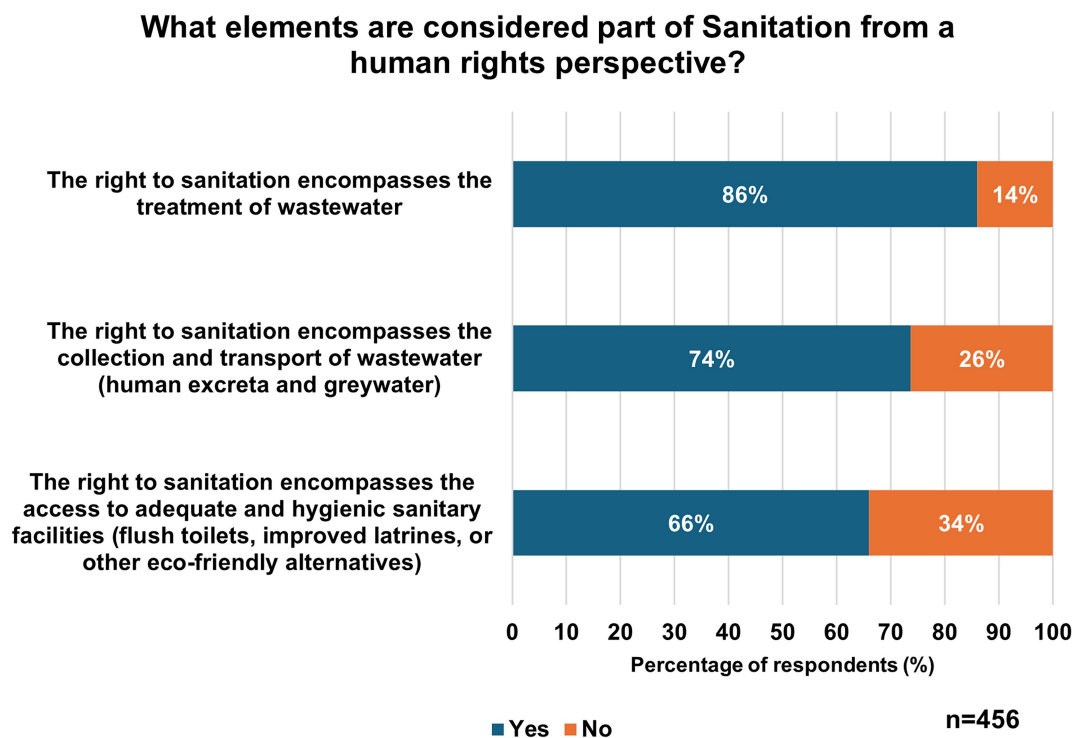


FIGURE 2
Public perception of sanitation as a human right.

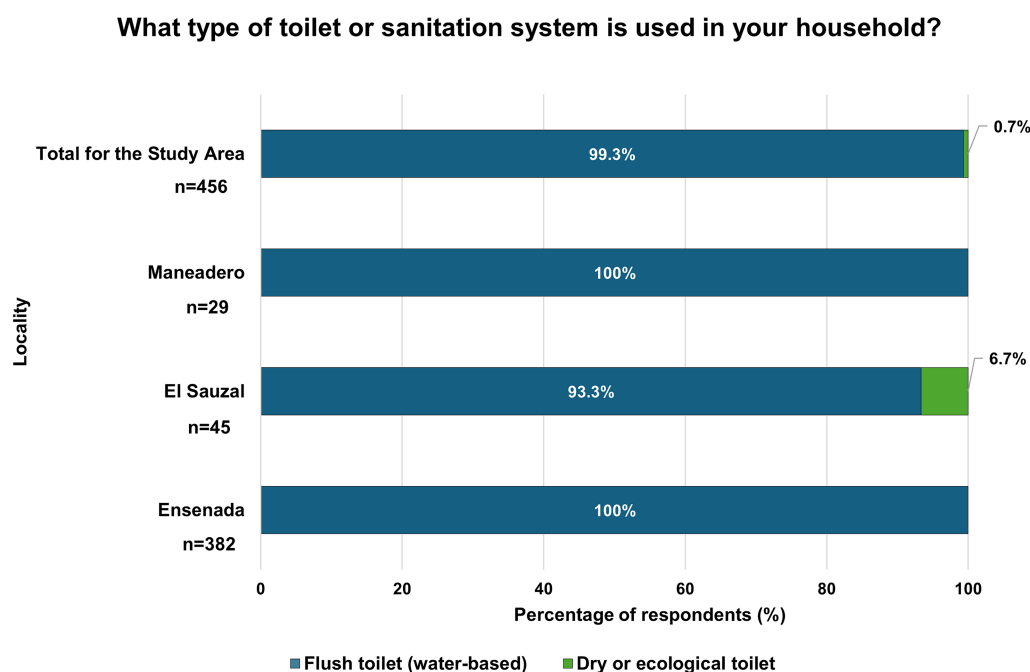


FIGURE 3
Types of household sanitation systems.

reports that sanitary sewer coverage stood at 76% in the urban area of Ensenada in 2023 and 2024, showing a decline over the past decade (Figure 6B). The discrepancies between the Census and CESPE data

stem from methodological differences: the Census includes septic tanks, sewer connections, and other forms of sewage disposal, whereas CESPE reports exclusively on public sewer connections. Furthermore,

How would you rate the cleanliness of restrooms in your workplace or educational institution?

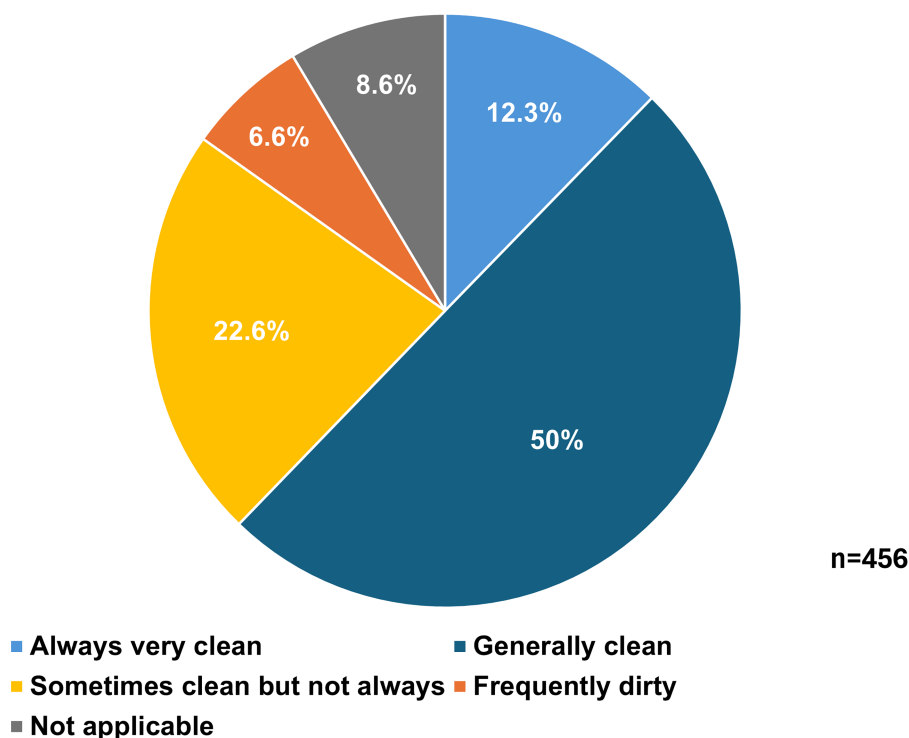


FIGURE 4
Perceived cleanliness of workplace and educational institutions restrooms.

CESPE does not provide disaggregated data for El Sauzal or Maneadero (CESPE, 2024b), highlighting a persistent issue of limited public access to detailed sanitation data, which impairs research, planning, and monitoring efforts. In Mexico, transparency laws guarantee access to public information, and a national platform allows citizens to request data from government agencies in a relatively straightforward manner. However, a recurring challenge is that authorities frequently provide only the minimum required response, which may be vague or incomplete. Similar data limitations are common in low- and middle-income countries and reflect systemic challenges in WASH sector governance (Chatterley et al., 2018; Rajapakse et al., 2023).

It is also important to consider that the declining trend in sanitary sewer coverage contradicts the principle of progressivity in the human right to sanitation, which establishes that once progress has been made in the enjoyment of rights, the States should not lower the level achieved. Progressivity involves both a gradual and advancing approach: graduality acknowledges that the full realization of rights is not immediate, but rather a continual process with short, medium, and long-term objectives, while progress ensures that the fulfillment of rights should always improve (Serrano, 2013).

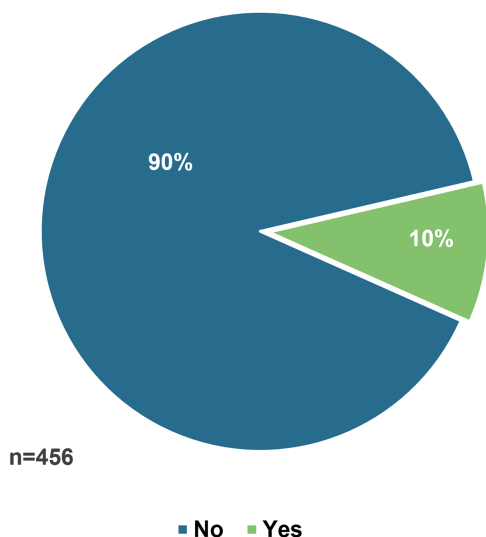
Survey results provided more granular insight into wastewater collection practices. While 88% of Ensenada respondents reported being connected to the public sewer system, only 58% of El Sauzal and 24% of Maneadero respondents had such connections. Reliance on septic tanks was highest in Maneadero (62%), followed by El Sauzal (24%) and Ensenada (2.6%) (Figure 7). A Chi-square test ($p < 0.001$)

confirmed a significant association between locality and type of wastewater system.

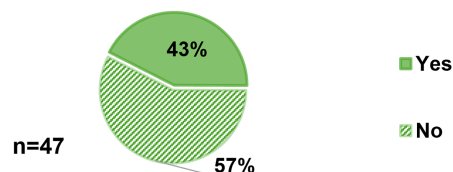
Issues related to septic tanks also emerged during the survey. A total of 39 residents indicated having a septic tank and were asked a follow-up question about any problems experienced. While most did not report serious issues, recurring concerns among respondents included unpleasant odors and challenges related to maintenance (Figure 8). These findings underscore the importance of improving maintenance practices to mitigate potential public health and environmental risks.

In addition to septic tank issues, the survey assessed broader sanitation conditions revealing patterns of inequality that extend to the outskirts of the urban region of Ensenada. Respondents were asked how often they had experienced problems in their neighborhoods such as clogged or collapsed sewers, sewage spills, and sewage odor in the past year. The results revealed that all three locations showed similar trends, with responses clustering around three categories: “Never,” “1 to 4 times a year,” and “Daily or almost daily” responses. This suggests a diverse range of experiences: some residents continuously struggle with sanitation issues, others experience problems intermittently, while a notable portion report having no issues at all. Statistically significant differences were found in the frequency of individuals reporting sewer clogging or collapse, as well as sewage spills, as confirmed by a Chi-square test ($p < 0.05$). The high concentration of extreme choices could be attributed to differences in sanitation infrastructure across areas, or in some cases, a heightened perception of problems following recent negative experiences. Maneadero exhibited the highest frequency of daily or near-daily problems,

(A) Does any member of your household have a physical disability (e.g., mobility impairment, advanced age, etc.) or suffer from a chronic illness that limits mobility and makes it difficult to access sanitation facilities?



(B) Does your household have sanitation facilities adapted for individuals with physical disabilities or chronic illnesses that limit mobility?



(C) When you or a household member with physical disability visit public places such as shopping malls, restaurants, parks, schools, or government offices, do you face difficulties accessing the sanitary facilities?

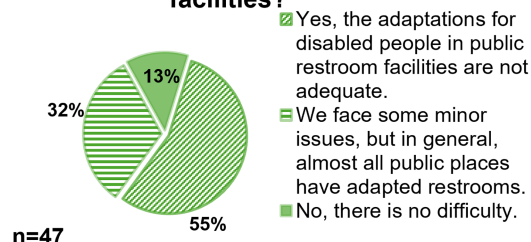
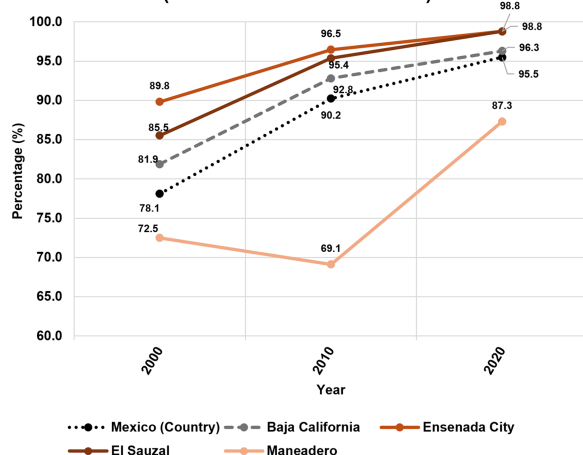


FIGURE 5

Access to sanitation and physical disability: (A) Households with persons with physical disabilities limiting access to sanitation facilities, (B) Households with adapted sanitation facilities for persons with physical disabilities, (C) Difficulties accessing public restrooms for people with physical disabilities.

A Households with connection to public sewer network, septic tanks, or discharged into a ravine, cracks, rivers, lakes, or the sea (National Census Indicator)



B Sewer coverage connected to the public network in the Urban Region of Ensenada (CESPE Indicator)

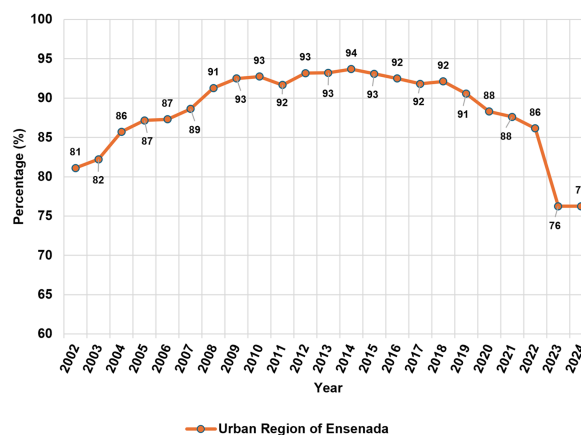


FIGURE 6

Sewer coverage. (A) Based on national census data (INEGI). (B) Based on CESPE and PIGO program data.

suggesting a deeper infrastructure deficit. In contrast, Ensenada reported fewer persistent issues, with El Sauzal occupying an intermediate position (Figure 9).

These patterns align with global observations that peri-urban and low-income urban areas often face relevant sanitation service gaps (Allaire et al., 2024; Meehan et al., 2025). Within Ensenada, informant

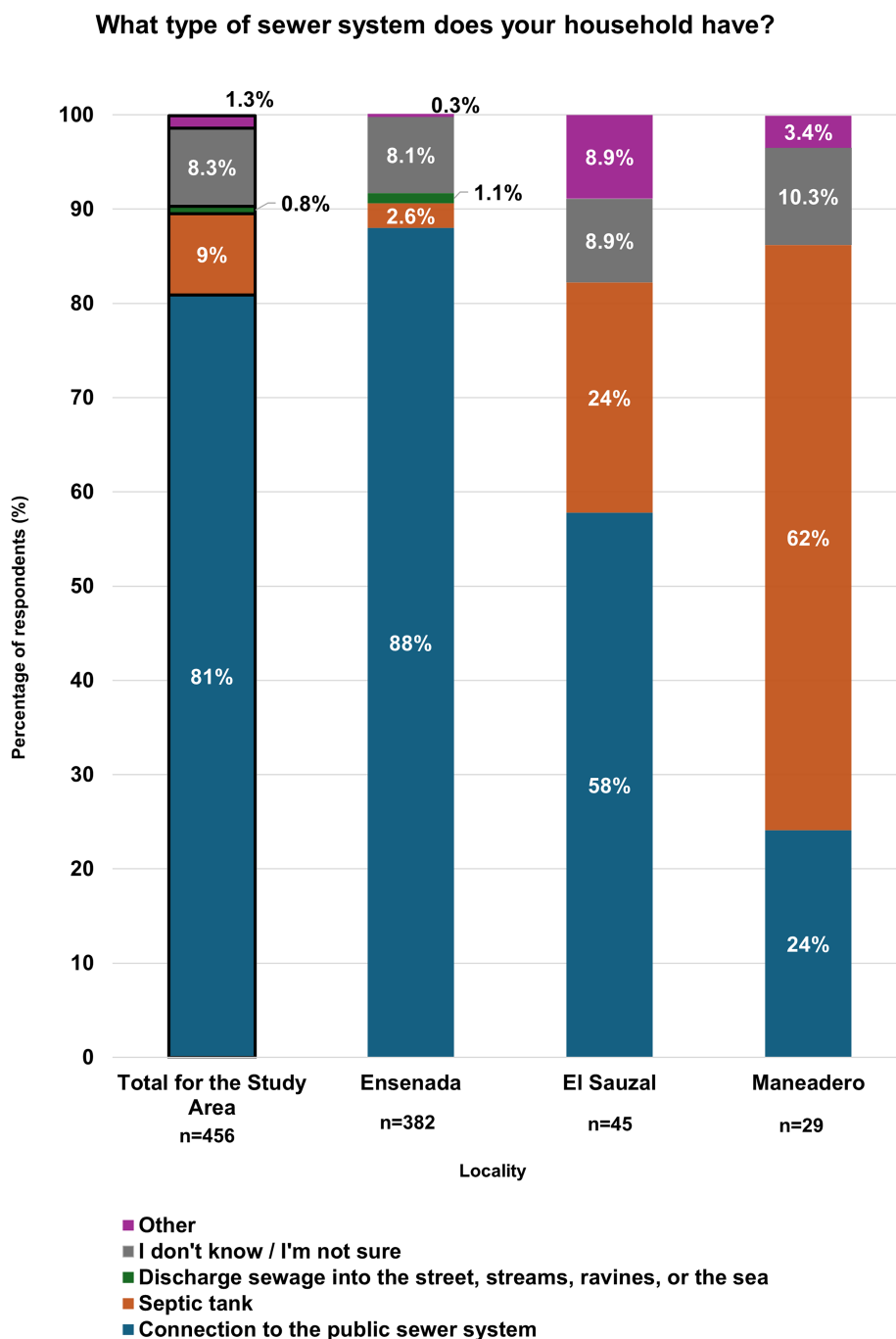


FIGURE 7
Types of sewer systems in households.

interviews confirmed that peripheral and poorer communities are disproportionately affected, exacerbated by unregulated land developments that lack formal service provision. According to Census data, while Ensenada's core areas demonstrate high sewer coverage, significant disparities persist at the periphery, especially in Maneadero (Figure 10).

The decline in sanitary sewer coverage challenges fundamental rights principles, while persistent service gaps in peripheral areas highlight the urgent need for infrastructure expansion, regulatory strengthening, and transparent information systems. Moreover,

addressing collection and transport deficiencies is critical, but must be complemented by effective wastewater treatment to fully safeguard public health and the environment.

4.4 Wastewater treatment

The Ensenada urban region, encompassing Ensenada city, El Sauzal, and Maneadero, operates five wastewater treatment plants (WWTPs) managed by CESPE. Official reports indicate that treated

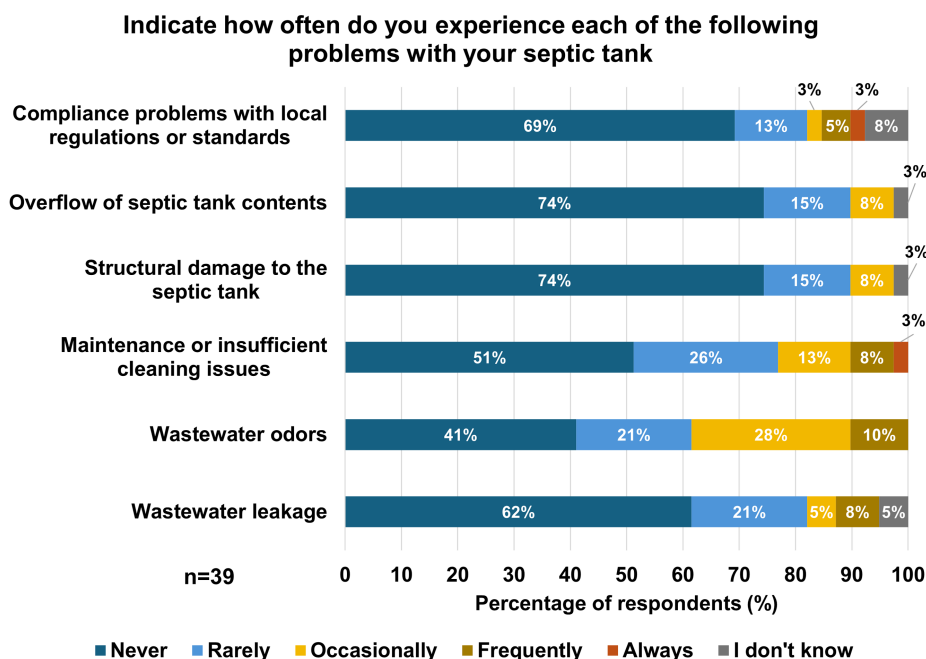


FIGURE 8
Reported frequency of septic tank problems.

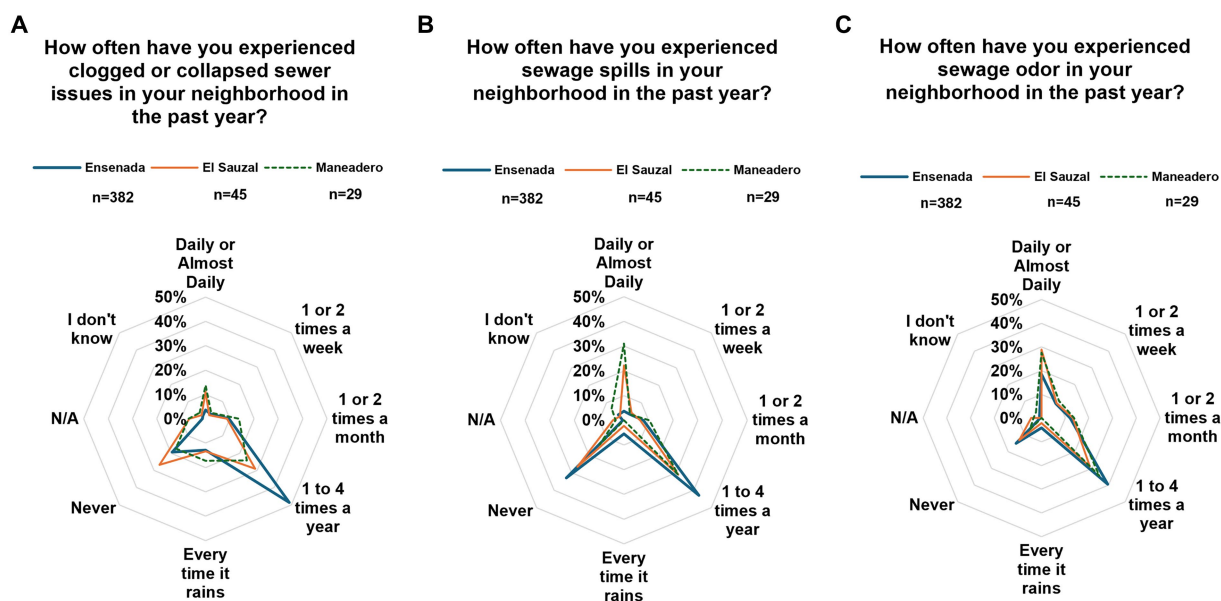


FIGURE 9
Perception of the sewer system problems in the past year related to: (A) clogged or collapsed sewers, (B) sewage spills, and (C) sewage odors, across Ensenada, Maneadero and El Sauzal.

wastewater volumes increased from 17.83 million cubic meters in 2012 to 21.59 million cubic meters in 2021 (CESPE, 2022), and that 100% of collected wastewater was treated during the past 8 years (CESPE, 2024b).

However, this official information contrasts with persistent reports of beach pollution and environmental deterioration over the past 4 years (Flores, 2022; La Jornada, 2022). Even CESPE has acknowledged operational problems at its treatment plants (García, 2022), raising

doubts about the effectiveness of treatment despite official coverage rates.

This discrepancy highlights a critical gap between infrastructure availability and operational quality. The “coverage of treated wastewater” metric accounts only for the volume processed by CESPE and excludes wastewater not connected to official networks. Moreover, it only reflects the quantity of treated water, without assessing whether it is treated properly. Data obtained

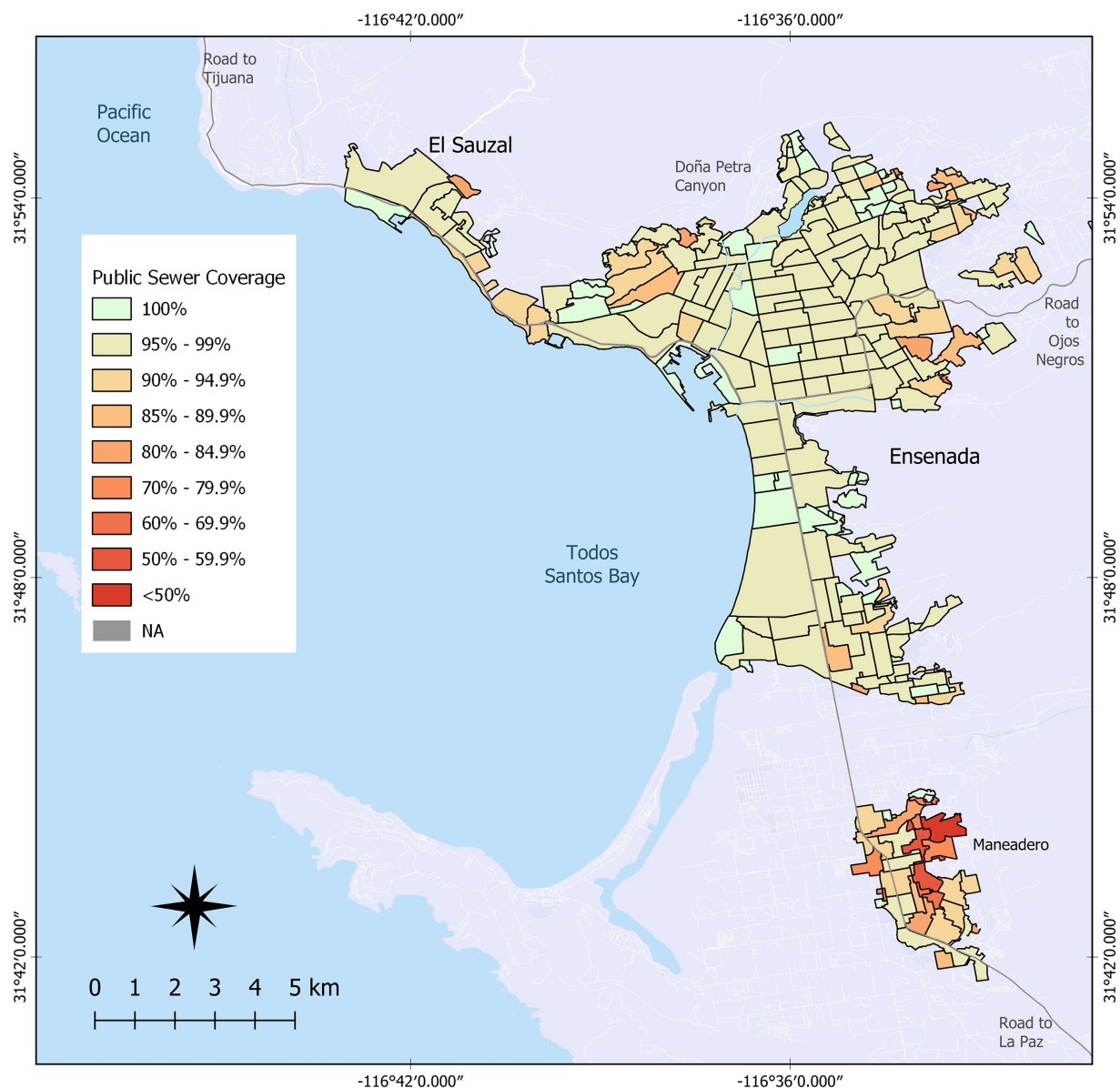


FIGURE 10
Sewer coverage and sanitation type in Ensenada urban region.

through the National Transparency Platform revealed operational efficiency rates in 2021 of 67.2% (El Gallo), 84.5% (Noreste), 87.4% (El Naranjo), 97.1% (El Sauzal), and 95.5% (Maneadero) (CESPE, 2022) (Figure 11). The downward trend in efficiency over the last decade underscores ongoing concerns regarding treatment adequacy.

Field interviews confirmed these issues. Experts from academia and government agreed that wastewater treatment infrastructure in Ensenada is insufficient and deteriorating, citing factors such as lack of maintenance, inadequate investment, urban sprawl, and industrial discharges exceeding plant design capacities (I-1, I-2, I-3, I-4). The lack of a national maintenance policy for decades has exacerbated infrastructure degradation (I-4).

Additionally, odor problems linked to wastewater treatment remain largely undocumented in official reports but are frequently reported in the media and citizen complaints (Flores, 2023; García,

2024). Interviewees noted that equipment failures, particularly at El Gallo WWTP, contributed to odor emissions affecting nearby residents (I-6). While odor inhibitors are used, they have proven insufficient to fully mitigate the problem.

Survey results further illustrate the impact of inadequate wastewater management: 20% of respondents reported experiencing sewage-related odors daily or almost daily in their neighborhoods (Figure 12). Persistent odor issues not only reduce quality of life but also erode public trust in sanitation systems.

These findings reveal that although Ensenada has relatively high access to sanitary infrastructure, operational inefficiencies and maintenance deficiencies undermine service quality. Addressing these gaps requires systemic improvements, including investment in plant rehabilitation, strict regulation of industrial discharges, transparent monitoring of treatment performance, and stronger enforcement of environmental standards.

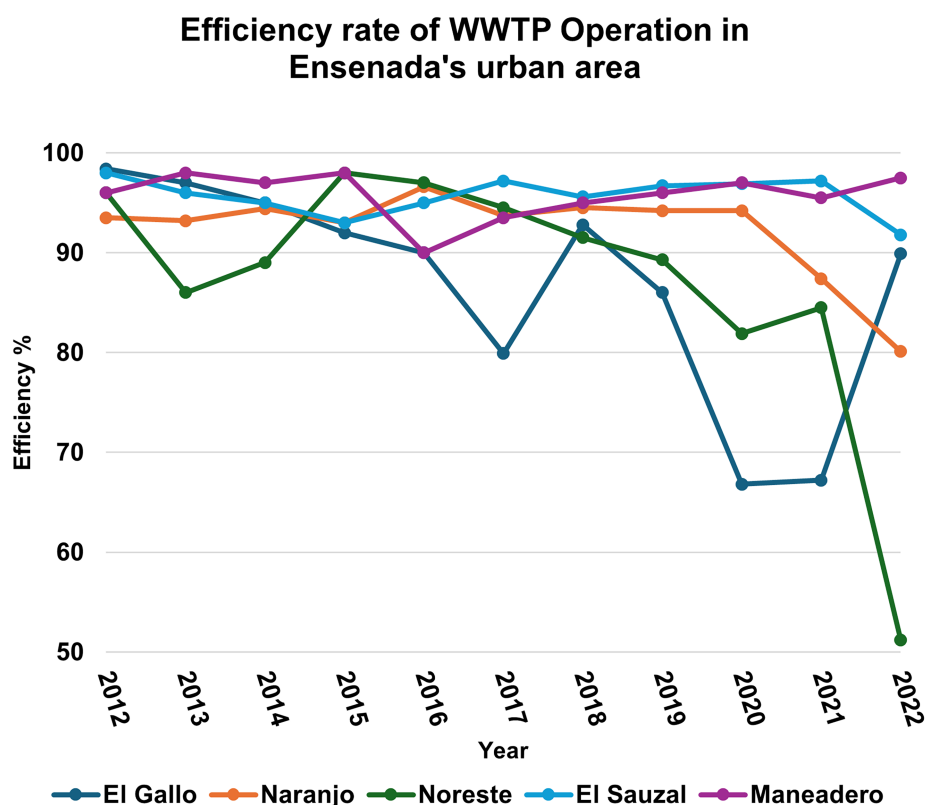


FIGURE 11
Efficiency in the operation of WWTPs of Ensenada urban area.

Frequency of sewage odors experienced in the past year

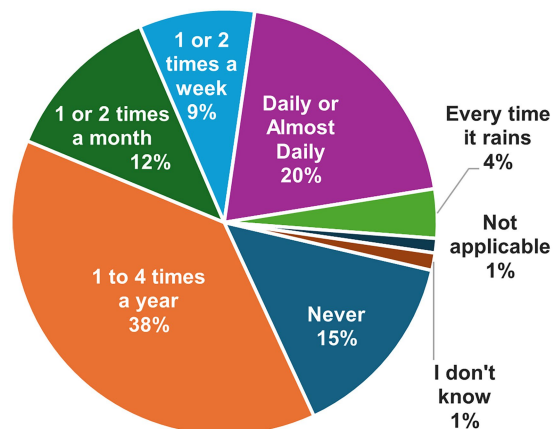


FIGURE 12
Perception of the sewage odors problems in the past year across Ensenada, Maneadero and El Sauzal.

It is important to recognize that wastewater treatment is not the endpoint. For a sustainable sanitation system, treated water must be safely reused or adequately discharged to prevent environmental and public health risks (Bhullar, 2013; Zimmer et al., 2014). Ensuring

the integrity of this final step must be a key priority in future sanitation planning.

4.5 Safe disposal or reuse of treated wastewater

Monitoring the quality of receiving water bodies is a key indicator of wastewater treatment effectiveness. In Ensenada's urban region, persistent concerns exist regarding coastal water pollution, often associated with wastewater discharges and odor issues (García, 2020; I-3). A recent and severe example is the contamination of Playa Hermosa, where enterococci levels reached 786 per 100 milliliters of water in 2022, far exceeding the WHO and Mexican thresholds of 200 (COFEPRIS, 2022). This led to a precautionary beach closure lasting nearly a year (Flores, 2022). Authorities attributed the contamination to failures at El Gallo WWTP, specifically the clarifier system (García, 2022; I-2; I-5; I-6).

Historical data further reveal long-standing pollution problems in the area. CONAGUA's monitoring network shows that areas like Doña Petra Creek, downstream of the Noreste WWTP, and La Lagunita wetland have consistently exhibited high levels of fecal contamination, often exceeding regulatory limits (see Supplementary Table S4).

Structural deficiencies also compound these problems. Issues include social housing developments outside municipal oversight (I-1), clandestine discharges (I-5), and operational challenges in treatment plants (I-4, I-5, I-6). Moreover, sampling practices may not

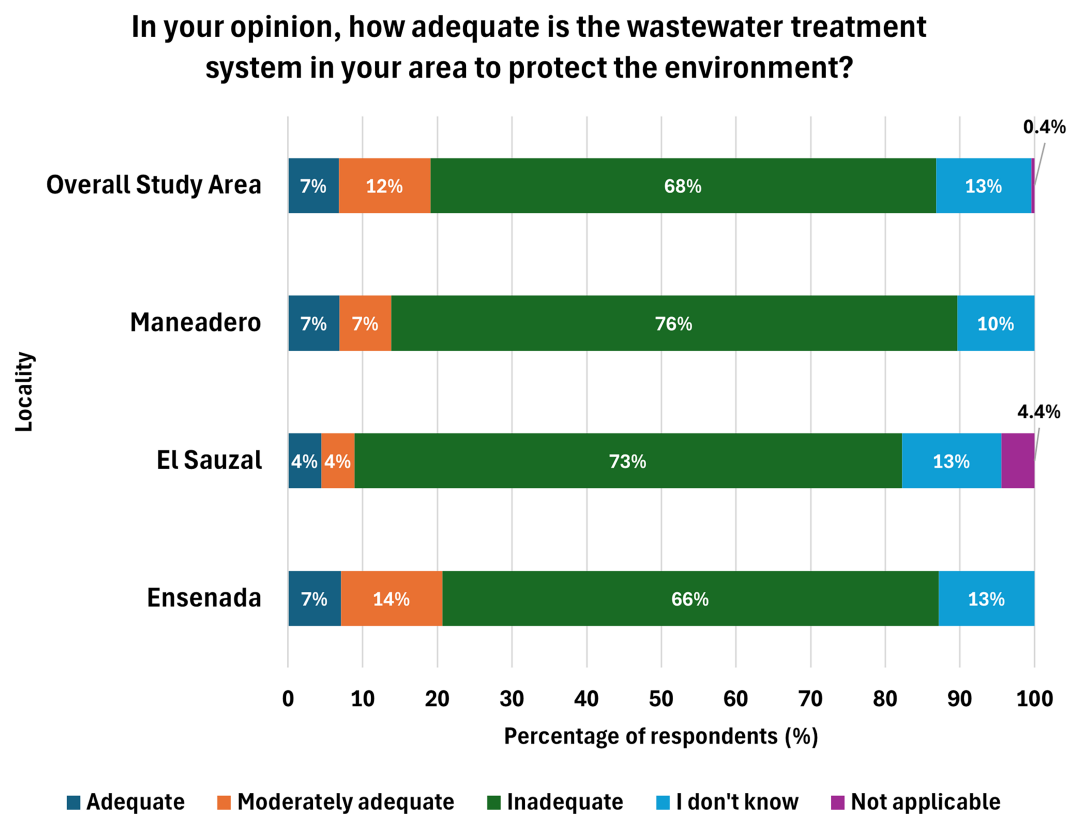


FIGURE 13

Perception of how adequate the local wastewater treatment system is in protecting the environment.

accurately reflect typical conditions, as they capture water quality at a single moment (I-6).

To complement official data, the survey asked residents whether they believed the local wastewater treatment system adequately protects the environment. Statistically significant differences were found in perceived effectiveness ($p < 0.05$), highlighting that, across the entire study area, 68% of the population consider it inadequate (Figure 13).

In a water-stressed region like Baja California, the reuse of treated wastewater offers a critical opportunity to augment available water resources. However, data on reuse is limited. Recent studies have indicated that the recycling of treated wastewater for irrigation and aquifer infiltration serves as a cost-effective alternative to mitigate the over-exploitation of aquifers within this municipality (Elizondo and Mendoza-Espinosa, 2020).

The 2018 State Water Plan reported a reuse rate of only 36.3% for Ensenada—compared to 76.2% in Mexicali—. However, more recent data indicates some improvements. Specifically, reuse from El Naranjo WWTP for floriculture irrigation in Maneadero increased from 37.29% in 2017 to 69.06% in 2023 (CESPE, 2024b). It is important to note that this data refers only to El Naranjo WWTP, not the overall wastewater generated across the municipality.

Public perceptions regarding wastewater reuse were also explored. A strong majority (76.5%) supported the reuse of treated wastewater as a solution to water scarcity (Figure 14A). Activities perceived as low-risk included firefighting (84%), street cleaning (75%), public garden irrigation (71%), and toilet flushing (68%). However, drinking (91%), bathing (66%), and

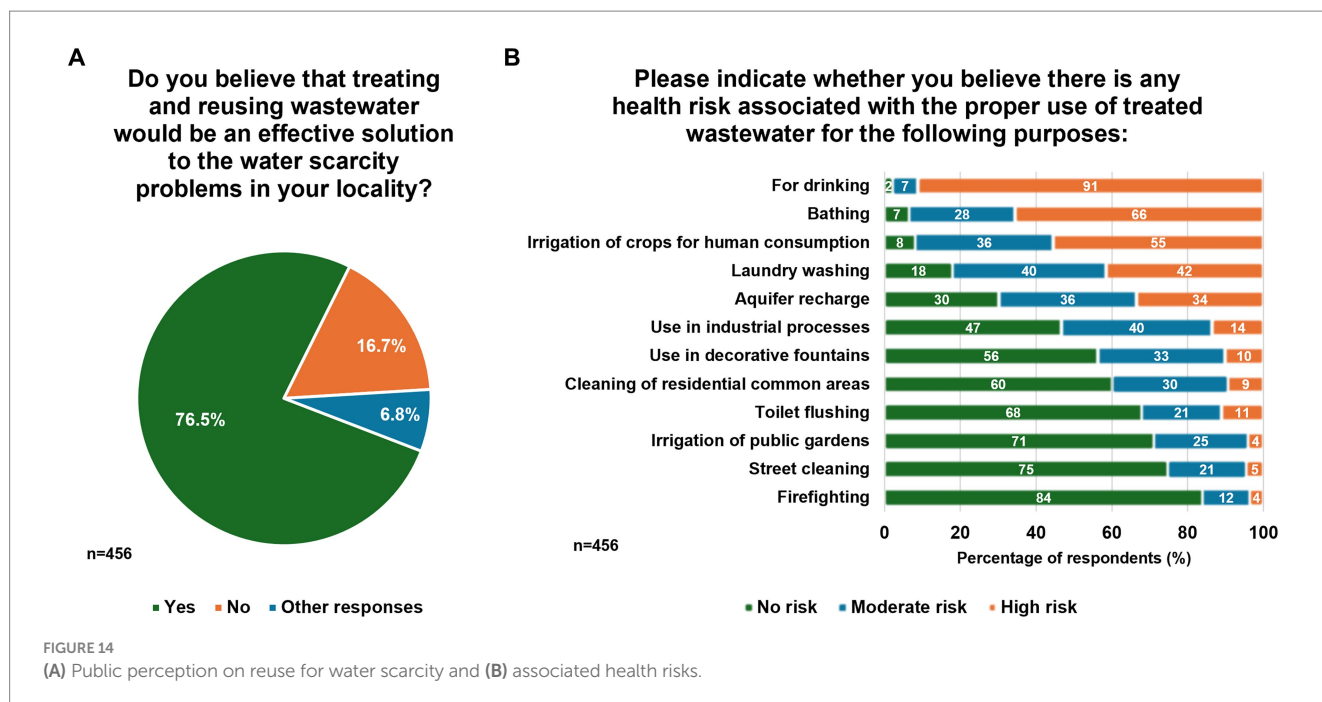
irrigation of consumable crops (55%) were seen as higher-risk applications (Figure 14B). A Chi-square test confirmed that these differences in perceived risk across uses were statistically significant ($p < 0.05$).

These results reveal both opportunities and challenges: while public support exists for certain reuse strategies, concerns about health risks must be addressed through improved treatment technologies, transparency, and public education initiatives.

5 Conclusion

In alignment with Sustainable Development Goal 6, this study highlights critical sanitation challenges in the Ensenada urban region. While access to basic sanitation infrastructure—such as toilets and sewer systems—is relatively high in Ensenada and El Sauzal, important disparities persist in Maneadero, where reliance on septic tanks remains prevalent. These findings reveal that sanitation services in peri-urban and lower-income areas lag behind, compromising both public health and environmental quality.

The decline in sanitary sewer coverage and the operational inefficiencies of wastewater treatment plants (WWTPs) raise serious concerns regarding the principle of progressivity in the human right to sanitation. Discrepancies between official data sources and the limited transparency of local information further hinder effective planning and monitoring, reflecting a broader systemic issue observed in many developing contexts.



Survey results underline the need to strengthen public awareness around sanitation as a comprehensive human right. Although wastewater collection and treatment are recognized by most residents as essential components, a significant portion still underestimates the importance of access to clean and hygienic facilities. Maintenance deficits in public restrooms and limited accessibility for people with disabilities remain critical gaps, requiring targeted infrastructure upgrades and inclusive policies.

Moreover, recurrent sanitation issues (such as frequent odor problems and concerns about treatment effectiveness) highlight the need for investment in preventive maintenance, odor control technologies, and continuous wastewater quality monitoring. Public perceptions toward the reuse of treated wastewater show cautious support for non-potable applications, suggesting potential pathways to improve water sustainability, provided that public health concerns are addressed through robust treatment standards.

Overall, this study underscores that improving sanitation services in Ensenada demands a multi-level approach: expanding infrastructure in underserved areas, enforcing maintenance and operational standards, enhancing public engagement, and ensuring transparency in data reporting. Promoting alternative sustainable sanitation technologies, especially in water-scarce and peri-urban regions, can also contribute to greater resilience.

By addressing these challenges, Ensenada can move toward a more inclusive, equitable, and sustainable sanitation system, contributing meaningfully to achieving universal access to adequate sanitation by 2030. This analysis provides a valuable framework for guiding targeted interventions and policymaking to uphold sanitation as a fundamental human right and to support broader local and global development goals.

Data availability statement

The datasets presented in this article are not readily available because the dataset is original and fully anonymized. It is not publicly

available to ensure proper management of its use and attribution, but may be shared for academic and non-commercial purposes upon reasonable request to the corresponding author. Requests to access the datasets should be directed to Vanesa García-Searcy, garcia.vanesa@uabc.edu.mx.

Ethics statement

The studies involving humans were approved by the Committee on Ethics and Evaluation for Research and Graduate Studies of the Instituto de Investigaciones Oceanológicas, UABC. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by all participants.

Author contributions

VG-S: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing. MV-C: Methodology, Project administration, Supervision, Validation, Writing – review & editing. DM-P: Methodology, Validation, Writing – review & editing.

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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.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/frwa.2025.1627694/full#supplementary-material>

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