



Community Based Participatory Assessment on Water Security on San Cristóbal Island, Galapagos

Spatial Mapping of Community Resilience, Water Governance, Usage, Infrastructure, and Flood Risk

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Abstract

This study applied a Community-Based Participatory Research (CBPR) approach to assess water-related challenges on San Cristóbal Island, Galápagos, Ecuador. Data was collected by means of semi-structured interviews (74 households), stakeholder interviews, expert consultations, and 150 resident questionnaires regarding water vulnerability and flood risk. This research assessed lived experiences alongside governance mechanisms, investment plans, and socio-economic status and highlights the individual responsibility and adaptability requirements by residents of San Cristóbal in regard to water scarcity, quality and floods.

The island's gravity-led distribution network covers 93.07% of households but operates intermittently (3 hours/day), necessitating storage at the household level and shifting maintenance responsibilities to residents. As a result, vulnerabilities differ across and within neighbourhoods according to storage type, cleaning practices, chlorine use and geographic location, none of which show consistent correlation. Spatial mapping of the system revealed pressure-sensitive segments, indicating uneven performance across the system, where pressure fluctuations compromise delivery. Moreover, limited contingency support has made neighbourhoods still awaiting connection to the main supply overly dependent on limited sources, leaving them particularly vulnerable during service interruptions.

Reported system failures are widespread: 89% of interviewed households reported at least one problem, most commonly water shortages, high turbidity, and pipe breakages. Vulnerability varies between households depending on the capacity of water reserves and the potential of (re-)contamination. Even for households that report a rigid cleaning regime, these problems are present. The multiple mentions of pipe leakages and muddy water indicate seepage into the pipeline system, suggesting that water quality is compromised before it reaches the households. However, according to some residents, contamination stems from the source, citing low efficiency at the drinking water treatment plant. This distrust in water quality translates to a high reliance on bottled water, which is uniform across the island despite its associated costs.

Reports on flood-related incidents are highly dependent on location, concentrated in places where local topography, incomplete drainage, or ravine bottlenecks amplify runoff. Notably, 23% of all questionnaire respondents reported that their homes suffer damage from flooding, highlighting the tangible impact of these events on residents. Despite significant municipal spending on flood relief, the creation of predictive flood models is restricted by limited technical knowledge and know-how, causing the infrastructural interventions to remain largely reactive, with affected areas identified only post-event. Comparing municipal investment plans with a resident weighted satisfaction index reveals that spending does not uniformly translate into higher satisfaction. Residents report greater value to reliability and communication with the community. Spatial analysis of the urban area Puerto Baquerizo Moreno shows that socio-economic vulnerability generally increases from coastal to peripheral neighbourhoods, but incomplete infrastructure, water shortages, and flooding do not always coincide with limited municipal support, meaning that some vulnerable areas still benefit from interventions while others remain underserved.

The results highlight how infrastructure performance and governance practices interact to shape everyday water-related vulnerability for the residents of San Cristóbal. The CBPR framework allows for enhancement of urban planning knowledge, with lived experiences of those most affected by it.

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Introduction

In 2010, access to safe drinking water and sanitation was declared a human right by the United Nations General Assembly (UNGA, 2010). Since then, many initiatives have been launched to meet Sustainable Development Goal 6 – ensuring water and sanitation for all by 2030. However, historical rates of progress would need to double for this to be achieved (UN Water, 2021). Beyond coverage, many countries face challenges to ensure the delivery of safe, quality drinking water at user level.

This issue is particularly relevant for small island developing states (SIDS) with little to no freshwater sources, as is the case for many islands on the Galapagos archipelago. The Galapagos archipelago consists of 13 main volcanic islands, of which 3 are most inhabited: Isabela, Santa Cruz, and San Cristóbal. While Isabela and Santa Cruz rely on aquifers or marine desalination for potable water, San Cristóbal is the only island with perennial freshwater streams (Riascos-Flores et al., 2025). In 2013, the municipality of the island opened a new drinking water treatment plant (DWTP) to replace an aging system, which greatly increased quality of the DWTP effluent (Houck et al., 2020). Two freshwater lakes form the source of potable water on the island: Los Americanos and Cerro Gato, both of which meet Ecuadorian standards for water to be used for human consumption (Grube et al., 2020). However, limited system capacity requires that each neighbourhood is only given 3 hours of water per day. This causes intermittent water supply and necessitates the use of household storage for inhabitants, which is associated with higher risks of recontamination (Calero Preciado et al., 2021). Gerhard et al. (2017) found contamination in 66% of point-of-use sites (n=50) on San Cristóbal, as measured by total coliforms. A similar result was found in the 2020 study by Grube et al., where total coliforms contamination was found in 52.2% (n=46) of residential tap water analysed, highlighting the challenges with regard to providing potable water at the household level.

In San Cristóbal, water governance requires balancing environmental, social and economic concerns (Mateus et al., 2020). 77% of income is generated by tourism with more than 72000 tourists arriving on the island per year (GADMSC, 2024). This great number of visitors puts a strain on water infrastructure and availability. Besides this tourist influx, the ecological diversity of the island comes at a price. The unique geographical location that facilitates the pristine environment, make it vulnerable to climate stressors. Precipitation on the islands is concentrated within the wet season, between December to May, and exacerbated during El Niño events (Paltán et al., 2023). These heavy rains subject the islands to severe floods, often leading to infrastructural damages.

On San Cristóbal, the 8300 residents have grown accustomed to these regular floods and erratic water supply, finding ways to adapt. Previous researchers have addressed some topics of water vulnerability by utilizing environmental impact assessments (Martínez-Fernández et al., 2020), physical-chemical data (Grube et al., 2020; Houck et al., 2020), and climate projections (Winckler et al., 2024). However, water-related vulnerability is more multi-faceted than its technical properties. To facilitate adaptive infrastructure management, a comprehensive understanding of residents' activities is valuable towards adding nuance to expert assessments (Feng et al., 2025).

Communities, as the ultimate beneficiaries of water and flood prevention services, should be integrated into water-related vulnerability assessments. Addressing community perceptions and fears is crucial to sustainable governance mechanisms. Community based participatory research (CBPR) is a research approach that equitably involves community members, academic researchers, and other stakeholders (Shalowitz et al., 2009). It is widely used within the field of social sciences and is

considered an ethical approach to improving rigor, relevance, and reach of science (Wilson et al., 2025). This study thus seeks to integrate the guiding principles of the CBPR framework to assess water-related challenges on San Cristóbal, Galapagos. In adopting this framework, this research aims to identify community-specific issues that might be overlooked by top-down assessment. These assessments tend to prioritize technical performance indicators (e.g. treatment capacity, pipeline coverage) while neglecting residents' lived experiences of water scarcity, intermittent service, and local adaptation. This disconnect often results in interventions that fail to address everyday vulnerabilities, such as uneven water delivery schedules, unmaintained drainage points, or overreliance on self-managed storage systems.

Through utilizing stakeholder interviews, household surveys, questionnaires, and expert consultations, a more comprehensive understanding of water challenges is acquired. Similar methodological approaches to water risk assessments have been applied in rural areas of Nagaon, India and El Tiple, Colombia, where the former also includes both water quality and flood risk (Bahamón-Pinzón et al., 2024; Bhuyan et al., 2024). This study provides a CBPR approach for assessing water-related challenges in small island developing states. Specifically, the aim is to find out "What water-related challenges do residents of San Cristóbal face with regards to the municipal water distribution system and flood risk?". Though it is important to acknowledge the context-specific realities of cultural and hydrogeological differences, the methodological framework can provide a basis for transferrable research in other regions where community needs are insufficiently addressed by governance structures. It is particularly relevant for municipalities where information is fragmented or not easily shareable across institutions.

The outcomes of this study are presented to the municipal government of San Cristóbal and the parish El Progreso, as well as researchers within the Galapagos Science Centre, Universidad San Francisco de Quito and the University of Virginia, for the design of future adaptive infrastructure strategies.

Adhering to guidelines set by Universidad San Francisco de Quito, The University of Virginia and Delft University of Technology, this analysis followed standard ethical procedures. All participants were informed on the proceedings and objectives of this project prior to sharing information, and fully aware of any recording, transcription, or photography taken. Participants were free to withdraw consent for the use of their data. Importantly, permissions were obtained from anyone mentioned specifically by name, as all other information has been anonymized.

2. Methodology

This chapter outlines the methodological approach adopted in this study, structured according to the subsections presented below. The framework follows the guiding principles of CBPR, combining community engagement with quantitative and spatial analysis.

2.1 Study Area

San Cristóbal is the fifth largest and easternmost island of the Galapagos Archipelago, home to the capital of the islands. The island is divided into what is considered an urban (Puerto Baquerizo Moreno) and rural (El Progreso) area. The urban area on the southwest contains a harbour, airport, many commercial services, tourism, and houses 7.290 inhabitants on an area of 655 hectares (GADMSC, 2024). It is subdivided into 18 'barrios' or neighbourhoods.

The rural area is also referred to as 'the highlands' at an altitude of 320 m, and houses 865 inhabitants. These 865 residents are spread throughout the remaining rural land on the island, entailing an area of 8,339 hectares. There are nine enclosures within this area, all of which are rural with the exception of one peri-urban area named the Cabecera Parroquial El Progreso (GAD Parroquial Rural El Progreso, 2025).

This study included the urban and peri-urban areas of San Cristóbal, i.e. the entirety of Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso. These also correspond to the 93,07% of households that are connected to the municipal water supply (GADMSC, 2024). The remaining households in the parish of El Progreso either receive water from the Parroquial El Progreso or manage their own water supply through rainwater collection or springs. Agricultural areas in the highlands receive untreated water from the Consejo de Gobierno (CGREG). However, this is solely for irrigation purposes and thus not considered in this study.

Figure 1 shows a visualisation of the neighbourhoods and their boundaries. These neighbourhoods (or some combinations of them) are used as a base in creating the maps described in section 2.4. Table 1 indicates the populations of each neighbourhood and the degree to which they are covered by this study (number of respondents and their household sizes).

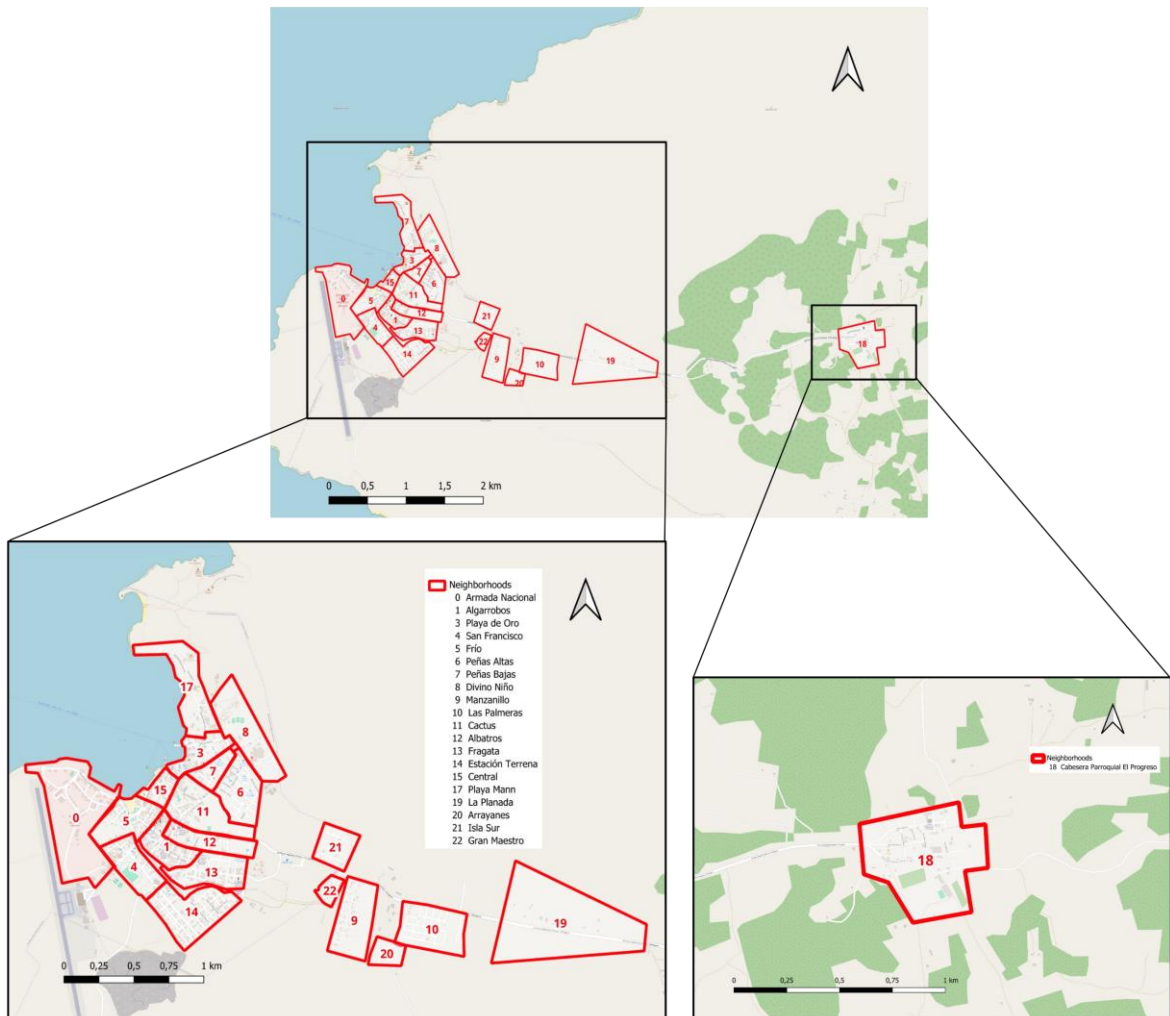


Figure 1: Urban and peri-urban neighbourhoods or 'barrios' of San Cristóbal Island.

Table 1: Overview of population and interview/questionnaire coverage by neighbourhood.

Neighbourhood	Population	Households Interviewed	People Reached through Interviews	Questionnaire responses
Albatros	506	3	8	9
Algarrobos	742	5	39	9
Arrayanes	30	2	8	3
Cabecera Parroquial El Progreso	667	8	25	13
Cactus	745	4	23	8
Central	253	4	12	10
Ciudadela del Maestro	140	1	4	2
Divino Niño	513	5	28	12
Estación Terrena	857	6	41	11
Fragata	590	4	14	11

Neighbourhood	Population	Households Interviewed	People Reached through Interviews	Questionnaire responses
Frío	374	4	20	12
Isla Sur	94	1	7	1
Las Palmeras	262	3	10	7
Manzanillo	234	2	6	2
Peñas Altas	888	6	27	16
Peñas Bajas	564	4	30	10
Playa de Oro	208	4	12	7
Playa Mann	69	3	12	4
San Francisco	221	3	18	3
Sector la Planada	200	2	7	2

2.2 Community Based Participatory Research

The present research assessed water-related challenges via various techniques including stakeholder interviews, semi-structured household interviews, transect walks, surveys, and expert consultations. These were carried out for a duration of 2 months, a visualization of the methodology is shown in Figure 2. All interviews were recorded through audio recordings, which were promptly transcribed to ensure full data capture.

Following the CBPR framework outlined by Wilson et al., 2025, this study was guided by the 8 principles (shown in bold) for sustained community engagement:

Strong community partnerships were formed by communicating to community leaders prior to interviewing residents. This ensured trust building and mutual understanding of the project's objectives.

The design of the project was based on community identified needs through initial consultations with professors from Universidad San Francisco de Quito and The University of Virginia that have experience with working in similar environments, and the project objectives were changed accordingly during the process based on feedback from residents.

A **collaborative research agreement** was reached with the municipality and parish of El Progreso prior to arrival on the island by notifying of the researchers' arrival and project proceedings. Each interviewee and survey participant were also made aware of project objectives prior to participating. **Data collection and analysis** were **transparent** and communicated to each participant, and survey sites were modified throughout the fieldwork to ensure proper coverage.

Collaborative decision-making processes were built upon the consultations with professors from both USFQ, The University of Virginia and TU Delft, and followed from interviews with stakeholders or residents.

Balance of research interests and community needs came from facilitating the initialization of infrastructure projects for the community by USFQ. Though not all identified needs were able to be included in this research, the researchers intend to advise for omitted challenges to be assessed in future academic research.

Sharing results in public community meetings will be adhered to via a public seminar held later this year on the island, with all residents and interested parties invited. A lightweight webpage with interactive maps for community use will be created.

A summary of this report will be shared with the autonomous government of the municipality and El Progreso to **provide accessible written reports for broad audiences**. Furthermore, an outline of the research will be written to accompany each map.

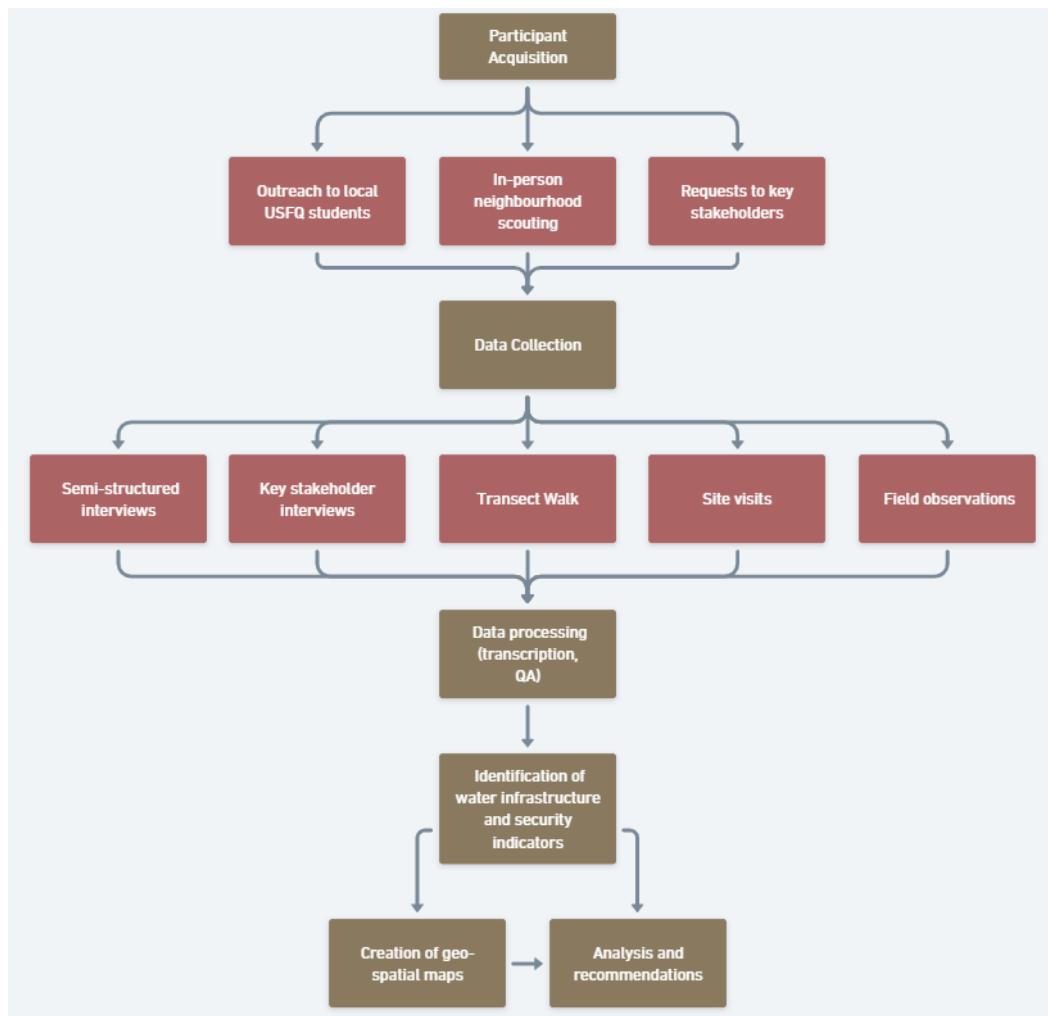


Figure 2: Overview of the data collection and analysis workflow.

2.2.1 Literature Study

Literature review provided the first assessments to identify key water-related challenges connected to potable water and flood risk. This included technical reports, urban plans, risk assessments, and

other grey literature related to San Cristóbal's infrastructure, planning, and management. These sources were fundamental to defining what challenges were included in this study, as well as the scope.

Alongside literature, expert consultations were held at the main campus of USFQ in Quito, with professors of civil engineering, hydrology, anthropology, and urban planning. As many of them have worked in the Galapagos, this gave valuable insight into the cultural context and governance mechanisms, especially for formulating interview questions.

The full list of the consulted documents can be found in Appendix A: Literature .

2.2.2 Semi-structured household interviews

Initial communication with the residents took place via USFQ, where university students were asked to fill out their contact information should they be interested in joining an interview. Researchers also encouraged students to reach out to family members and friends. Thus, the first few interviews were with (relatives of) USFQ students.

The majority of fieldwork subsequently consisted of carrying out semi-structured interviews with residents of the island. These interviews were conducted in groups of 2 or 3 researchers at a time, often going house-to-house to gather participants. Conversations with residents took place through open-ended questions, such as "What problems have you experienced with the water system?" or "How do you manage water shortages?". This facilitated discussions on different forms of self-organized water governance and kept the interview non-formal. These interviews aimed to understand residents' experiences, perceptions, and challenges comprehensively.

2.2.3 Stakeholder interviews

Besides residents, researchers reached out to municipal staff and employees from key local institutions. Amongst them, mayor of the Cabecera Parroquial El Progreso, engineers from the municipality, firefighters, school heads, municipal workers, and councilmen. These interviews contained more targeted questions surrounding the water distribution system and flood management practices. This helped with identifying governance mechanisms from several viewpoints.

2.2.4 Transect walks

The transect walk is a tool for locating spatial and technical deficiencies in infrastructure. Researchers adhered to the informal structure of household interviews, while encouraging residents to explain things during a walk around the neighbourhood. This gave the opportunity to residents to point out vulnerable areas or self-organized infrastructure projects. Locations were saved with the Garmin GPS i67 or QField mobile app, alongside a geographical recording of the transect route. In addition to revealing the spatially-specific challenges, transect walks emphasize management of local resources whilst ensuring participatory collaboration in the observations.

2.2.5 Questionnaire

Alongside interviews that targeted a comprehensive understanding, questionnaires were conducted during two weeks of the field work. These were distributed both to households that had participated in the semi-structured interviews and to additional residents across the island to increase coverage and representativeness. By capturing quantitative data on water security, governance, and flood risk per barrio, spatial inequalities were highlighted, allowing to identify areas where intervention is most needed.

2.3 Data Processing

Different data sources required different processing steps. The filled questionnaires were digitised manually into a csv format, with barrio, question, and response. This was used to programmatically calculate metrics and draw insights for certain maps.

The following data processing pipeline was designed for the audio-format semi-structured interview data: the interview recordings were cleaned, transcribed to text and translated to English. After this, LLM-based question-answering extracted relevant information from the interviews.

2.3.1 Recording

The interviews were recorded and stored on the researchers' mobile phones. This was the only recording equipment available, did not incur additional cost and was minimally intrusive during the data collection phase. The microphone was held within a metre of the subjects or placed on a surface (table/desk/chair) nearby. At the end of each day, the recordings were uploaded to the TU Delft OneDrive folder and removed from the local devices. Due to the different mobile phones used, the audios were in a mix of formats and specifications (.m4a, .aac, etc).

2.3.2 Cleaning

Some audios had extended silences and were cleaned using the open-source Praat software (Boersma & Weenink, 2025). Further, all audios were converted to the .wav format using ffmpeg, with mono audio and a 16000Hz sampling rate (Suramya Tomar, 2006).

2.3.3 Transcription and Translation

All audio recordings were transcribed locally using Whisper large v3 turbo, a transformer-based open-source model from OpenAI (Gerganov, 2024). Though direct Spanish QA exists, the transcripts were translated into English through use of Llama-2 70B, a high-parameter instruction-tuned large language model (LLM), (Meta, 2023). Translation was done to increase understanding of the conversations among non-Spanish speaking researchers.

Question-Answer Extraction

Information was extracted from the transcripts using LLM-based QA. Meta llama, Qwen, Claude, and LiquidAI models were tested on their extraction capabilities. For each model, a test run was done for 4-5 transcripts, after which the prompt or questions were reformulated. The selected extraction model was Claude Sonnet 4.5. All the responses were aggregated into one large CSV for downstream dataframe creation and statistics. Find more details regarding the data processing in Appendix B: Data Processing.

2.4 Spatial Analysis

Geographical data collected through the interviews were imported into QGIS (QGIS Project, 2024). Corresponding information was matched to point of interest using PyQGIS, Python, or manual attribution as appropriate.

2.4.1 Map of Public Water Distribution System

At the time of the study, a complete map of the island's water infrastructure was not available. Therefore, the reconstruction of the water distribution system relied primarily on qualitative information obtained through targeted interviews with municipal engineers and workers from the

Jefatura del Agua Potable at the GADMSC. This provided the official schedule of water supply for each barrio, and locations of main pipelines and valves. The attained map with a simplified representation of the island's water network was then validated by one of the workers in an interview and feedback session.

2.4.2 Community and Water Infrastructure Mapping

This section examines the spatial and social dimensions of water infrastructure and governance across the study area. It focuses on self-organized water management practices, usage patterns of public and private sources, and the failures and responses experienced by households in San Cristóbal.

Self-Organized Water Governance Practices

In order to visualize the different forms of self-organized water governance, the type and usages of household-level storage systems were mapped through data gathered in the interviews. Interviewees were asked about their type of storage, management of the water storage, management of treatment practices, and preferences for consumption.

The following categories were formed for each theme (shown bold) according to the range of answers in the interviews.

- **Type of storage** was categorized into tanks, cisterns, or both.
- **Management of the water storage** consists of the cleaning practices that interviewees indicated. This was divided into those that clean it monthly, bi-monthly, quarterly, half-yearly, yearly or less. Additionally, never was assigned to interviewees that have not cleaned their storage system since they live there.
- **Preferences for consumption** were found to be either bottled water, filtered water, boiled water, or water directly from the tap.
- **Filter replacement practices** are categorized as: unknown, never, more than four times a year, four times, three times, twice, once a year, and less often.

Type and management of storage, and preferences for consumption were mapped spatially within the different neighbourhoods. For the management of the treatment practices (replacing of water filters), data was analysed universally due to the lower number of interviewees that partake in these practices.

Given the small sample size within each neighbourhood, the analysis included not only the individual interviewees but also the persons with whom they share their primary water source, as well as all household members engaging in the same drinking water practice.

Moreover, some neighbourhoods have been merged as described in Appendix C-1 Types of water governance neighbourhood groups

Usage patterns of public water distribution and private bottle consumption

The spatial analysis of usage patterns relies on two types of water usage: that which is supplied by the municipality through the piping system, and bottled water. As the distribution system relies on metered connections, yearly usage per barrio was available by courtesy of the municipality. This was converted to average usage per person with an estimation on population data from the 2022 national census as described in Appendix B-2 Population estimation (INEC, 2022).

As many interviewees indicated a reliance on bottled water, this was also considered as a measure of water usage. Responses obtained from semi-structured interviews regarding consumptions of bottled water were collected and converted to units of bottles/person/week. This was made possible by utilizing questions regarding the amount of people living in the household.

Experienced Failures and Responses

Mapping the experienced problems with the water distribution system is key to highlighting areas of improvement. In the semi-structured interviews, residents were asked about system failures and how they handled these. It was apparent that failures regarding the piped water fell within one of four categories: water shortage, water clarity, pipe leakage, or water-related health issues. All the mentioned problems were gathered under one coded data file, and assessed on responsible party, frequency of occurrence, and time of resolution. This information was promptly mapped to create a visualization of the challenges that residents of San Cristóbal face with regards to the distribution system and pipeline.

2.4.3 Flood Risk Mapping

Flood risk was mapped by integrating predetermined, perceived, and experienced flood-risk from complementary data sources. The objective was to visualize institutional classifications, household perceptions, and observed flood impacts in a three-layer gradient map.

Predetermined flood risk was derived from official classifications by the GADMSC risk reduction department, which utilizes technical support from the Japan International Cooperation Agency (JICA). JICA provided a standardised disaster risk assessment framework, which has since been adapted by local governments across Ecuador for multiple types of natural hazards, including flooding (Japan International Cooperation Agency, n.d.). The JICA framework applied a qualitative and categorical three-tier scale (high, medium, low), derived from a combination of (i) historical flood occurrence and spatial distribution based on local observations and community reports and (ii) precipitation intensity and frequency data supplied by the National Institute of Meteorology and Hydrology (INAMHI) (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025). Because no detailed topographic model is available, this approach provides an indicative and comparative, suitable for public awareness and preliminary spatial planning assessment, rather than detailed hydrological forecasting.

At the time of study, the most recent classification following the JICA methodology was performed in 2021 (Medina, 2022). Earlier, in 2015, the municipality had established a precautionary measure introducing a 10 m setback zone on both sides of the ravines, where construction is prohibited due to the high flood risk identified through the JICA model (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025). Both the neighbourhood classifications and the setback zones were incorporated into the predetermined flood-risk layer.

Perceived flood risk was calculated as the mean of questionnaire responses to Question 7 (“*I am concerned about flooding in my neighbourhood during the rainy season*”), on a Likert scale from 1 indicating ‘strongly disagree’ and 5 ‘strongly agree’. To ensure an acceptable minimum sample size of 10 questionnaires per neighbourhood, certain neighbourhoods were merged, as detailed in C-2 Flood Risk neighbourhood groups. Although the sample size is relatively small compared to the overall population, this limitation does not prevent the identification of meaningful patterns, as previous

participatory mapping studies have shown consistent results even with few participants (Le et al., 2024).

Experienced flood risk was represented by the proportion of residents reporting household damage from flooding. This percentage was determined based on the number of people responding a 'agree' or 'strongly agree' to Question 11: "*When there is a flood, my house suffers a lot of damage*". The same neighbourhoods, as shown in Appendix

C-2 Flood Risk neighbourhood groups, were used to ensure consistency with the perceived flood risk.

Additional spatial and qualitative components were incorporated into the map, including:

- Known pathways of the ravines (*encañadas*) around the urban areas of Puerto Baquerizo Moreno obtained from Google Earth files from the municipality and available satellite data (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025). Main runoff flow paths, indicated by local residents and the interview with a municipal engineer of the risk reduction department.
- Locations of critical points were highlighted, including places that are particularly prone to flooding or experienced damages identified from the semi-structured interviews with residents and an interview with the municipality risk team (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025). Each point was linked to a short anecdote or background information. These qualitative inputs help to illustrate the lived experiences and underlying causes behind the numerical data. The points are divided in 4 categories:
 1. Prolonged street flooding
 2. Private damage
 3. Beach flooding
 4. Ravine
- Contour lines showing topography based on a 30m resolution satellite imagery obtained from previously performed research on the University of San Francisco de Quito by Peralta, 2020.

2.4.4 Perceived Satisfaction toward Water Governance

Mapping water governance alongside residents perceived satisfaction aims to identify areas that may be underserved. These areas can then be prioritized for further investigation or targeted for more in-depth studies.

Water governance has been defined here as the ‘institutional arrangements affecting procedures and outcomes in water-related infrastructure including all municipal plans on sewerage, drinking water supply, and flood management’. Previous studies have noted integration of community concerns into such governance processes (Mateus et al., 2020).

To represent municipal attention, a proxy is used: the municipality’s investment projects related to water infrastructure, sewage systems, and flood-prevention measures. Investments in these sectors not only address immediate infrastructure needs but also contribute to broader community development, improve public services, and support sustainable long-term planning. Data were drawn from the 2020–2024 and 2024–2027 Plan of Desarrollo (GADMSC, 2020) (GADMSC, 2024), focusing specifically on interventions at the neighbourhood level.

Initial satisfaction indicators were based on the structure of Bhatta et al., 2024 sustainability assessment framework: efficiency, resiliency, and community support. To ensure consistent understanding in the questionnaire, community support was subdivided into participation and communication. Following interview feedback, resiliency was changed to reliability, as many residents specified importance on the municipality’s responsiveness when problems arise.

The following four statements were evaluated using a Likert scale in the questionnaire and linked to the four dimensions of efficiency, reliability, participation, and communication:

- *“I think the water infrastructure is effective”*

- “I think the plans regarding the water infrastructure include community participation”
- “I believe the municipality communicates transparently about the plans regarding water infrastructure”
- “I believe the municipality takes responsibility when something breaks”

An overall satisfaction index was then calculated for each neighbourhood as a weighted average of these four dimensions. The importance of each indicator was validated by residents, and pairwise comparisons were used to determine the final weights contributing to overall satisfaction (1000 Minds, 2025) as shown in Table 2: Relative weights of satisfaction dimensions derived from the participatory weighting method. For the purposes of analysis, some neighbourhoods were grouped based on the number of questionnaires collected, spatial proximity, and the number of municipal projects associated with each area, as explained in Appendix C-3 Formal Governance and Perceived Satisfaction neighbourhoods groups.

The complete procedure, including survey design and the weighting methodology, is described in detail in Appendix C-6 Participatory Weighting Method for the Dimensions of the Overall Satisfaction Index. A full list of projects included in the maps is presented in Appendix C-4 List of Municipal Investment Projects, while additional methodological details are provided in Appendix C-5 Specification for the spatial representation of projects in the investment plan layer.

Table 2: Relative weights of satisfaction dimensions derived from the participatory weighting method

Dimension	Weight (%)
Reliability	34.38%
Efficiency	28.13%
Participation	18.75%
Communication	18.75%

2.4.5 Socio-Economic Vulnerability Mapping

To explore potential correlations between socio-economic inequalities and access to safe drinking water, a relationship often observed across diverse urban contexts (Oskam, 2021), a relative socio-economic vulnerability map of Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso was developed.

The study aims to examine whether intra-urban socio-economic differences correspond to variations in water infrastructure and access across neighbourhoods. It focuses on identifying relative differences in living conditions rather than producing a comprehensive vulnerability assessment, given the exploratory nature of the analysis and the limited availability of neighbourhood-scale data.

Socio-economic vulnerability indices are commonly constructed as composite frameworks integrating economic, physical, and social dimensions, including income, housing quality, education, and access to services (Savelberg et al., 2025; Li et al., 2023). Building on these approaches, this study identifies two proxy indicators that can reflect relative socio-economic differences at the neighbourhood scale.

1. Standard of Living –represents spatial differences in material living conditions, expressed through the physical state and maintenance of buildings and roads, which together mirror local access to resources and services (Pradhan & Agrawal, 2025) (Dadang, 2024)
2. Community Infrastructure – indicating the availability of social and public facilities that enhance neighbourhood resilience and cohesion (McShane & Coffey, 2022).

Both indicators were assigned equal weighting (50%), consistent with the INFORM methodology (Savelberg et al., 2025) and normalised in 0-1 scale, where 0 indicates high vulnerability and 1 indicates low vulnerability.

Given the city's small urban scale and the limited availability of statistical data, a direct observation-based approach was used to assess the Standard of Living indicator and was applied systematically to ensure consistency and comparability across neighbourhoods. This involved field observation of building and road conditions, evaluated on a five-point qualitative scale from "low" to "high," where "low" represents the poorest observed condition and "high" the best.

Information on community infrastructure indicator was instead derived from the Plan de Desarrollo 2020-2024 (GADMSC, 2020). Further details on the indicators and scoring procedure are provided in Appendix D: Social economic vulnerability indicators.

3. Results and Discussion

This chapter presents the findings of the study, integrating qualitative, quantitative, and spatial data to evaluate water-related challenges, governance mechanisms, and community perceptions on San Cristóbal Island. The results are organised thematically, reflecting the deliverables presented to the community (i.e. maps).

3.1 Public Drinking Water System in San Cristóbal

This section provides an overview of the organizational and physical structure of the public drinking water system on San Cristóbal Island. It outlines the main governance mechanisms that regulate water management and the technical configuration of the distribution network supplying the island's population.

3.1.1 Governance Mechanisms

In San Cristóbal, water quality governance follows a top-down approach. The Consejo de Gobierno del Régimen Especial de Galápagos (CGREG) is responsible for issuing regulations and funding on water and sanitation within the Galapagos (Mateus et al., 2020). These regulations form a basis for the plans and initiatives taken by the Municipal Decentralized Autonomous Government, Gobierno Autónomo Descentralizado Municipal (GADM), which bear responsibility for the quality and distribution of potable water. San Cristóbal houses two decentralized autonomous governments, that of the municipality of San Cristóbal (GADMSC), and that of the parish El Progreso (GAD El Progreso). The latter, however, does not manage the piped drinking water supply. The GADMSC Drinking Water and Sewage Department, Jefatura de Agua Potable y Alcantarillado, manages the treatment plants, pipe system, truck deliveries, and waste streams on the island.

Every month, the water quality of the municipal storage tanks and DWTP effluent is measured and sent to another department within the GADMSC, Dirección de Gestión Ambiental. This unit has direct communication with the Parque Nacional Galápagos, that cover water quality monitoring on all islands (Parque Nacional Galápagos, n.d.). The Parque Nacional assures that each island conforms to the CGREG regulations. To further ensure that the water quality meets national requirements, yearly analysis results as well as implemented water management systems are sent to the Agencia de Regulación y Control del Agua (ARCA). ARCA controls and monitors water quality and quantity at the sources and public services across the country (Gobierno Ecuador, 2025). In terms of monitoring and enforcement of drinking water regulations, responsibilities are clearly defined and managed on the island. This is supported by literature, where quality assessments mostly adhere to Ecuadorian and WHO standards. However, the efficacy varies by plant and across time, occasionally leading to effluent that is deemed contaminated under WHO standards (Grube et al., 2020).

3.1.2 Distribution System

The municipal pipeline system that provides drinking water to households, is connected to all established urban areas and the Cabecera Parroquial El Progreso. This constitutes 93.07% of households on the island. The island houses a large freshwater source in the El Junco crater, which is connected to multiple perennial streams that feed the intake of the municipal water system. Cerro Gato, a lagoon on the southern side of the island, provides the water for the town of Puerto Baquerizo Moreno and is connected to the DWTP in Las Palmeras. Another freshwater source on the southeast side of El Junco, Los Americanos, provides water for both the town and the Cabecera Parroquial El Progreso and is connected to the DWTP in El Progreso.

Water travels from these fresh-water sources through semi-buried pipes to the treatment plants: two in Las Palmeras, and one in El Progreso, each with a maximum capacity of 15 L/s and designed to operate continuously (24/7).

The DWTP in El Progreso has one municipal tank, supplying the Cabecera Parroquial and upper areas of Puerto Baquerizo Moreno. The remaining treated water is transported to one of four municipal tanks in Las Palmeras, each with a capacity of 300 m³ and connected to the DWTP in Las Palmeras.

The total 1500 m³ of water is thus distributed to the population pipes. The system is entirely gravity-fed, limiting water delivery to approximately three hours per day per neighbourhood to maintain sufficient pressure across all households. Water flow is regulated by multiple valves throughout the city, which workers open and close according to schedule. In the morning, water is directed to the lower points of the island, where it arrives with the highest water pressure. Downstream valves are then shut off, allowing pressure to build and supply upper neighbourhoods. After three hours, valves to higher areas are closed incrementally. During periods when inflow to the distribution tank increase, the water system operates also at night, but this rarely provides enough water to upper-elevation neighbourhoods, benefiting only a few households. The schematization for the entire system, including main valves, as well as intake points and treatment plants, is displayed in Figure 3.

Distribution Hours and Schematic Piping System

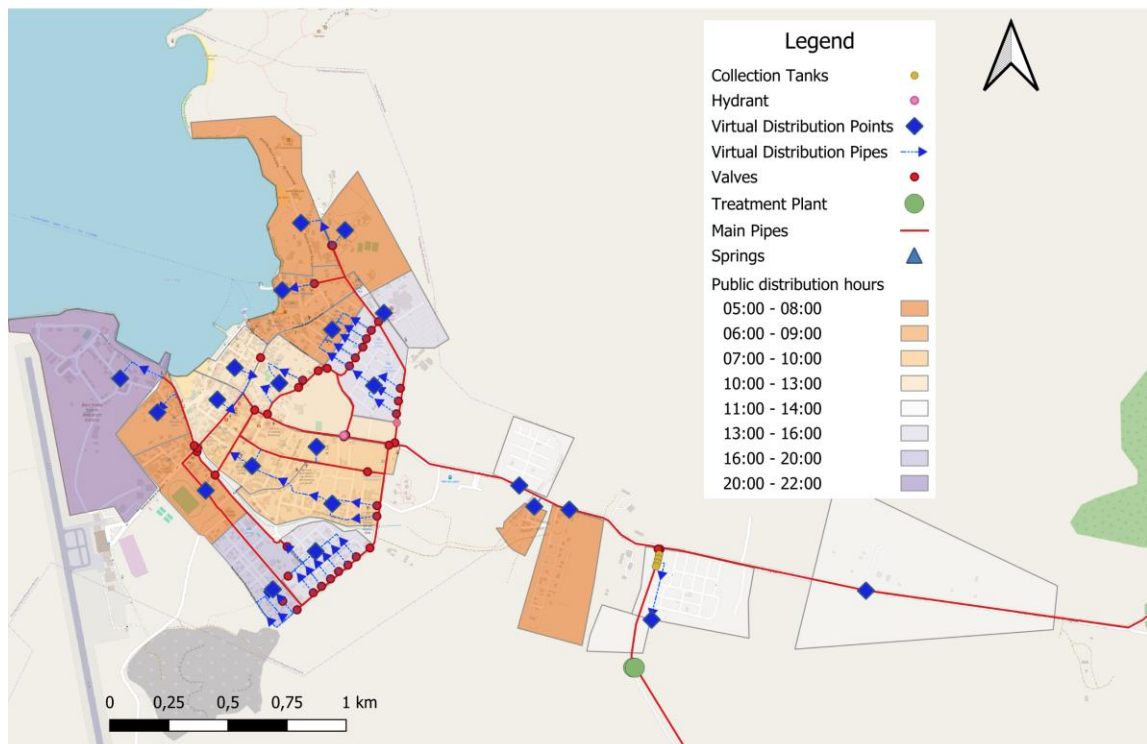


Figure 3: Simplified representation of public piping system, Puerto Baquerizo Moreno, San Cristóbal, Galapagos.

Distribution Hours and Schematic Piping System

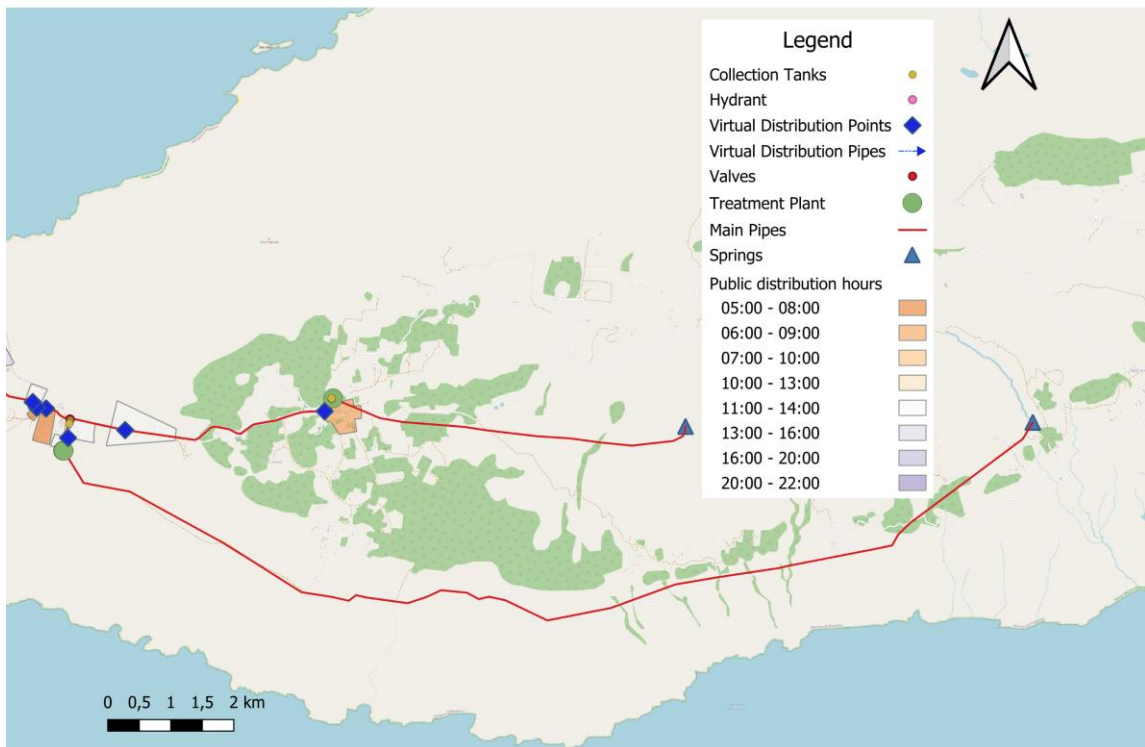


Figure 4: Simplified representation of public piping system, springs and rural areas (Cabecera Parroquial El Progreso, San Cristóbal Island, Galápagos).

Neighbourhoods that receive water either very early (orange) or late (purple) in the day have the highest pressure and subsequently experience less water shortages. The virtual pipelines and distribution points indicate the locations where the larger pipes (4 inches) branch into household connections (1/2 inch).

3.1.3 Contingency Supply

An estimated 38 households, or 2.12%, rely on tankers with treated water. This includes the newly constructed areas (parts of La Planada, Manzanillo), and some households in El Progreso. For houses that fall within the jurisdiction of GADMSC and have no piped connection (yet), or experience pressure issues, reliance on a delivery truck is free for 3 minutes of pressurized water connection, and costs \$90 per 600 gallons afterwards. For businesses this is \$120.

The municipal truck makes rounds every day and adheres to a schedule in which households receive priority based on a waiting list. Priority is given to institutions such as schools and hospitals, followed by households within the municipality's jurisdiction, particularly those affected by low pressure, accidents, or lack of connection to the network. In emergencies and when supply allows, residents outside the jurisdiction, mainly in the highlands, are also served. During short-term disruptions like pipe breaks, the municipality provides water free of charge for one to two days until service is restored. (*Técnica de Saneamiento Ambiental*, personal communication, September 2025).

The truck is filled at the hydrant, which is the only water distribution point where flow is 24/7. In case of breakage or maintenance on the municipal truck, the firefighters have a similar truck that can do the rounds and help support municipality. However, through the interview with them it was unveiled that some people will call the fire department in request of water to bypass the municipality. This

practice may be accredited either from the fact that the fire department does not charge for the service or from the perceived inefficiency of the municipal system. This in turn leads to pressure issues in the distribution system, because usage of the hydrant lowers the pressure in the main pipeline.

As noted above, the map (Figure 3, Figure 4) provides a schematic and simplified representation of the public water distribution system. It serves as a valuable tool for illustrating to the community the origin of their water supply and how it is distributed among neighbourhoods. Additionally, the map can help identify potential vulnerabilities within the network where a single malfunction could disrupt service to multiple areas. However, a more specific map would have to be constructed in order to transfer locations of all pipelines and valves.

3.1.4 Conclusion

The governance and management of water in San Cristóbal operate through a well-defined but highly centralized system. Responsibilities are distributed across several government bodies which collectively ensure water quality adheres to national standards. While institutional coordination appears robust, effectiveness varies between plants and overtime, occasionally leading to inconsistent service quality.

The distribution system demonstrates broad infrastructure coverage, reaching over 93% of households through a gravity-fed network supplied by multiple freshwater sources and treatment plants. However, this pressure-dependent design limits the daily water supply to a few hours per neighbourhood and leaves higher-elevation areas more vulnerable to shortages. Although tanker delivery provides a crucial contingency mechanism, its limited capacity and the informal use of fire department trucks highlight structural inefficiencies and inequities in access. The schematic mapping of this system therefore not only clarifies how water is allocated across neighbourhoods but also identifies critical vulnerabilities, such as dependence on key valves and pressure-sensitive segments, that need attention in future planning and infrastructure reinforcement efforts.

3.2 Self-Organized Water Governance Practices

In the absence of consistent municipal service, residents have developed self-organized systems to secure water for daily use. These strategies, ranging from private storage and cleaning routines to community coordination, demonstrate adaptive forms of governance that compensate for institutional gaps.

3.2.1 Spatial Variation in Water Storage Infrastructure: How Differences in Access and Condition Affect Household Resilience and Drinking Water Quality

Interview results indicate that all households rely on privately managed water sources, primarily due to the intermittent supply from the municipal pipeline. Two types of water storage infrastructure were identified: tanks and cisterns (Figure 6: Examples of a cistern (left) and a tank (right)). Field observations show that cisterns are typically covered or located underground, whereas tanks are placed outdoors and exposed to sunlight. This distinction affects water quality and resilience: studies indicate that plastic tanks are more susceptible to temperature fluctuations and microbial activity, whereas concrete systems such as cisterns are more durable and chemically stable (Nwoke H.U et al., 2019; Shalgar, 2024). In this context, the spatial distribution of tanks and cisterns across neighbourhoods provides insight into household adaptation and water security. Areas dominated by

cisterns, including, Frio, Playa Oro, Playa Mann and Fragata (Figure 5) may reflect greater long-term investment and protection of water quality, while neighbourhoods with mostly tanks or mixed systems, such as Divino Niño, Peñas Altas, Cabecera Parroquial El Progreso and the neighbourhoods in between the centre of Puerto Baquerizo Moreno and El Progreso (Figure 5), may indicate temporary or resource-constrained strategies and higher vulnerability to water quality degradation.

Water Storage Infrastructure by Neighbourhood (Groups)

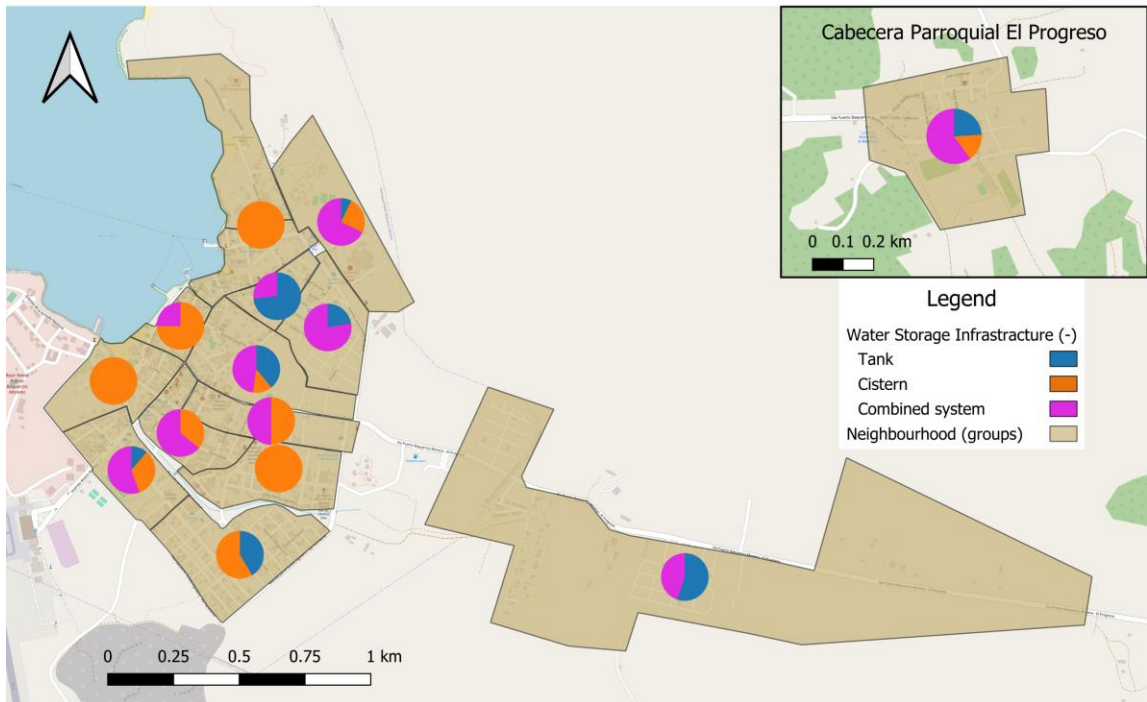


Figure 5: Map showing the spatial variability of household water storage infrastructure across neighbourhoods and neighbourhood groups in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal, Galápagos.



Figure 6: Examples of a cistern (left) and a tank (right)

3.2.2 Spatial Variation in Water Storage Cleaning Frequency: How Community Engagement, Infrastructure, and Hygiene Awareness Influence Maintenance Practices

Spatial variation in the frequency of water storage cleaning reflects differing levels of community engagement, infrastructure quality, and awareness of WASH (Water, Sanitation, and Hygiene) principles. WASH encompasses the provision of safe water for drinking and domestic use, the safe removal of waste, and the promotion of hygienic behaviours that protect health (World Health Organization, 2011). Despite municipally led initiatives to raise community awareness on sanitation, their campaigns fail to meet all WASH principles.

Interviews conducted in la Cabecera Parroquial El Progreso revealed that GAD-led initiatives distributed chlorine tablets and provided insights on water storage management biannually until late 2024. These efforts temporarily improved hygiene behaviours and maintenance regularity, consistent with findings by Mushota et al., who demonstrated that community and school-based WASH education programs significantly strengthen routine water safety practices (Mushota, O. et al., 2021). This is reflected in higher frequencies of cleaning in the area (80% of the people in our sample in the area clean their storage tank more than twice a year).

While the use of chlorine indicates some understanding of disinfection, it is insufficient for comprehensive maintenance. Chlorination alone cannot ensure microbiological safety without prior removal of sediments and biofilm, which reduce chlorine effectiveness and allow pathogens to persist (Artiola, Janick F et al., 2012). Therefore, the use of chlorine tablets cannot substitute the manual cleaning.

In our study, approximately 33.8% (25 out of 74) of surveyed households reported adding chlorine to their storage tanks while still full, without prior manual cleaning, as a cleaning method. Among these households, 20% reported relying solely on chlorination to clean their storage units. In contrast, 12.2% (9 out of 74) of households reported adding chlorine powder only after emptying and manually cleaning the tank to remove debris.

The map (Figure 7) therefore highlights neighbourhoods where proper maintenance of water storage units is less frequent (Albatross is a good example), identifying areas where renewed educational interventions and technical support could most effectively strengthen long-term water safety.

The comparison between water storage types and cleaning practices revealed a significant pattern. The Pearson correlation between tank ownership and monthly cleaning frequency was slightly above 0.3, indicating a moderate positive relationship, whereas that for cistern ownership was -0.24 , indicating a slight negative one. This difference likely reflects the greater accessibility and smaller size of tanks, which make cleaning easier, as well as a higher awareness of proper storage unit maintenance among tank owners.

Water Storage Cleaning Frequency by Neighborhood (groups)

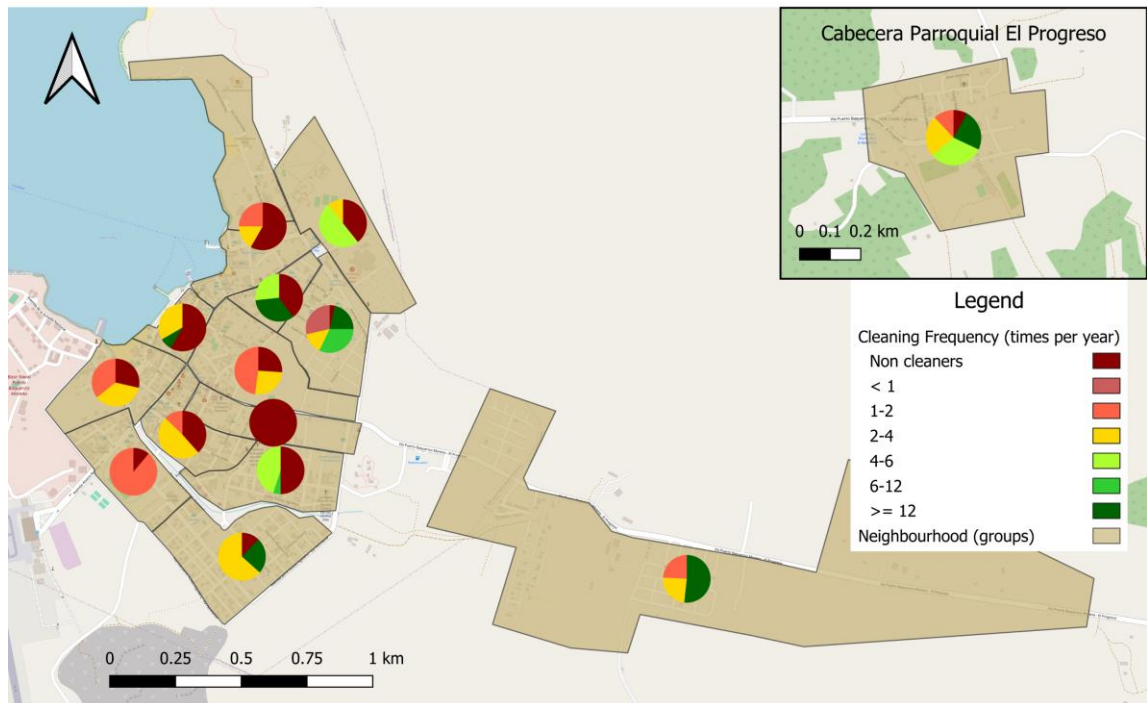


Figure 7: Map showing the spatial variation in cleaning frequency of the water storage unit across neighbourhoods and neighbourhood groups in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal, Galápagos.

3.2.3 Spatial Variation in Drinking Water Sources: How Access, Community Trust, and Safety Perceptions Shape Household Water Choices

Households reported several drinking water sources, including boiled water, filtered water, tap water (used by very few respondents; $n = 2$ in our sample), and bottled water. Water filters are scarce on the island and must be imported from the mainland, making them inaccessible to many households. As a result, many residents ($n = 51$, around 70%) depend on 20-liter bottled water containers sold by three private companies operating locally. In general, those who purchase bottled water expressed low levels of trust in the piped supply and refused to consume it, even after boiling. This is especially the case for neighbourhoods Playa Oro, Playa Mann, Peñas Bajas and San Francisco (Figure 8). Nonetheless, some concerns have been raised by residents regarding the quality and safety of the bottled water available on the island. Differences in drinking water sources across neighbourhoods reveal spatial patterns in access, affordability, and user trust, exposing potential inequalities.

Drinking Water Sources by Neighborhood (groups)

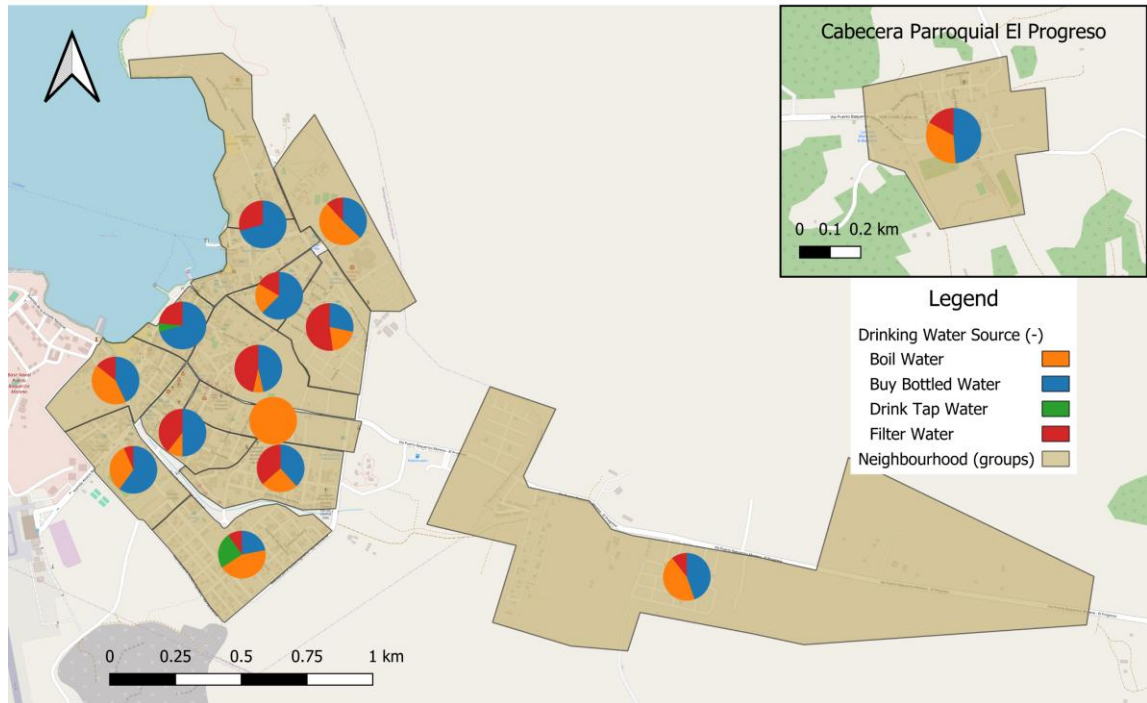


Figure 8: Map showing the spatial variation in the preferred drinking water source across neighbourhoods and neighbourhood groups in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal, Galápagos.

3.2.4 Household-Level Filtration Effectiveness: How Maintenance, Awareness, and Cartridge Availability Influence Water Quality

63.5% of households ($n = 47$) report using small drinking-water filters for daily consumption, with replacement frequency varying considerably across respondents. This variation likely reflects differences in maintenance habits, awareness, and access to replacement cartridges. According to manufacturer guidance and independent reviews, most household filters require replacement every three to six months depending on usage intensity and source water quality (Aquafilter, n.d.). Filters used for longer periods tend to lose adsorption capacity and can promote microbial growth within the filter medium, reducing water quality of the filtered water (Filpure, 2024). In the study sample, 4 households reported changing filters more than four times per year, 3 households between three and four times, intervals broadly consistent with recommended practice. In contrast, 4 households changed filters once or twice per year, 1 household less than once per year, and 35 households were unable to specify a replacement frequency. Low or unknown replacement rates indicate potential health risks due to filter saturation and microbial build up. These patterns likely reflect both limited awareness of maintenance requirements and financial or logistical constraints, as replacement cartridges must be imported from the mainland at high cost.

3.2.5 Water Management in Public Institutions: How Maintenance Practices, Municipal Support, and Parental Initiatives Shape Drinking and Sanitation Access

Relevant to community-scale management are the cases of public institutions such as schools and hospitals. An interview with a teacher from a public primary school revealed that maintenance of the school's storage tank is largely managed internally. Cleaning and minor repairs are performed by

school staff, while larger projects, such as major repairs or structural upgrades, are supported by the municipality, which provides both materials and labour.

At the school level, stored water is used exclusively for sanitation purposes. For drinking water, parents collectively organize by class to purchase bottled water for their children.

A second interview in a public nursery school highlighted the same kind of management inside the stable.

3.2.6 Household Responses to Water Scarcity: How Municipal Supply Failures and Infrastructure Gaps Drive Emergency Deliveries and Rainwater Harvesting

Water scarcity remains a persistent challenge on San Cristóbal Island. Interviews revealed that municipal water sometimes fails to reach households due to pipeline failures, problems at the source, low pressure, or, more rarely, drought. In such situations, residents typically request emergency water deliveries from the municipality via tanker trucks (see 3.1.3 Contingency Supply).

A few cases of rainwater harvesting were identified as a response to these shortages. This practice is largely uncommon in the lower part of Puerto Baquerizo Moreno, where no examples were found. In El Progreso, La Planada, and Manzanillo, a small number of households have implemented basic systems. In most cases, collected rainwater is used for cleaning or garden irrigation; however, in La Planada, one system was directly connected to household storage tanks, allowing residents to rely on rainwater when the municipal supply is interrupted.

The need for such systems in La Planada is heightened by the absence of a complete piped network (see 3.1.3 Contingency Supply), while in other neighbourhoods they become particularly relevant during water rationing periods.

3.2.7 Conclusion

Spatial variation in water management across Puerto Baquerizo Moreno reveals strong inequalities in infrastructure, maintenance, and access. While all households depend on privately managed sources, areas dominated by cisterns, such as Frío and Playa Mann, show greater resilience and investment, whereas neighbourhoods with tanks or irregular cleaning, including Albatross and Cabecera Parroquial El Progreso, remain more vulnerable to contamination. Differences in cleaning frequency and reliance on chlorination alone highlight gaps in WASH awareness, calling for renewed education and technical support. Patterns of bottled water use and filter maintenance further expose disparities in affordability, trust, and maintenance capacity. Institutional cases demonstrate partial municipal support complemented by community initiatives, while rainwater harvesting emerges as a limited but adaptive response to supply failures.

It should be noted that observed relationships between storage type and vulnerability to water quality degradation suggest associations rather than direct causes, as residents were not directly asked how these factors influence their water security.

Additionally, because cleaning frequency are reported without assessing effectiveness and only the percentage of filter owners are reported rather than filter types, the precision of spatial comparisons is limited.

Overall, the maps complement municipal data by identifying where targeted interventions, education, infrastructure improvements, and community engagement are most needed to strengthen water security and resilience, while acknowledging the limitations inherent to our approach.

3.3 Usage Patterns and Reliance on Bottled Water

As mentioned in the ‘Self-Organized Water Governance Practices’ chapter 70% of the interviewees show a lack of trust in the quality of their tap water, relying on the purchase of bottled water (3.2.3 Spatial Variation in Drinking Water Sources: How Access, Community Trust, and Safety Perceptions Shape Household Water Choices). This water is sold by 3 private companies which use the same water of the public distribution system after adding further treatment. These companies are located in El Progreso, Las Palmeras and Peñas Altas.

3.3.1 Per Capita Public Water Consumption Stands Out from the Restrained Patterns of Residential and Rural Areas

The relative consumption differs a lot between neighbourhoods. The high value for Las Palmeras and Peñas Altas can be attributed to the water bottle company that fills their water from the public water source. Playa Mann, Playa de Oro and Central have high relative values because of the high presence of hotels and Airbnb’s. Also for Playa Mann, the presence of the university and a school can explain the high consumption in relation to how many people live in the neighbourhood. Although the values are rough and qualitative this first layer can show a predominance of water consumption in the touristic part of the town, while more rural areas tend to “save” more water. Furthermore, the neighbourhoods that lie lower obtain water early in the morning and with a higher pressure, which leads to higher consumption values. The visualization is given on the map by a colour gradient with increasing shades of blues (Figure 9).

Public Water Distribution and Private Bottle Water Consumption Usage Patterns

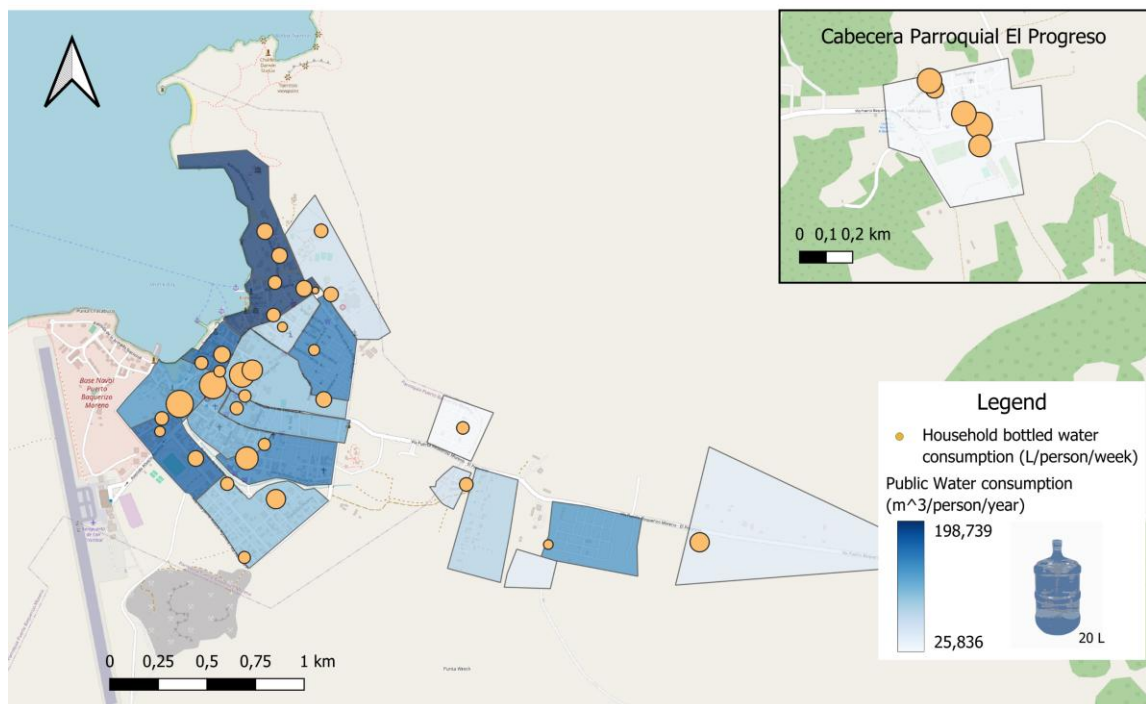


Figure 9: Map showing the usage patterns for relative water consumption across neighbourhoods in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal, Galápagos.

3.3.2 Overreliance on Bottled Water: Average Person Buys More Than 13 L of Processed Water per Week

The map illustrates per capita weekly consumption of bottled water, indicated by the size of yellow dots. Statistical analysis shows that bottled water consumption follows a log-normal distribution (Hynds et al., 2012), as confirmed by the Kolmogorov-Smirnov (KS = 0.146, $p = 0.326$) and Anderson-Darling (AD = 0.451) tests. Since the KS p -value exceeds 0.05, there is no evidence to reject the log-normality assumption (Figure 10).

Consumption of 20-liter bottles ranges from 0.125 to 2 bottles per person per week. Among 72 respondents, 52 (70%) reported purchasing bottled water, and 37 (50%) provided precise consumption data. The mean consumption was 0.68 bottles per person per week (13.6 L), with a median of 0.5 bottles per person per week (10 L).

Both the mean and median consumption suggest a significant reliance on bottled water, as these values approximate the daily individual drinking needs (1.94 L/day and 1.43 L/day respectively). This indicates that, among those who use bottled water, it constitutes a major component of their daily hydration, even though people may spend part of the day outside the home and rely on alternative water sources.

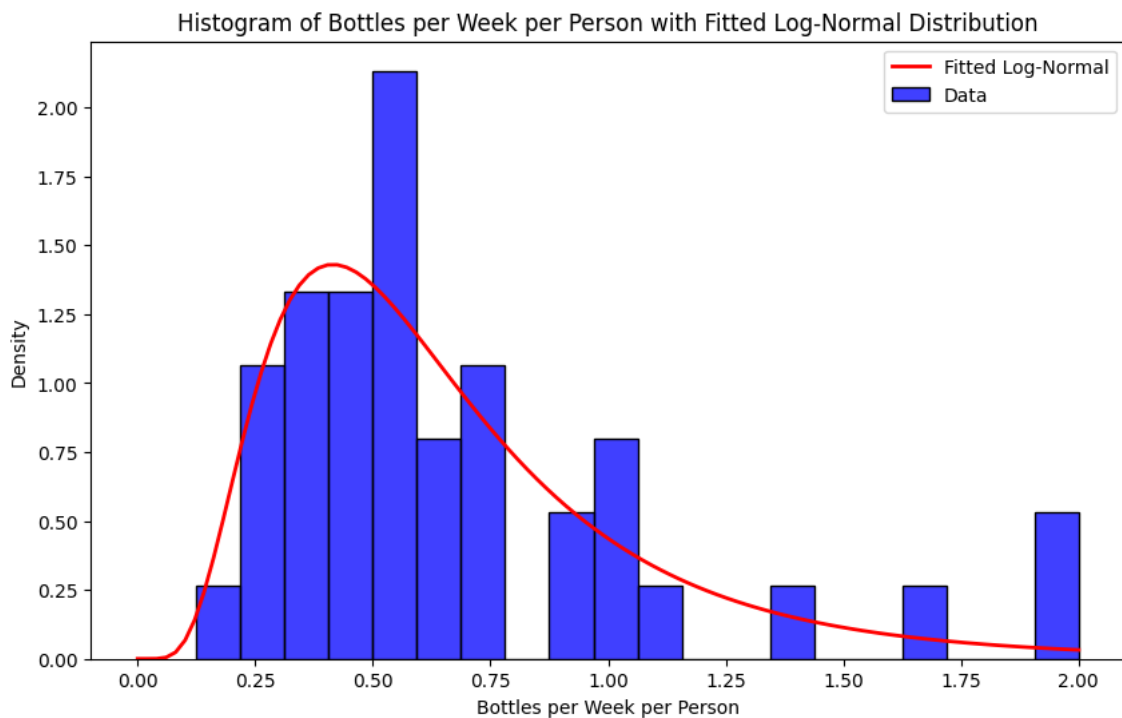


Figure 10: Fitted Log-Normal distribution for bottled water consumption (Bottles per Week per Person)

3.3.3 Conclusion

Spatial analysis of public water consumption reveals pronounced variability among neighbourhoods, with higher relative consumption concentrated in touristic and institutional zones such as Playa Mann, Playa de Oro, and Central, which also fall under the neighbourhoods where the pressure of water is

highest. Peripheral and more rural areas display more conservative usage patterns, also due to the weak water pressure.

The analysis highlights a significant dependence on bottled water across the study area, driven primarily by a lack of trust in the quality of tap water. Although the three private bottling companies rely on the same public water source, their additional treatment processes appear to provide users with a perceived sense of safety.

The distribution of bottled water consumption follows a log-normal trend, indicating a strong skew toward lower per capita usage, with a minority of households purchasing larger quantities. This variability reflects differences in access to alternative water sources, income levels, and trust in local water governance. Together, these findings point to an overreliance on consumption of treated bottled water, particularly in well-serviced yet low-trust areas, emphasizing the need for improved transparency and communication regarding water quality standards within the public supply system. Strengthening public confidence in tap water could significantly reduce dependency on bottled water and promote more equitable and sustainable water consumption practices across neighbourhoods.

3.4 Experienced Failures and Responses

The failures regarding the water distribution, indicated by residents, are mapped in Figure 11. Among the 74 households surveyed, 89% mentioned problems related to the water system, with 65% mentioning more than one problem.

Experienced Water Security Issues

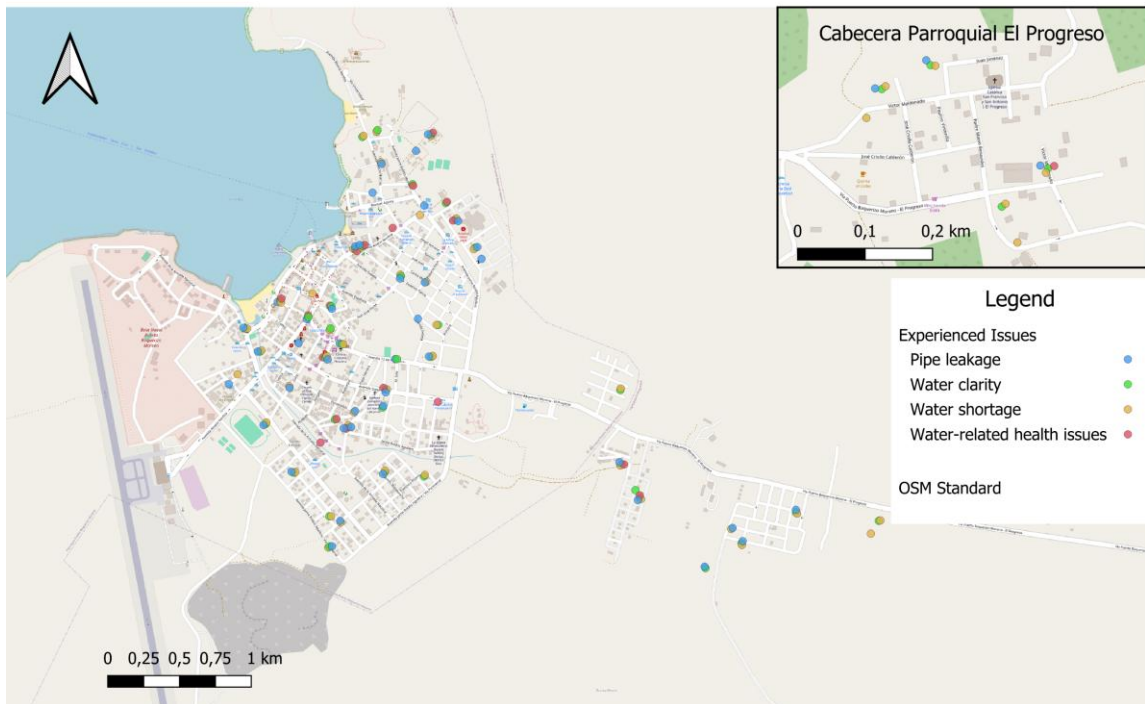


Figure 11: Spatial Distribution of Experienced Water-Related Issues (n=74), San Cristóbal, Galápagos.

3.4.1 Hindrance by Water Shortages Varies Between Household Storage and Barrio

The most occurring problem mentioned by interviewees (62%) is water shortages, with a median time to resolution of 7 days where stated. In the case of rations, these problems relate to periods of drought. But shortages also occur due to construction cut-offs, or breakages in the system. When these are not resolved in a timely manner, residents are forced to rely on water tankers. For about half of interviewed households (52%), occurrences of multi-day shortages don't happen more than once a year. In general, problems are resolved within a week or less, with 37% of gauged shortages within 3 days. Due to the nature of the gravity-led distribution system, relatively small damages can lead to loss of pressure, and thus, absence of water, which means that the municipality has to act quickly when there is an issue in the pipeline.

Households located farther from the centre of Puerto Baquerizo Moreno tend to experience greater difficulties with water shortages. This may be due to lower water pressure, resulting in little to no water during their allotted three-hour supply window, or to challenges in communication with municipal authorities.

"{When are problems with the pipeline} There are days when there is no water, several times, people didn't get notified... this year it's happened about three times ... they cut off the water, but they didn't notify us"

Resident San Cristóbal, Gran Maestro

Furthermore, time of resolution has a positive correlation with distance to the municipality, due to quicker response times within the city of Puerto Baquerizo Moreno and perceived urgency of the problem (higher density of people). Communication regarding cut-offs due to construction or rations are also better organised.

"We adapt by making sure we have a full cistern. We're always warned in advance, a notice is sent, so we already know and we make reserves."

Resident San Cristóbal, Playa Mann

Naturally, residents that mention receiving notices are less hindered by system cut-offs, with the exception of very prolonged lack of water. Unannounced short-term water shortages (<1 days) coincide most with the neighbourhoods at median-altitude that receive water between 10:00-16:00. As mentioned in 3.1.2 Distribution System, these areas receive water at the lowest pressure, which can be the cause for their tank or cistern not filling up properly within the 3 hours.

Outliers to the short-term water shortages are households that use a cistern. Pearson correlation between cistern type storage and water shortage is -0.13, indicating that they are less prone to experiencing water shortages, whereas for tanks this correlation is 0.17. This ties into the volume of their reserves, as cisterns are generally larger (3-4 m³) than tanks (1.5-2.5 m³).

3.4.2 Trust in Water Treatment Efficacy Low, Residents Perceive Lack of Infrastructure

As shown by drinking preference, little residents trust the potability of their tap water, with almost none drinking straight from their system. In line with this, many interviewees (58%) told of high turbidity or discoloration in their water. For some, this is accredited to an overuse of chlorine tablets, while others believe it to be caused by improper water treatment.

"One day the water came out like milk ... I think it must be because of the chlorine they put in it, right? Too much chlorine."

Resident San Cristóbal, Cactus

"The quality is not good. Not even the water that comes from the treatment plant. I don't think they give it the proper treatment."

Resident San Cristóbal, Playa de Oro

A reoccurring issue surrounding turbidity is cloudy water during heavy rains. Although this is mostly temporary, and residents note that after letting their taps run for a few minutes the water clears up, it negatively impacts trust in water security.

Some interviewees also mentioned leaving the tap water in a glass or container, and seeing it turn green and flocculate within a few days. These experiences either indicate improper treatment or (re-)contamination during the distribution or household storage.

Household treatment requires consistent adoption and individual responsibility, which is variable on San Cristóbal. Interestingly, no clear correlation was found between the frequency of cleaning and the

occurrence of reported water quality problems. Some residents reported cleaning their tanks more frequently precisely because of recurring turbidity, whereas others cleaned less often because they rarely encountered unclear water. Consequently, increased cleaning frequency does not necessarily translate into better mentioned water quality. More likely is a link between the secureness of the water storage and recontamination due to particles coming from outside. In line with this, households with cisterns reported less water clarity problems, as these are often below ground and properly sealed.

Recontamination during the distribution is closely related to pipe leakages and breakages, which are analysed in System Capacity Fails to Meet Drinking Water and Sanitation Needs: Concerns over Population Growth. It is also known that gravity-fed systems can suffer from negative hydraulic pressure, especially for higher areas, which can draw contaminated (ground)water into the pipes (Gerhard et al., 2017). Any tears or small holes can furthermore impact biofilm growth, which is hazardous in systems with intermittent water supply because of potential for pathogens (Calero Preciado et al., 2021). Interview answers indicate that such leakages or seepages do occur within the distribution system.

“When it rains, the sewers overflow and contaminate the {tap} water.”

Resident San Cristóbal, Albatros

“The pipe gets clogged with mud ... I have water, but it's full of mud from the rain.”

Resident San Cristóbal, Frio

During the interviews, some residents highlighted an ongoing dispute within the municipal council regarding the water treatment plants in Las Palmeras. On the 25th of August and 17th of September 2025, inspections were conducted at the plants which showed considerable deteriorations (*Concejal Colegiado Municipal*, personal communication, October 2025). According to the councillor that raised the dispute, chlorination and agitation pumps were out of service; valves were heavily oxidized, some inoperable; the reservoir had deteriorated roofing; pH doser was inoperative and there was an overall lack of maintenance on the building.

The research team was later invited to visit the drinking water treatment plant in El Progreso, where it was observed that the chlorination tank was also out of operation. Workers, however, managed to compensate by manually adding chlorine tablets, and all treatment steps were otherwise in order. This situation highlights broader concerns about facility maintenance and has understandably heightened anxiety among the island's residents.

3.4.3 Residents Attribute Health-Related Issues to Tap Water

In line with the lack of trust in water treatment, 19 interviewees mention having experienced health issues due to water. Naturally, it is difficult to pinpoint the exact cause of illnesses, and attribution to water is subject to perception. As one resident rightly pointed out, it could just as easily be attributed to other causes.

“Inflammation, infections ... but sometimes it's also the food, depending on what's served ... I can't say for sure that it's just the water.”

Resident San Cristóbal, Algarrobos

Interviews revealed fears of chlorination by-products and heavy metals in the water having carcinogenic effects on the human body. Some residents mention that the heightened cases of cancer on the island are caused by contaminated tap water. Though this cannot be verified, it signifies why so many households feel necessitated to rely on bottled water or boiling.

Unsurprisingly, turbidity has a positive correlation with attributed health problems, with 16 out of the 19 households also mentioning having bad water clarity as indicator of improper water quality. Other perceived causes are sewage spills and floods.

3.4.4 System Capacity Fails to Meet Drinking Water and Sanitation Needs: Concerns over Population Growth

A major concern among residents is that the existing water and sanitation systems are insufficient to support further population growth. This issue extends beyond water distribution to the combined sewage system as well. Among the 74 households interviewed, 44 (59%) reported pipe breakages related to either drinking or wastewater, with 28 specifically citing wastewater problems. Most of these failures were attributed to undersized pipes and a lacking system unable to handle the required water volume—a problem reflected in residents' responses.

"{The water supply} right now, it's from 6 am to 9 am, more or less 3 hours a day... when it runs out, I get worried because I don't have water... the population has increased... we're now at a point where it seems like we're collapsing due to the population growth"

Resident San Cristóbal, Albatros

"I would like the filters and systems at the plant to be updated, because they are not designed to supply the population we have now... In the future, the water we have today will be of even lower quality."

Resident San Cristóbal, Divino Niño

Expanding the capacity of the drinking water treatment plants is, unfortunately, not a straightforward task. Overexploitation of the freshwater source is limited, as it depends entirely on rainfall and is therefore highly seasonal. However, water losses resulting from pipe breakages are preventable and could be significantly reduced through infrastructural upgrades. Most interviewees noted that such issues are usually resolved "quickly," with a median repair time of 3.5 days. Still, water spills are strongly disapproved of on the island, reflecting the value associated with freshwater.

As for the wastewater issues, most occur during heavy rains, when stormwater floods the system, causing pipes to burst or spill out. This is associated with bad smell on the streets, wastewater pollution to the sea, and sickness by exposure to bacteria. Instances like these signify the need for better flood-risk management and water infrastructure control.

3.4.5 Conclusion

A vast majority of interviewed households reported experiencing one or more water-related problems, the most common being water shortages. Although shortages rarely last more than 2 weeks, households with limited storage capacity are deeply affected by these instances, especially when cut-offs occurred without notice.

Perceived water quality was linked to residents' health concerns and general trust in the system. Many residents mentioned low confidence in the quality of tap water, with some even associating it

with inflammations or stomach infections. This distrust is reinforced by visible contamination (e.g. cloudy water, particles) and raises questions about the general efficiency of the drinking water treatment plants.

Pipe leakages and breakages occur frequently, leading to sewage spills in the city and seepage of contaminated water into the distribution system as mentioned by interviewees. Residents are afraid that the system capacity will be exceeded with further population growth.

All of these experiences highlight the community's challenges, where despite technically receiving water, uncertainty in availability, quality, and reliability remains.

3.5 Flood Risk

This section presents the research conducted regarding perceived, experienced, and institutionally determined flood risk on San Cristóbal Island.

3.5.1 Flood Risk Context: Environmental Factors and Flood Management Approach on San Cristóbal

Precipitation on San Cristóbal is strongly seasonal, with most rainfall occurring during the wet season from December to May. Mean annual precipitation during 1981-2017 ranged from approximately 500 mm in the lower coastal areas to around 1,670 mm in the highlands. Interannual variability is strongly influenced by El Niño –Southern Oscillation (ENSO) dynamics, with El Niño years receiving up to three times more rainfall than non-El Niño years (Paltán et al., 2021). According to Paltán et al. (2021), precipitation is predominantly delivered through short, intense convective events during the wet season, while the dry season is characterized by light mist or “*garúa*.”

The high-intensity rainfall events, combined with the island’s steep topography, impermeable volcanic soils and limited stormwater drainage infrastructure generate rapid surface runoff and flood potential. To protect urban areas, runoff is concentrated in *encañadas*, ravines formed by a combination of natural flow paths and man-made channels designed to convey water safe and quick to the sea. Within the city of Puerto Baquerizo Moreno, these ravines have a well-defined, fixed course and become active each year during the wet months. In contrast, the upper parts of the catchments also contain less clearly defined or well dug out ravines, where the natural drainage pathways are more diffuse. Some of these only become active during particularly intense rainfall events, making discharge behaviour highly irregular and difficult to predict, especially given interannual variability (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025).

According to Articles 389 and 390 of the *Constitución de la República del Ecuador* (the Ecuadorian Constitution), the State is mandated to protect individuals, communities and nature from the negative effects of disasters of natural or anthropogenic origin through risk prevention, disaster mitigation, recovery and the improvement of social, economic and environmental conditions (Ministerio de Defensa Nacional, Ecuador, 2021). Risk management is conducted under the principle of subsidiarity and decentralisation, which assigns direct responsibility to institutions within their territorial jurisdictions, thereby making the Municipal Decentralised Autonomous Government (GAD) of San Cristóbal responsible for protecting Puerto Baquerizo Moreno from flood hazards (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025).

The municipality undertakes this responsibility by: (i) identifying areas of risk; (ii) regulating building permits in flood-prone zones; (iii) channelling and maintaining pathways for runoff in ravines (*encañadas*); (iv) coordinating emergency response; and (v) supporting post-flood repairs and recovery (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025). Flood risk identification is primarily based on observations of past experiences and precipitation data, supported by a qualitative risk classification model JICA (Japan International Cooperation Agency, see section 2.4.3 Flood Risk Mapping).

At present, municipal flood management follows a predominantly reactive approach, intervening based on occurred past events in contrast with a proactive predicting approach. This stems largely from limited available data, mainly a lack of topography data, needed to produce hydraulic and runoff

simulation to be able to predict floodings. Now, the proactive measures taken such as digging out new parts of ravines, are derived from a response to previous events rather than predictive modelling.

3.5.2 Predetermined Flood Risk Layer: High Risk Concentrated in Flatter Coastal and Uphill Areas

The predetermined flood-risk classification, based on a three-tier system and applied at neighbourhood scale, shows that the lower coastal parts of the city and the higher areas above the city are most prone to flooding (Figure 12). Main reason for this is the topography; runoff converges and becomes stagnant in lower and flatter zones. The urban areas situated uphill of the city are relatively flat terraces compared to their surrounding slopes, making them more suitable for settlement but also more susceptible to water accumulation. In addition, part of the ravine systems in these upper zones are less clearly defined and maintained than the channels within the city, reducing their capacity to convey runoff.

Since Cabecera Parroquial El Progreso is official outside the responsibility of the GAD, it is not included in the flood-risk classification published by the municipality (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025).

Predetermined Flood Risk Layer

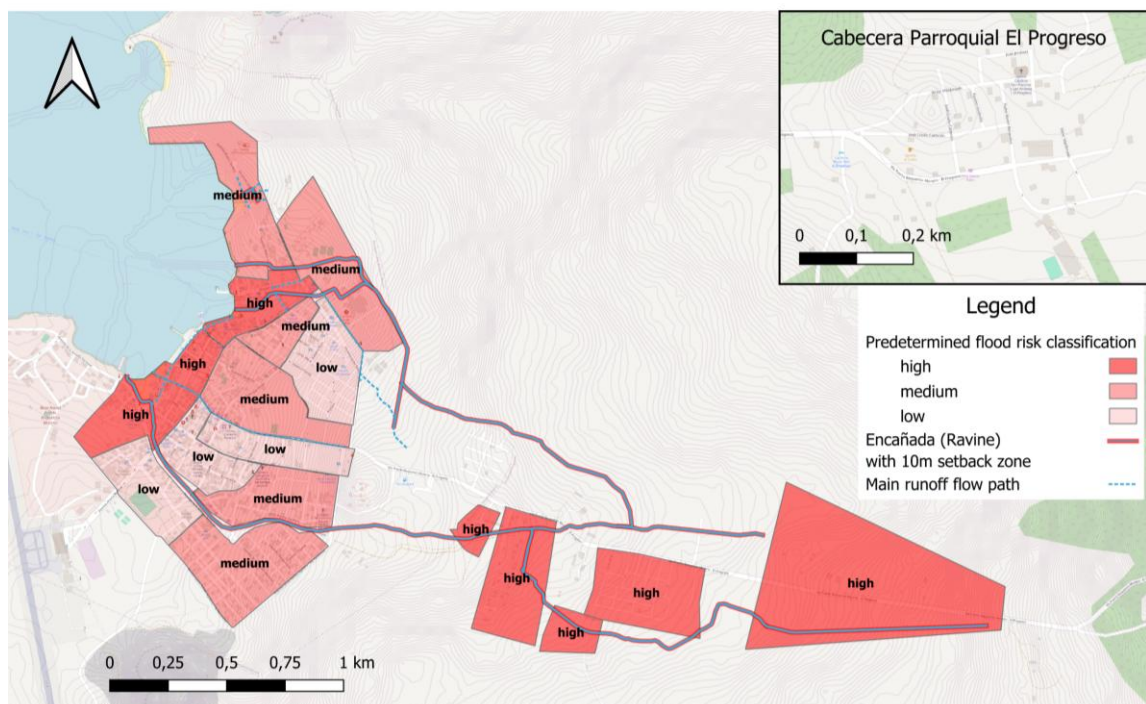


Figure 12: Predetermined flood-risk layer derived from the municipal classification conducted with technical support from JICA (2021), San Cristóbal, Galápagos. (The classification should be interpreted as indicative and comparative, suitable for public awareness and preliminary spatial planning rather than detailed hydrological forecasting).

3.5.3 Perceived Flood Risk Layer: Generally Moderate Concern at Neighbourhood Scale with Strong Within-Neighbourhood Variability

The mean scores of the neighbourhoods shown in Figure 13 that represent concern for flooding range from 2.94 and 4.08 on a five-point Likert scale, indicating a generally moderate level of flooding

concern with limited spatial variation. On average, responses range from “neutral” to “agree” when residents were asked whether they were concerned about flooding in their neighbourhood.

When compared with the predetermined municipal flood-risk classification, the spatial distribution of the concern scores shows both correspondence and divergence. Darker shading, indicating higher concern, aligns with officially identified high-risk zones along the lower coastal and upper-elevation neighbourhoods, suggesting that residents’ perceptions broadly reflect areas of known exposure. However, some discrepancies are emerging. Notably, San Francisco and Algarrobos record the highest mean concern scores, despite being classified as low flood-risk zones. A similar pattern is observed in Peñas Altas, where concern levels are elevated relative to its mapped risk classification. These anomalies may reflect localised experiences of surface runoff, recent flood incidents, or heightened awareness due to nearby events rather than the generalised municipal classification.

At the same time, the perceived flood concern layer is subject to several limitations that constrain its accuracy and representativeness. First, the small sample size increases the influence of outliers: (individual experiences) that are not representative of broader neighbourhood conditions. In addition, the uneven spatial distribution of respondents within neighbourhoods, combined with the use of neighbourhood-averaged scores, may fail to capture local variability and smooth out contrasts, making it difficult to map areas sensitive areas. This can be seen back in the fitted distributions of responses per neighbourhood shown in Appendix F-3: Perceived Flood Risk Distribution. Nine out of twelve neighbourhoods have a standard deviation greater than 1.0, reaching up to 1.52 in the merged neighbourhoods above the city. In Central, for example, a single “1: strongly disagree” response among an otherwise consistently concerned set disproportionately affects the neighbourhood-level average, highlighting how individual responses can influence summary statistics in small samples. These pronounced variations indicate that flood perceptions differ considerably even among nearby households. This can come from localised experiences, suggesting the need to assess flood vulnerability at a finer spatial resolution, or the variability show cases that flood perception is not only shaped by objective exposure but also by individual awareness and sensitivity to risk.

Perceived Flood Risk Layer

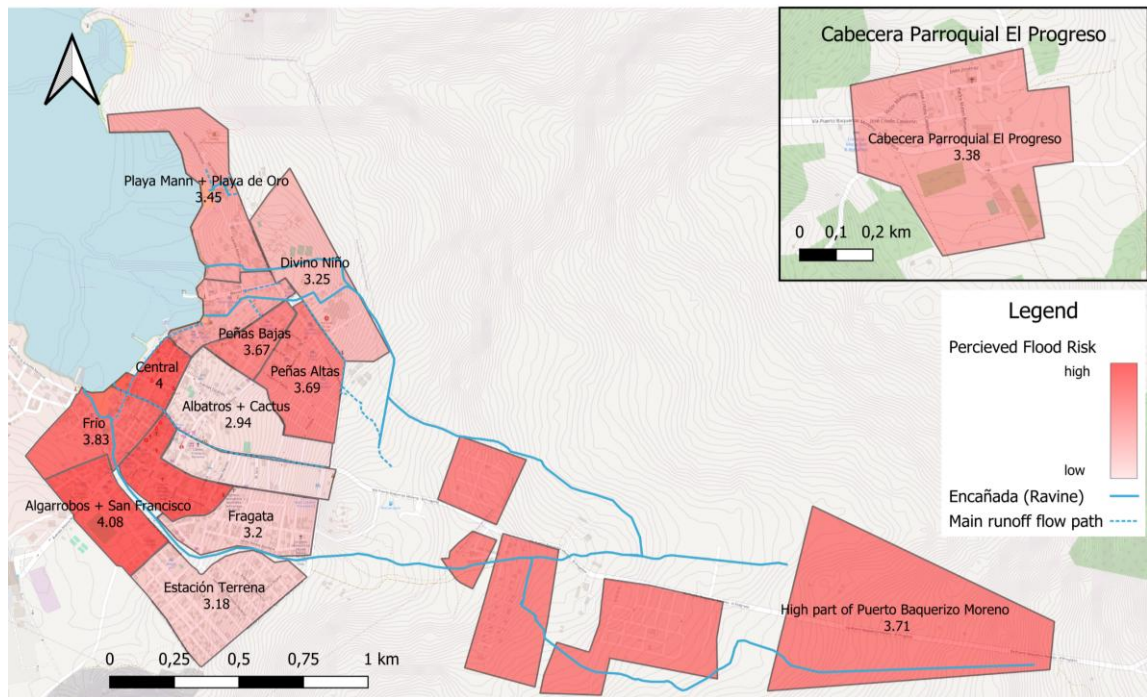


Figure 13: Perceived flood-risk layer derived from questionnaire responses, San Cristóbal, Galápagos (mean flood-risk concern per neighbourhood on a 1-5 Likert scale).

3.5.4 Experienced Flood Risk Layer: Pronounced Spatial Variability in Damage with High Incidence in Peripheral Neighbourhoods

The proportion of surveyed residents reporting damage to their homes due to flooding per neighbourhood ranges from 0% to 49%, indicating pronounced spatial variability shown in Figure 14. The highest reported incidences occur mainly in neighbourhoods located outside the central urban area, reflecting greater exposure to unchanneled runoff and limited protective infrastructure.

When compared with the predetermined municipal flood-risk classification, both similarities and differences emerge. Neighbourhoods uphill of the city classified as high-risk zones, consistently report the highest damage incidence, while some low-risk areas like Algarrobos, San Francisco and Albatros, show damage percentages comparable to high-risk zones such as Frio. Conversely, Playa de Oro, despite its high-risk classification and low laying location around a main ravine, shows relatively few reported cases. These inconsistencies may reflect the limitations of the experienced flood-risk layer.

The proxy limits to capture the physical impact of floodings due to several factors: (i) sampling constrains in both size and spatial distribution, (ii) absence of a temporal dimension, as the data does not account for how long respondents have lived in the area or when the damage occurred, (iii) socioeconomic conditions that affect the capacity of households to invest in resilient construction or drainage measures, (iv) variation in damages magnitude, and (v) small-scale variations in topography affecting local runoff and exposure. These limitations restrict the layer's ability to represent actual flood risk exposure and explain some inconsistencies observed when comparing it with the predetermined municipal classification. For instance, the relatively low damage report of Playa de Oro

may reflect effective mitigation measures, as this is a wealthy neighbourhood, and the combination of the constraints of the sample size and small-scale topography variations within the neighbourhood can miss the flood prone buildings that experienced damages.

When compared with perceived flood concern, further contrasts appear. In Peñas Altas, respondents expressed concern about flooding yet reported no direct household damage. Conversely, in the uphill neighbourhoods and in Cabecera Parroquial El Progreso, concern levels are relatively low despite a notable proportion of households having experienced flood-related damage. Indicating that in these high-risk classified areas the moderate level of concern might not come from a lack of awareness, but from a place of acceptance and resilience towards flooding. Indicating that in these high-risk classified areas the moderate level of concern might not come from a lack of awareness, but from a place of acceptance and resilience towards flooding.

Experienced Flood Risk Layer

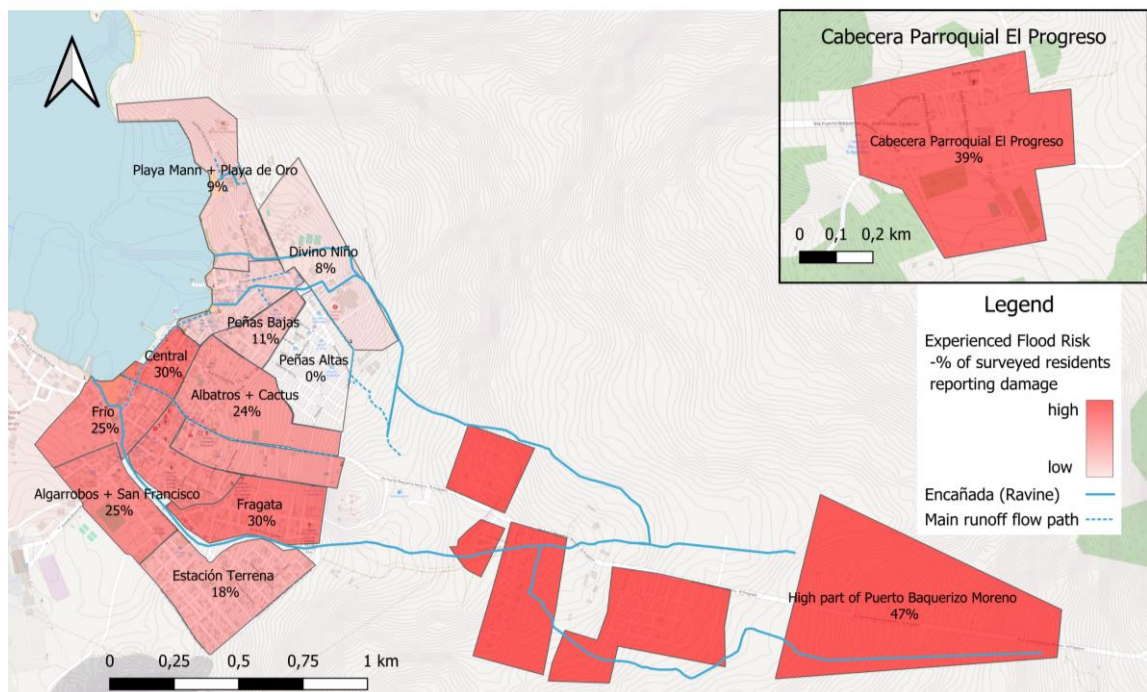


Figure 14: Experienced flood-risk layer showing the proportion of households reporting flood-related damage based on questionnaire responses, San Cristóbal, Galápagos.

3.5.5 Critical Locations Layer: Key Sites and Resident Narratives Highlighting Flood Risk

A total 19 critical points and stories regarding flood risk were identified across Puerto Baquerizo Moreno (see Figure 15), comprising 7 locations of prolonged street flooding, 7 points of reported private property damage, 3 ravine-related problem sites, and 2 repeatedly flooded beach areas. These points are qualitative in nature and should not be interpreted quantitatively. They are derived solely from the 74 semi-structured interviews and include only events with a coherent narrative, sufficient detail, the year of occurrence, and the reported severity of the flooding. Rather than providing an exhaustive inventory, the layer illustrates the types of flood-related challenges residents experience and adds the human narratives behind the mapped flood patterns.

Critical Observation Points Regarding Flood Risk

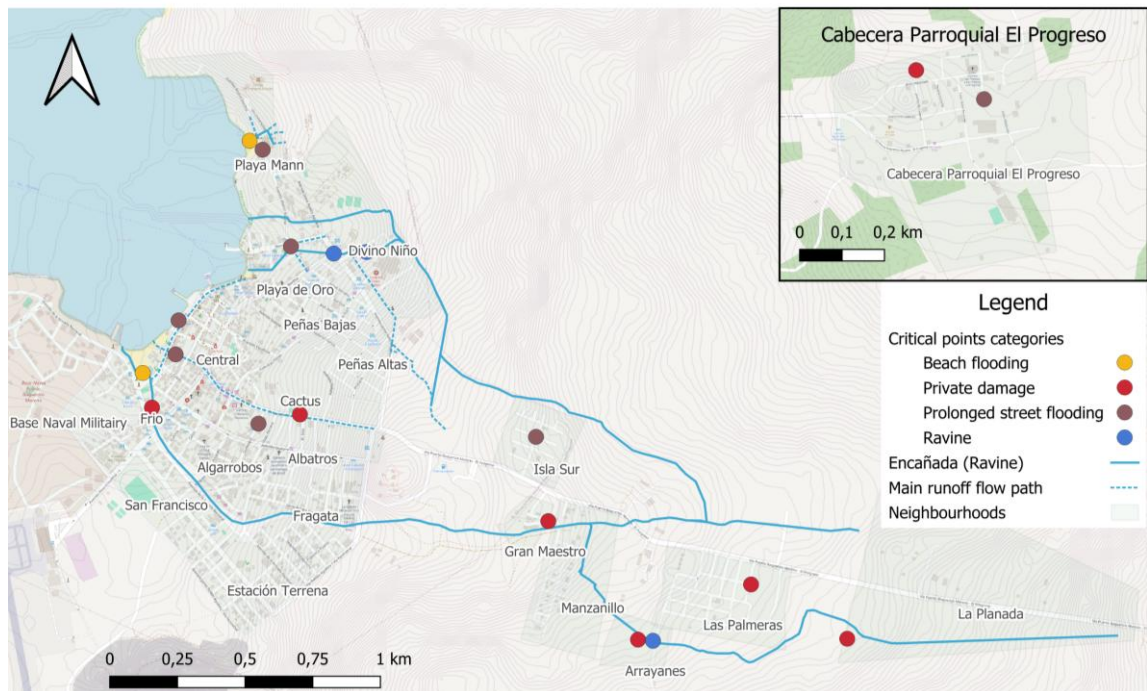


Figure 15: Critical flood points and narratives derived from semi-structured interviews with residents and municipal staff, San Cristóbal, Galápagos.

A reoccurring theme found is local topography causing runoff converging in flatter areas. Residents show local resilience by building walls or barriers to redirect runoff to protect their homes. In the city, many residents report blackwater mixing with runoff from malfunction drainage infrastructure, which increases the disturbance of prolonged street flooding. The ravines inside the city are maintained regularly, and aside from a now known bottleneck, overflow is limited. In uphill areas, anecdotes from La Planada and Arrayanes point to insufficient local conveyance capacity, causing overflow directed to urban areas. These anecdotes describe serious flood events requiring emergency response in La Planada and street depths up to 70 cm in Arrayanes with children “snorkelling through the streets”.

In La Planada a recently built box culvert failed to prevent the inundation, likely due to design limits or atypical rainfall linked to interannual variability. The municipality now plans a second culvert parallel to the slope to intercept runoff before it reaches the urban area.

3.5.6 Island-Wide Flood Perception: Insights from all Questionnaire Responses

When looking at total questionnaire data (Appendix E: Questionnaire Analysis), Q12 shows lack of confidence in the effectiveness of the existing infrastructure regarding flood protection, but the mean score between ‘disagree’ and ‘neutral’ indicate moderate dissatisfaction. According to Q11 responses, 23% of all respondents agreed with the statement that their house suffers damage from flooding.

Regarding perceptions of flooding as a normal aspect of life on San Cristóbal (Q9), the distribution suggests partial acceptance but mixed attitudes overall, with few holding strong views either way. This reflects a community that recognises flooding as an issue but remains ambivalent about its inevitability and the extent of required municipal intervention. Q10 reveals strong stated willingness

among residents to participate in or invest in flood mitigation efforts, although such attitudinal measures are often influenced by social desirability bias.

A comparison of Q7 and Q8, examining concerns about flooding and associated debris, shows very similar response distributions, indicating that debris is perceived as an inherent component of flood events. Debris is not explored in depth in this study, as it was not cited as a direct cause of damage in any of the semi-structured interviews with residents. Nonetheless, anecdotes included debris-related disturbances, such as chickens carried by runoff and accumulating in stagnant water downstream, increasing the risk of prolonged street flooding.

3.5.7 Conclusion

Overall, flooding on San Cristóbal constitutes a serious and spatially variable hazard, with approximately 23% of respondents agreeing that their household has experienced flood-related damage. The combination of steep topography, impermeable volcanic soils, and limited stormwater infrastructure amplifies runoff generation and the potential for localised inundation in lower and flatter zones. Flood risk is concentrated in low-lying coastal and uphill neighbourhoods. Local topography and site-specific drainage design frequently determine whether individual properties are affected, resulting in contrasting impacts among adjacent buildings. These small-scale variations in elevation and drainage capacity emerge as a recurring underlying cause across the island.

Current municipal flood protection management remains largely reactive, with interventions guided by past events rather than predictive modelling. This approach reflects limited available data to be able to anticipate overflow pathways or evaluate the effectiveness of mitigation structures. Findings from neighbourhoods uphill highlight both elevated risk and instances where recent engineering works have underperformed. This underlines the need for improved technical understanding of flow dynamics and drainage capacity of the ravines.

Future efforts should prioritise systematic ravine mapping with topographic analysis to identify bottlenecks and weak points, thereby strengthening proactive planning, maintenance, and data-informed design to enhance resilience and reduce reliance on post-event responses. The current reactive system is particularly vulnerable to interannual rainfall variability associated with El Niño events. In addition, community perceptions indicate a desire for improved flood protection infrastructure highlighting the need for effective planning and interventions.

3.6 Formal Governance and Perceived Satisfaction

The results of the two layers are visualized in Figure 16: Map showing the spatial variation in satisfaction with water governance and the distribution of investment plans in Puerto Baquerizo Moreno, San Cristóbal Island, Galápagos Islands. . Both layers use a red gradient scale, serving as a visual reference to facilitate comparison and highlight potential correlations between municipal investment and residents' dissatisfaction. The information of the different plans added in the municipal investment layer can be found in Table 9.

3.6.1 High Satisfaction Does Not Universally Correlate to Significant Spending

The comparative analysis between the municipal investment map (top-down perspective) and the citizens' perceived satisfaction map (bottom-up perspective) reveals notable spatial asymmetries across neighbourhoods.

Areas of Mismatch Between Investment and Satisfaction

The most evident disparity is observed in Playa Mann and Playa Oro, where investment levels are relatively high, yet citizen satisfaction remains below the citywide average (Figure 16). In Playa Oro, the total investment across Projects 3, 5, and 8 amounts to USD 222,330, while in Playa Mann, Projects 5 and 8 total USD 129,000 (Table 9). However, only USD 93,333 is allocated to flood prevention in Playa Oro, a major concern in both neighbourhoods, as reflected by the predetermined and perceived flood risks, which are further illustrated in the critical flood-risk points layer (see 3.5.2, 3.5.3, 3.5.5). This limited investment in addressing a key local issue may help explain the low satisfaction scores in these neighbourhoods, where efficiency and communication are rated around 2.5, and Playa Oro exhibits particularly low reliability at 2.14 (Figure 18, Figure 19, Figure 21).

Areas with Low Investment and Low Satisfaction

Central, Peñas Altas, Cactus, and Albatros exhibit low satisfaction levels, which, combined with the absence of significant government investment, highlights the need for greater municipal attention (Figure 16).

In Central, dissatisfaction is primarily driven by a very low communication score (1.8) and moderate discontent regarding efficiency (2.6) and reliability (2.8) (Figure 18, Figure 19, Figure 21) potentially linked to persistent flood problems in the area (see 3.5.4 Experienced Flood Risk Layer: Pronounced Spatial Variability in Damage with High Incidence in Peripheral Neighbourhoods).

In Peñas Altas, low satisfaction is mainly associated with reliability and communication (both 2.5), while efficiency is slightly higher at 2.8. The low scores in Peñas Altas, as well as in Cactus and Albatros, may also be influenced by water scarcity issues: the neighbourhoods' positions correspond to lower water pressure (3.1.2 Distribution System), which can create localized shortages and help explain the lower efficiency ratings, particularly in Cactus (2.5).

Areas with High Investment and High Satisfaction

A more balanced relationship between investment and satisfaction is observed in the neighbourhoods surrounding the main ravine (Encañada de Barrio Frío), namely Frío, Estación Terrena, San Francisco, Algarrobos, and Fragata. In these areas, satisfaction generally exceeds the neutral threshold of 3.0, with the exception of Algarrobos (2.71), where residents report lower satisfaction regarding reliability (Figure 16, Figure 21: Map showing the spatial variation in perceived reliability of water governance in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal Island, Galápagos Islands.). The coexistence of both investment and relatively high satisfaction suggests that transparent and inclusive processes can enhance community trust. The most notable example is found in Barrio Frío, which has benefited from approximately USD 469,000 in projects (ID Plans 5, 7, 8, 10, and 16 in Table 9 and Table 10). These projects primarily address issues related to sewage systems and flood prevention through ravine maintenance, challenges which this neighbourhood has been facing in the last years (3.5.5 Critical Locations Layer: Key Sites and Resident Narratives Highlighting Flood Risk).

Cabecera Parroquial El Progreso, together with the neighbouring areas located just below it, represents another positive case, with an overall satisfaction score of 3.23, particularly high for participation (3.84) (Figure 20), and a substantial number of projects amounting to approximately USD 2.9 million, while the adjacent neighbourhoods show slightly lower satisfaction levels (2.85) and a moderate number of planned projects. However, since some projects were not included in the

investment plan layer and several neighbourhoods were methodologically grouped, it is possible that the reported scores do not entirely reflect all available information. These aspects, relevant both to this area and to the city as a whole, are further discussed in the following subchapter.

Perceived Overall Satisfaction and Investment Plans



Figure 16: Map showing the spatial variation in satisfaction with water governance and the distribution of investment plans in Puerto Baquerizo Moreno, San Cristóbal Island, Galápagos Islands.

Perceived Overall Satisfaction and Investment Plans



Figure 17: Map showing the spatial variation in satisfaction with water governance and the distribution of investment plans in Cabecera Parroquial El Progreso, San Cristóbal Island, Galápagos Islands.

Perceived Communication of Water Services

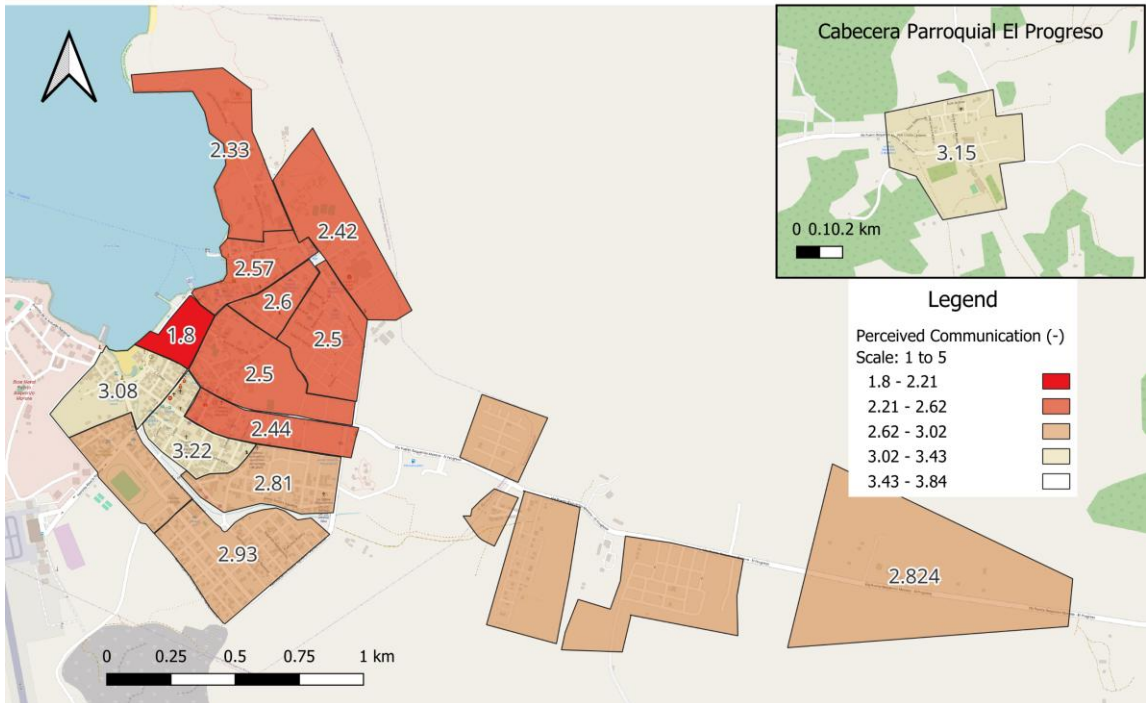


Figure 18: Map showing the spatial variation in perceived communication of water governance in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal Island, Galápagos Islands.

Perceived Efficiency of Water Services

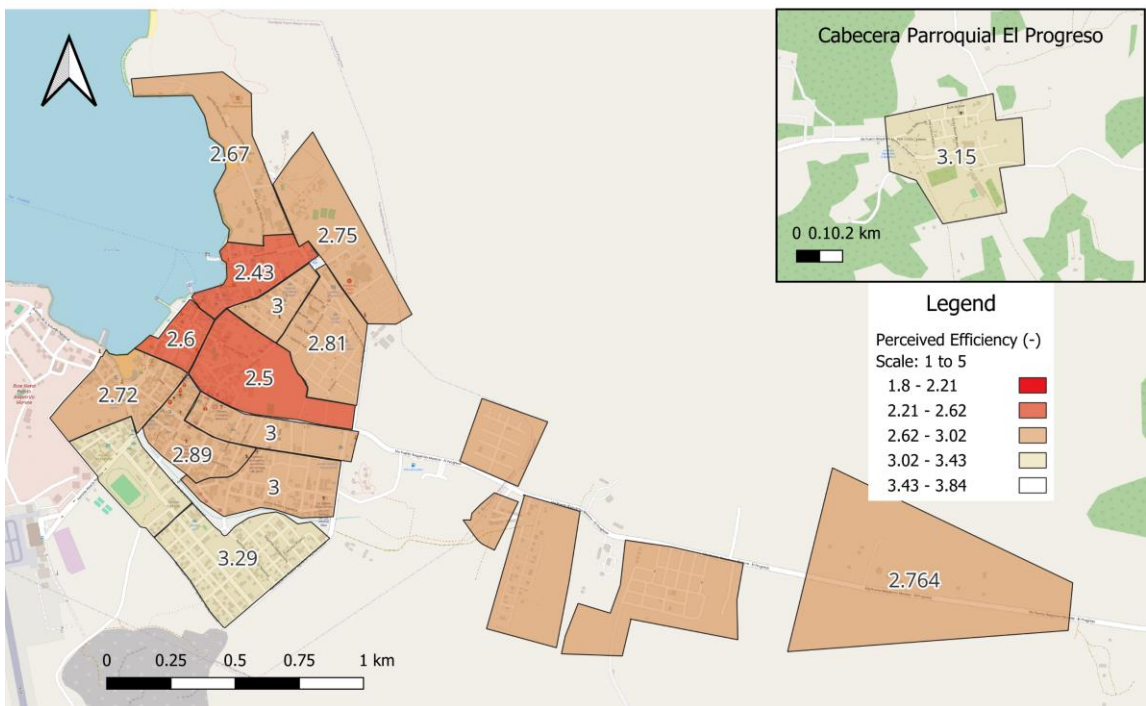


Figure 19: Map showing the spatial variation in perceived efficiency of water governance in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal Island, Galápagos Islands.

Perceived Participation of Water Services

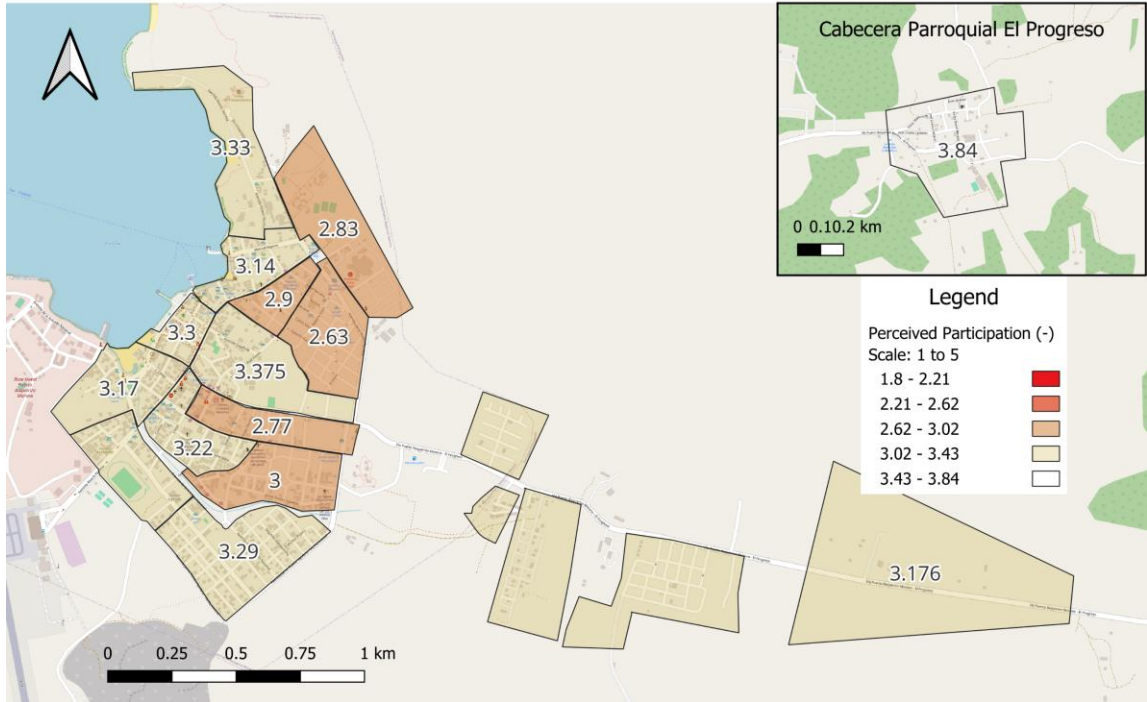


Figure 20: Map showing the spatial variation in perceived participation of water governance in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal Island, Galápagos Island.

Perceived Reliability of Water Services

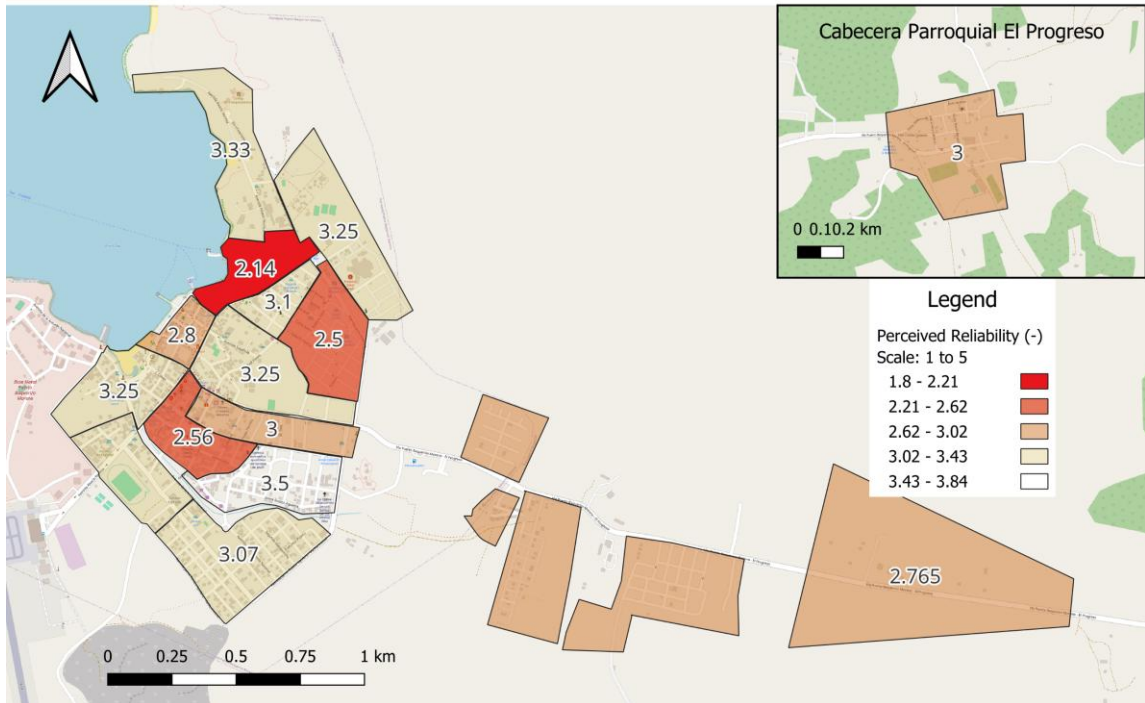


Figure 21: Map showing the spatial variation in perceived reliability of water governance in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal Island, Galápagos Islands.

3.6.2 Satisfaction Shows Minimal Variability due to Localized Infrastructural Challenges

Across all neighbourhoods, the range of perceived satisfaction values remains relatively narrow. When considering all dimensions combined, scores vary only from 1.8 to 3.84, and the overall satisfaction index spans an even smaller interval, from 2.61 to 3.23.

This limited variability can be explained by the localized nature of water-related issues in San Cristóbal. The main challenges are seldom neighbourhood-wide; rather, they tend to occur at the household or street level. As a result, within a single barrio, strongly dissatisfied and satisfied respondents often coexist, producing moderate averages that mask underlying heterogeneity. For instance, Estación Terrena and San Francisco record an overall satisfaction index of 3.15, yet several localized issues with the water infrastructure are highlighted within these two neighbourhoods, eight water shortage cases, six pipe leakages, and six water clarity problems were reported (Experienced Failures and Responses)neighbourhoods. The . These cases illustrate that satisfaction at the neighbourhood scale does not necessarily reflect the unevenness of experiences. The compression of the satisfaction scale is further influenced by methodological constraints, particularly the grouping of some low-density neighbourhoods into larger units due to data limitations. For example, the neighbourhoods between the lower sector of Puerto Baquerizo Moreno and the Cabecera Parroquial El Progreso were merged into a single analytical area. Although the group shows an overall satisfaction score of 2.85, local feedback reveals internal contrasts:

In La Planada, several respondents reported persistent issues, including the lack of connection to the piped water system and the resulting dependence on municipal water trucks, which often causes delays and inconvenience (3.1.3 Contingency Supply). The area also experiences serious flooding problems.

In Arrayanes, respondents mentioned issues related to water quality, pipe leakages, flooding, and the sewer system. As illustrated by the following comment, these observations confirm that notable dissatisfaction can be obscured when neighbourhood data are aggregated.

“The water is yellow and rusty, not drinkable. Pipes were poorly installed and now exposed by erosion. Flooding enters my house every year, and there’s no sewer system. Authorities ignore us, the municipality never fixes anything”.

Resident San Cristóbal, Arrayanes

A third explanation for the narrow scale relates to local perceptions and cultural attitudes toward water governance. Many residents demonstrate a degree of adaptive acceptance, viewing infrastructural limitations as a normal condition rather than a failure of governance. This tendency helps explain why satisfaction scores cluster around the neutral point, even when problems are acknowledged.

A representative example comes from an interview in Isla Sur, where a resident stated:

“We can’t ask for much — it’s part of living on an island, a paradise. Because of conservation, we can’t demand more, and we just have to wait for the authorities to decide when they can fix things”

Resident San Cristóbal, Isla Sur

3.6.3 Planned Projects and Community Experiences are Nonconform

As described in the detailed methodology in Appendix C-5 Specification for the spatial representation of projects in the investment plan layer, some projects were repeated across multiple investment plans (2020–2024 and 2024–2027), resulting in higher total investments for these areas. On maps, this could visually suggest greater municipal attention. However, interviews with local residents sometimes contradicted the official plans, raising questions about potential unmet promises.

A clear example is the replacement of water supply pipelines in the Cabecera Parroquial El Progreso (Table 12: Projects which appear in both Plan Desarrollo 2020-2024 and 2024-2027). The combined investment of USD 240,000, USD 90,000 from the first development plan and USD 150,000 from the second, is among the largest documented in the available literature. Yet, residents of the Cabecera Parroquial El Progreso report that no work has been carried out and pipelines have not been replaced in over 60 years.

This type of mismatch between planned and perceived implementation likely occurs in other neighbourhoods as well and may help explain cases where satisfaction remains low despite a high number of planned projects, coupled possibly with miscommunication and delays.

Apart from the Cabecera Parroquial El Progreso, Frío stands out as one of the areas receiving the highest level of investment relative to its small size. This is largely due to the urgent need for environmental restoration, as the area has suffered from severe contamination over time. Once a popular beach, Frío is now affected by frequent sewer leaks, stagnant water, and pollution from boat

maintenance activities (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025). Moreover, the accumulation of construction debris that had been historically used to fill nearby channels, contributing to the physical degradation of the coastline. For this reason, part of the investment is allocated not only to the removal of this material, but also to the relocation of boat maintenance areas (*baraderos*) and the monitoring of water quality.

Conversely, some projects do not appear on the investment map due to missing financial data. For example, Project 4 (Table 9), concerning the construction of a box culvert was originally conceived to prevent water from flowing into La Planada. However, after a major flood in La Planada in 2024 (3.5.5 Critical Locations Layer: Key Sites and Resident Narratives Highlighting Flood Risk), it became evident that the existing drainage system was insufficient to handle extreme rainfall. In response, the municipality initiated a new project to redirect runoff and channel water away from La Planada, aiming to reduce future flood risks (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025).

Another planned project not visible on the map addresses flooding issues in the Divino Niño neighbourhood, particularly in the area near the hospital. The project proposes diverting the “Encañada del Barrio Frío” to prevent water from reaching the street adjacent to the hospital (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025).

The absence of projects on the investment map may occur in other areas and help explain cases where satisfaction is high despite a low number of mapped plans.

3.6.4 Conclusion

The findings highlight that satisfaction does not necessarily scale linearly with investment. While some neighbourhoods, such as Estación Terrena, Frío, and El Progreso, show a clear alignment between high investment and high satisfaction, others, like Playa Mann and Playa Oro, reveal persistent dissatisfaction despite substantial funding, mainly due to weaknesses in communication and efficiency and the limited attention to flooding issues.

The limited variability of satisfaction values across neighbourhoods suggests that water-related challenges in San Cristóbal are highly localized, often confined to specific households or streets. This localized nature results in moderate average scores that tend to mask significant internal disparities. Furthermore, many residents appear to have adapted to infrastructural shortcomings, exhibiting a form of contented resignation shaped by both environmental constraints and governance limitations. Several respondents also emphasize a sense of privilege in living on an island with a freshwater supply, unlike the other inhabited islands of the Galápagos, which may contribute to a greater tolerance for infrastructural inadequacies.

It is important to acknowledge certain limitations that may have influenced these results. First, the use of investment data as a proxy for municipal attention assumes a direct relationship between planned expenditure and government engagement, an assumption that is not always hold true in practice, especially when project outcomes are delayed or poorly communicated. Additionally, the grouping of some neighbourhoods, required to compensate for limited sample sizes, may have obscured variations at smaller spatial scales and limited the visibility of localized issues. Despite these constraints, the analysis provides valuable insights into the spatial relationship between investment, satisfaction, and governance on the island, offering a foundation for more targeted interventions in future planning efforts and contributing to greater government transparency, thereby strengthening the relationship between the municipality and the community.

3.7 Socio-Economic Vulnerability

The spatial distribution of relative socio-economic vulnerability across Puerto Baquerizo Moreno is examined using an observation-based exploratory indicator. The results aim to explore potential correlations between socio-economic inequalities, access to safe drinking water and exposure to flood risk by comparing the socio-economic vulnerability map with the findings of the previous results.

3.7.1 Mapping Relative Socio-Economic Vulnerability

The results of the relative socio-economic vulnerability map are shown in Figure 24, derived by the community infrastructure indicator (Figure 22) and standard of living indicator (Figure 23). Darker shades of red indicate areas of greater relative socio-economic vulnerability, based on the selected indicators and parameters.

Neighbourhoods located near the coast are almost transparent, with Central showing no coloration at all and scoring the lowest values across all indicators. This part of town contains most of the hotels, shops, universities, and tourist-oriented services, and its buildings and roads are well maintained to ensure a positive experience for visitors.

Moving inland, the colour gradually deepens, reflecting growing socio-economic disparities within Puerto Baquerizo Moreno. This shift corresponds to the transition from the tourist-oriented coastal zone to more residential areas. For example, Estación Terrena shows a darker shade, driven by its low Standard of Living score (0.25, Figure 23: Spatial variability of the Standard of Living Indicator in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal, Galápagos.).

Further inland, the neighbourhoods just uphill of the city, display marked variation despite their proximity. Isla Sur and La Planada appear in the darkest red, as they are newly developed areas with unpaved roads and houses still under construction. Living standards in these neighbourhoods are expected to improve in the coming years as neighbourhoods develops further. A similar pattern is observed in Arrayanes, which, starting from a relatively higher Standard of Living score (Figure 23), shows signs of gradual improvement and future consolidation.

From the comparison of all thematic maps (shown in 3.1-3.6) and the socio-economic vulnerability map, several areas emerge as particularly significant, which are discussed in the following subchapters.

Community Infrastructure Indicator

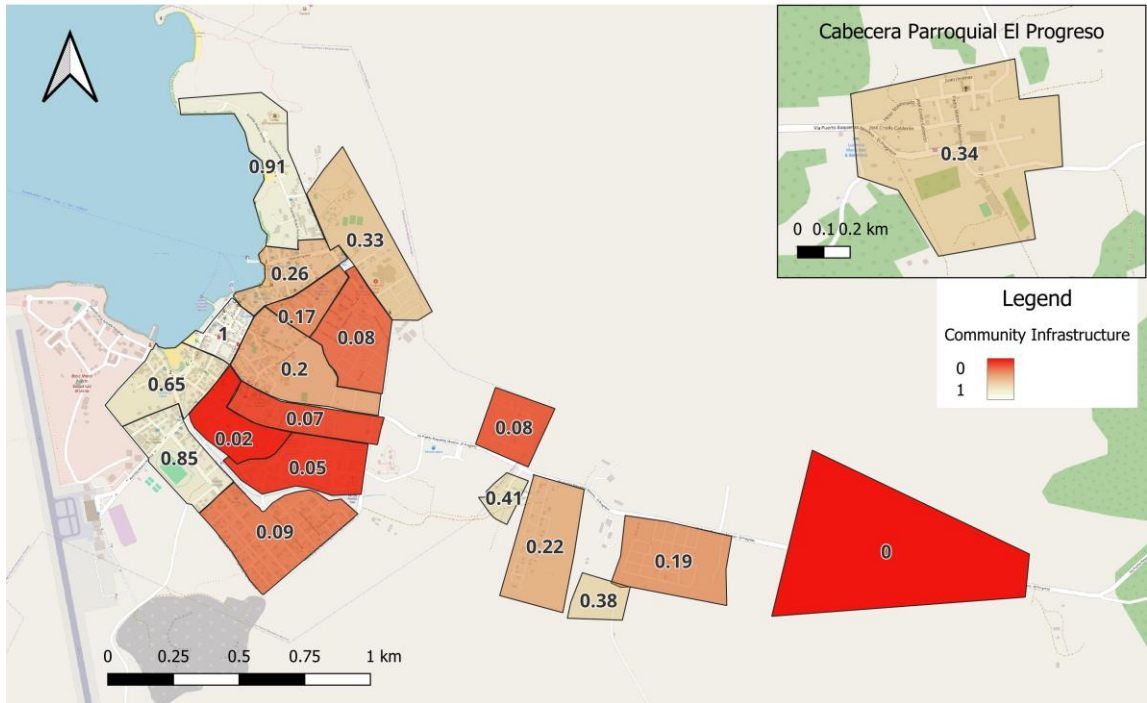


Figure 22: Spatial variability of the Community Infrastructure Indicator in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal, Galápagos.

Standard of Living Indicator

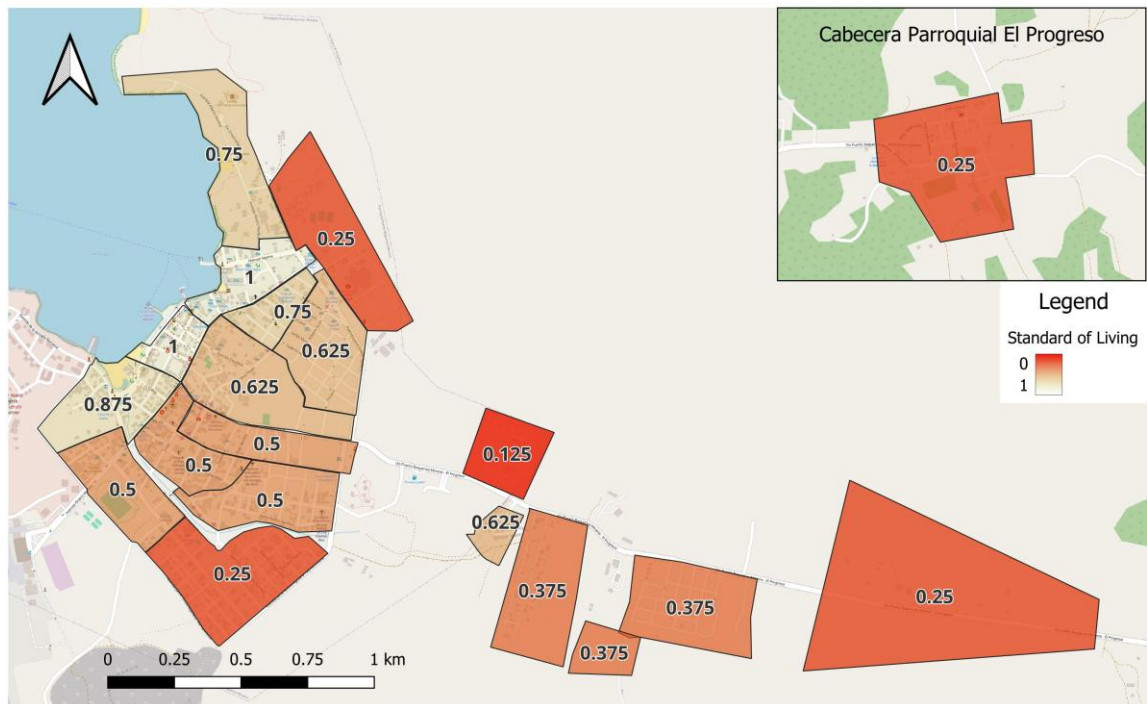


Figure 23: Spatial variability of the Standard of Living Indicator in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal, Galápagos.

Socio-economic vulnerability differences

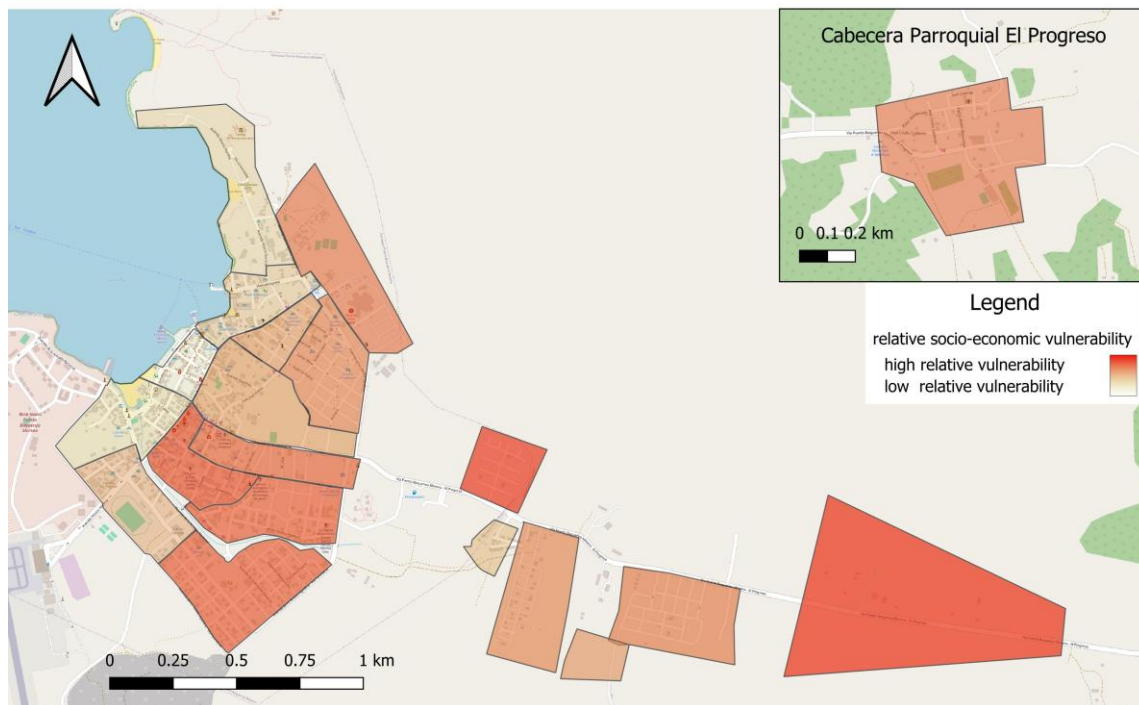


Figure 24 : Relative socio-economic vulnerability differences in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso (top right), San Cristóbal, Galápagos.

3.7.2 Conclusion for Peripheral Areas: High/Moderate Socio-Economic Vulnerability, Multiple Challenges, Strong Satisfaction, and Extensive Municipal Planning

The neighbourhoods: Arrayanes, Isla Sur, Las Palmeras, La Planada, Manzanillo, and Cabecera Parroquial El Progreso, stand out on the vulnerability map (Figure 24). Displayed in dark red, these areas exhibit marked socio-economic contrasts with the urban core. Although they host only 17% of the total population, they account for 30% of the documented water shortage problems, with 39% of questionnaire responses in Cabecera Parroquial El Progreso reporting household damage due to flooding and 47% in the remaining neighbourhoods. Flood management is particularly challenging due to the prevalence of unpaved streets, which become waterlogged during heavy rains, while the partial absence of water infrastructure, especially in Isla Sur, La Planada, and Arrayanes, forces reliance on intermittent truck deliveries or informal drainage systems. These conditions confirm residents' narratives of being "left behind" in service provision and highlight the importance of local adaptation strategies such as rainwater harvesting.

Despite these issues, low satisfaction levels are not fully reflected in the survey results likely due to methodological constraints and the visible presence of recent municipal investments. Overall, this area is characterized by multiple challenges and a darker tone on the socio-economic vulnerability map, yet it also appears to be a focus of government attention and resource allocation.

Similar patterns are observed in Divino Niño and Estación Terrena, both of which display low standards of living. Vulnerability in these areas is further evidenced by flood risks in Divino Niño and water shortage problems in Estación Terrena. Nevertheless, both neighbourhoods have recently benefited from municipal drainage improvement projects. In this case, higher satisfaction levels may suggest that visible municipal action can effectively rebuild community confidence.

3.7.3 Conclusion for Mid-Altitude Neighbourhoods: Moderate Socio-Economic Vulnerability with Varying Levels of Problems, Satisfaction, and Investment

The central area of Puerto Baquerizo Moreno, which includes the neighbourhoods of Albatros, Algarrobos, Fragata, Cactus, San Francisco, and Peñas Altas and Bajas, shares a similar mid-range level of socio-economic vulnerability (Figure 24)., though notable differences emerge across other indicators. Within this group, Fragata and San Francisco are most affected by flooding, yet they also benefit from substantial municipal investment plans, resulting in moderate overall satisfaction levels. In contrast, the remaining neighbourhoods, despite being well-serviced and facing low flood risk, are largely excluded from current investment programs, which is reflected in their lower satisfaction scores.

3.7.4 Conclusion for Coastal Neighbourhoods (Malecón): Low Socio-Economic Vulnerability, High Investment, Mixed Satisfaction, Strong Water Security, High Flood Risk

Neighbourhoods such as Frío, Central, Playa de Oro, and Playa Mann all perform well on socio-economic vulnerability indicators (Figure 24). In Frío, the correlation between municipal investment and satisfaction is positive, with high levels of both funding and resident approval. Conversely, in Playa de Oro and Playa Mann, substantial investments correspond with relatively low satisfaction, particularly in relation to communication, suggesting that top-down infrastructure spending has not effectively translated into a sense of inclusion or responsiveness. Consistent with their lower socio-economic vulnerability, these neighbourhoods benefit from reliable high-pressure water supply; however, they remain among the most affected by flood risk and, most notably, by sewage overflow events.

4. Evaluation

This section evaluates the community-generated maps for San Cristóbal, highlighting how they complement municipal data and provide insights into water governance, flood risk, and socio-economic vulnerabilities. It also considers methodological limitations and outlines recommendations to enhance water security.

4.1 Contributions

As discussed in the Introduction, the maps were developed through community participation. Their purpose is to be compared with the information already available from the municipality. Table 3 illustrates how the community-generated maps contribute to and complement the existing municipal data. They are provided in QGIS format as well as an interactive web-based format for the community.

Table 3: Contribution of each map to the existing municipal data.

MAP	Contribution
3.1 Public Drinking Water System in San Cristóbal	This map contributes to give a spatial visualization of how and when the water reaches each neighbourhood and can help the municipality as a starting point to produce an actual map of the entire public potable water infrastructure, which at the time is not existing.
3.2 Self-Organized Water Governance Practices	These maps reveal spatial variations in household water practices that official records overlook, highlighting zones of greater vulnerability and resilience, guiding targeted municipal interventions to improve water quality and community awareness.
3.3 Usage Patterns and Reliance on Bottled Water	Spatial visualization of the information that the municipality already has (water consumption by neighbourhood) combined with insight on water bottle consumption per household (bottom-up).
3.4 Experienced Failures and Responses	Institutional responsibility for monitoring and supply is limited to the municipal storage tanks and pipeline functionality; this map therefore provides a broader assessment of the efficiency of the water system and highlights areas or topics that require improvement.
3.5 Flood Risk	Showcases flood vulnerability and community resilience by combining official classifications with residents' experiences and perceptions, supporting municipal flood-management and proactive flood response.
3.6 Formal Governance and Perceived Satisfaction	The map contributes as a valuable tool to identify areas of low satisfaction, assess how effectively investments respond to community needs, and prioritize future interventions.
3.7 Socio-Economic Vulnerability	Provides a relative view of socio-economic vulnerability within San Cristóbal, useful for exploring correlations with other risk layers and understanding spatial inequalities across neighbourhoods, helping identify disadvantaged or developing areas and supporting more equitable decision-making.

4.2 Limitations

Several limitations arise from methodological constraints, data availability, and the urban context, and should be acknowledged when interpreting the results and conclusions.

4.2.1 Data collection

The semi-structured interviews and questionnaire were central to capturing residents' experiences. Nonetheless, their reliability is constrained by:

- Sample size and spatial coverage: Limited respondents per neighbourhood and uneven spatial distribution may have missed local variability failed to represent the average neighbourhood's perspective.
- Temporal factors: The duration of residency and timing of past events were not considered, limiting temporal representativeness of the collected data. The absence of a temporal dimension particularly affects maps that quantify the spatial distribution of negative experiences, as done in Experienced Flood Risk and Experienced Failures and Responses.
- Response bias: Personal awareness, risk perception, and social desirability may have influenced answers, particularly regarding water governance and perceived flood risk.
- Verification of qualitative data: Self-reported information from the semi-structured interviews and questionnaires, such as cleaning habits and flood experiences, was not independently verified. While these narratives provide valuable local insights, their accuracy cannot be assured.

Semi-structured interviews:

The semi-structured interviews format was chosen to create a comfortable environment to collect qualitative insights into local vulnerabilities, underlying causes and community resilience. However, its flexibility also introduced limitations. As questions were not always phrased identically, and the depth of probing varied between interviews, the information collected differed slightly among participants, reducing comparability and potentially leading to the omission of relevant details.

Furthermore, the processing step with LLM-based QA introduced certain extra limitations and considerations, viz., the hallucination of the AI model when answering a particular question, or the non-standard replies generated by the LLM. For example, for the question 'what is the size of your tank?', receives answers like '1.5cu.m' or '1x1x1.5cu.m'. Specifying units, dimensions, and how concise the response should be reduced mismatches. Further, some LLMs hallucinated answers. 'Which neighbourhood do you live in?' was one such example. If an answer was not mentioned, but another neighbourhood was discussed, that neighbourhood would populate the answer field. This showcased the need for better prompt engineering.

4.2.2 Secondary Data

- Population and consumption estimates: Household-level or neighbourhood-level population data were unavailable; estimates relied on the 2022 census figures.
- Water usage patterns: Only annual consumption data were available, preventing analysis of seasonal variations. Due to the lack of recorded separation between household and commercial water use, along with the absence of certain water meters, the accuracy of consumption estimates is further reduced.
- Infrastructure mapping: The municipal water distribution and ravine maps were incomplete and of insufficient resolution to identify the precise location of network elements.

Supplementary information derived from interviews and satellite imagery provided only a simplified representation of the actual systems

- Predetermined flood-risk classification: The municipal flood risk layer is qualitative, lacking fine-scale topographical or hydrological modelling. This limits its predictive accuracy and obscures the meaning behind the high-medium-low classifications.

4.2.3 Neighbourhoods Aggregation and Use of Proxies

- Neighbourhood aggregation: Low sample sizes necessitated merging some neighbourhoods, smoothing local contrasts in self-organized water governance practises, perceived flood risk and governance satisfaction.
- Proxy indicators: Several indicators were represented through indirect measures, each carrying inherent assumptions and limitations:
 - Socio-economic vulnerability relied on observation-based proxies, which may not fully capture household-level inequalities or the condition of community infrastructure.
 - Experienced flood risk used reported household damages from the questionnaire sample as a proxy for flood exposure, which may not reflect unreported or less severe events.
 - Investment plans employed projected municipal expenditure per neighbourhood as a proxy for government attention, assuming a direct relationship between planned investment and institutional engagement. An assumption that may not hold in practice.

4.2.4 Contextual Considerations and Implications

Results should be interpreted within the socio-economic and temporal context of San Cristóbal. Residents' perceptions and experiences are inherently subjective and influenced by individual circumstances, meaning the findings represent a temporal snapshot rather than a predictive model. Nonetheless, they provide valuable insights for participatory planning and highlight areas for further quantitative and longitudinal research.

4.3 Recommendations

This study highlighted several recommendations within closing knowledge gaps and combatting fragmentation aimed at increasing the water security on San Cristóbal. For instance, demographic information such as number of inhabitants, occupation, income, and residential building types will improve understanding of socioeconomic factors. Besides their influence on water security, the municipality mentioned their importance for risk assessments in regards to environmental disasters.

From our findings, it is evident that residents carry individual responsibility for household level water treatment, leading to a variety of practices which are not equally effective. To this end, local sensitisation and awareness campaigns by governmental or non-governmental organisations and educational institutions, to educate residents on the usage of chlorine, water filters, and cleaning practices, can enhance water security. It was also found that there is a desire toward an increase in the water system capacity, to support future population growth and eventually a continuous supply of higher quality, which can only be made possible by large infrastructural operations. Many problems and conflicts associated with water security are related to the sewer system, in particular, inadequate flood drainage leading to sewage spills and contamination of water bodies. It may be advised to study the viability of a separated sewer system or increasing the capacity of the current one.

Reoccurring flood events are common in San Cristóbal. Current flood management is reactive, based on past events rather than predictive modelling due to limited data and technical capacity. Future efforts should prioritise systematic ravine mapping with cross-sectional area analysis to provide valuable information for assessing local conveyance capacity, thereby helping identify flood-prone areas within the current network. High-resolution topographic and precipitation data, together with in-situ measurements of surface roughness, channel geometry, infiltration rates, and other key hydrological variables, would provide the foundation for hydraulic simulations, improved flood prediction and identification of required improvements.

5. Conclusion

This study presents a holistic approach to quantifying water-related risks among community members in regards to the municipal distribution system and flood risk of San Cristóbal, Galapagos Islands. To this end, a methodological framework was used consisting of semi-structured interviews, resident questionnaires, stakeholder discussions, transect walks, site visits, and field observations. These community centred research approaches were coupled with expert consultations and machine learning analysis.

The results highlight a centralized institutional governance of potable water distribution that reaches most residents. However, the gravity-fed network supplies intermittently and causes uneven distribution of pressure amongst neighbourhoods. This supply necessitates the use of household storage systems, in which responsibility of maintenance is conveyed to the individual. Thus, vulnerability differs between households, depending on type of storage, and availability of at-home drinking water treatments. The vast majority of residents rely on bottled water, but this also comes with its price. Thus, water security at the household level is bounded within the limits set by income, education, and the availability of parts and services (e.g. for filters).

Furthermore, gauged experiences with water-related problems among the community yielded a low trust in water quality. This is accentuated by residents mentioning cloudy or muddy water from the tap, and associated health issues. Thus, most residents rely on bottled water or filters and associate the lack of clear water with inefficient treatment. Another issue highlighted by interviews is that of pipe leakages and bursts, most occurring within the rain season, which can lead to sewage spills and street flooding.

Reoccurring flooding locations and prone areas are concentrated in low-lying coastal zones as well as uphill parts where runoff converges in flatter sections. Experienced flood risk is highly dependent on local topography and design and thus occurs across the island. Neighbourhoods can experience flooding at localized points while adjacent areas remain dry, highlighting challenges for urban planning. Mitigation measures remain reactive rather than proactive due to limited technical data. Although municipal stormwater ravines are designed with hydrological and topographic considerations in mind, infrastructural projects still fail to meet community needs, as is seen in flood-events anecdotes and coastal neighbourhoods where, despite substantial investment plans, dissatisfaction with the water governance persists.

Overall, satisfaction does not increase proportionally with investment, as some neighbourhoods exhibit negative attitudes towards governance despite substantial planned interventions. Dissatisfaction appears to be driven more by deficiencies in communication and transparency than by an actual shortage of investment. However, the general satisfaction remains moderate as many residents note their privilege in living on an island with freshwater (which is not the case for the other inhabited islands), thus making peace with the fact that infrastructural barriers remain. When taking these analyses together alongside social vulnerability within the island, certain critical correlations become clear: perimetral areas of Puerto Baquerizo Moreno, i.e. between the urban and rural land, are most socially vulnerable and exhibit higher problems with water shortages and flood risk; central neighbourhoods experience variable levels of problems with areas high in flood risk receiving considerable investments, but otherwise fall behind government support; coastal neighbourhoods are least likely to fall behind government support and have low socio-economic

vulnerability, but residents have low satisfaction due to prolonged and reoccurring issues with sewage spills and floods.

Despite almost full coverage of a water distribution network and institutional support for ensuring proper water quality, water security at point-of-use requires heavy infrastructural maintenance and repairs. Furthermore, there is a need for better education on household level water practices, including cleaning and filtration. This alongside institutional flood management implementations can be beneficial to the residents of San Cristóbal and relief current water vulnerability on the island.

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Appendix A: Literature Study

The following literature sources were consulted to gain an understanding of the water situation in San Cristóbal.

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Appendix B: Data Processing

This section expands on some details regarding the data processing mentioned in the methodology section of the report.

B-1 Transcription

As the downstream task was question-answering (QA), different transcription models were evaluated based on information loss rather than WER or other standard metrics. For 3 transcript-audio pairs, 2 Spanish experts counted the number of facts present in the audio but missed by the transcription. Transcripts have between 500-5000 words. Facts include answers to questions regarding water supply, usage, issues mentioned with the water system, and more.

Table 4: Performance of different models for audio transcription

Model	Whisper base	Whisper medium	Whisper large v3 turbo	Whisper large v3
Missing facts / transcript	5+	1-3	0.33	0.33

Whisper v3-turbo had sufficient performance with higher throughput compared to whisper large v3, and was thus selected to perform the transcriptions. In cases where automatic transcriptions omitted critical sections of conversations, Spanish-speaking researchers reviewed the audio and completed the missing content. To protect participant privacy, all personal names referenced in the recordings were removed prior to this review and the downstream translation task. All data remained stored locally or on a secure shared drive with exclusive researcher-only access.

B-2 Translation

The selection of Llama-70B was informed by a manual intelligibility evaluation conducted by three Spanish-proficient researchers over 3-4 transcripts. Prior to this, several smaller models (e.g., Gemma2-9B-IT and Llama-3.1-8B-Instruct) and larger ones (Claude Sonnet 4.5) were tested for suitability. An instruction-tuned model was required to ensure that proper nouns (such as neighbourhood names like *El Progreso* or *Las Palmeras*) remained untranslated, and that domain-specific terminology was interpreted correctly (e.g., translating *llave de la calle* as street water valves rather than “keys of the street”). The translation model was run using GDPR-compliant service lemonfox.ai (LemonFox, 2025). Only anonymised data was passed to the translation api, and no data remains stored on any 3rd party server.

B-3 Question-Answering

The QA design required some prompt engineering and tailoring of the questions. The questions were divided and clearly marked as one of a few categories:

1. Yes/no questions with a 1/0 answer (E.g: Do they have a cistern?)
2. Category questions with a number per category (E.g, how often do they clean the cistern? (categories: [once a year or less: 1, once a few months: 2, more than once a month: 3])

3. There are describe questions for long answers, personal stories. (E.g, describe the issues they have faced with health due to the water), for more nuanced understanding of the community viewpoints
4. Numerical questions with a numeric answer. (E.g, How large is the tank? 2.5 cu.m)

Llama3.2 8B, Liquid AI LFM Extract 1.2B, Qwen, Claude and a few other models were tested for accuracy (human-verified mistakes) and answering rate (proportion of non-NA answers). Claude Sonnet 4.5 was chosen due to its reliability (no human-verified semantic mistakes in the 5 transcripts reviewed) and consistency (>95% answering rate).

The prompt supplied to the model was as follows:

“You must go through the provided context transcript and the list of questions csv (Id,Q).

Read the transcript carefully and answer the questions in the format (ID,Q,A,Context) and save as an output CSV parallel to the transcript. (If output file exists, skip that transcript and processing).

For yes/no questions (marked with (yes/no)), output 1 or 0 only for the answer.

For questions that have a category list provided. Answer only with the number of the category the answer falls into

For describe questions, provide a description that does not miss out on any relevant points. You can summarise points but ensure no information is left out.

For numerical (frequency, Number of etc) answer with just the number that can be converted to float type. Be mindful of the unit asked If an answer is provided in a different unit, use your knowledge to convert that unit to the desired unit.

For every question, you can provide a context column to indicate the snippet of text from the transcript you used to get the answer.

Do not create the answer if it does not exist in the transcript. Only use the transcript information. Say NA if no answer. You can still provide context you think is relevant in the context column even if the answer is NA.”

B-2 Population estimation

The sectors chosen by the government for the “catasto” (INEC, 2022) don’t match exactly the division of the barrios according to the municipality. Some were easy to unify and count for one neighbourhood, but for others, the sectors that crossed multiple barrios, a qualitative choice was made:

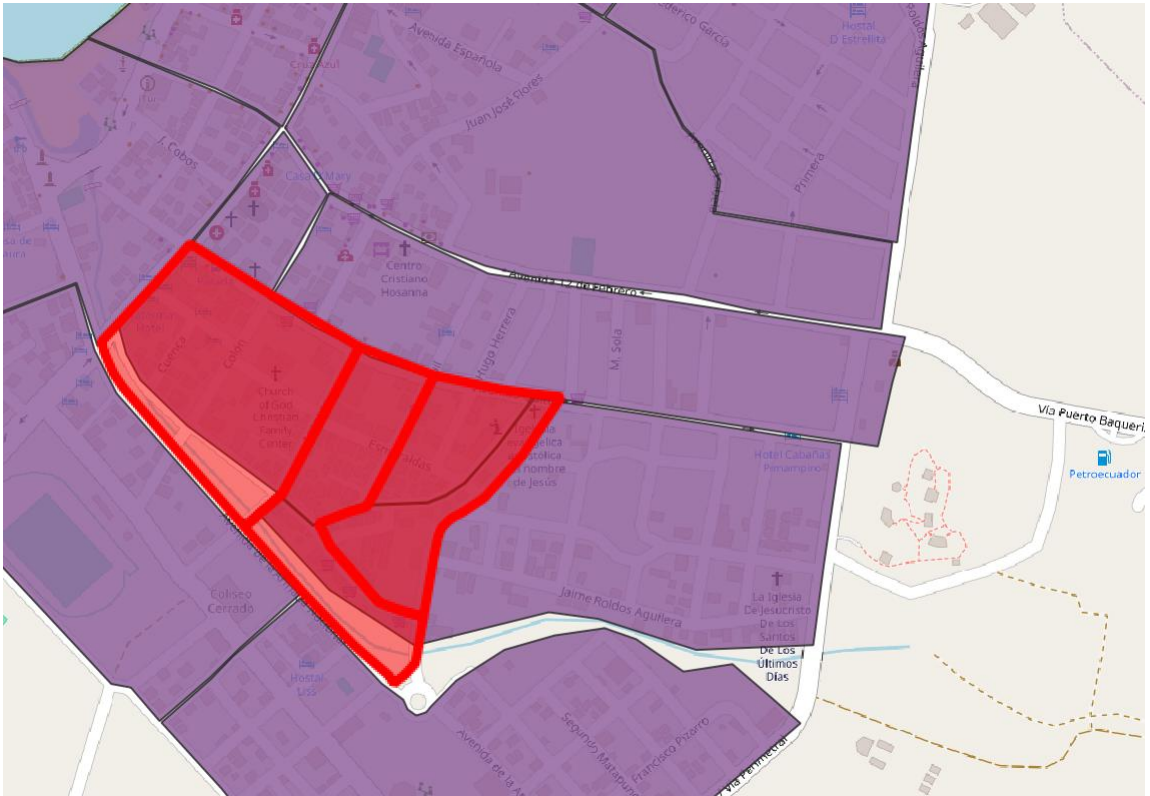


Figure 25: Barrio Algarrobos, population = 742

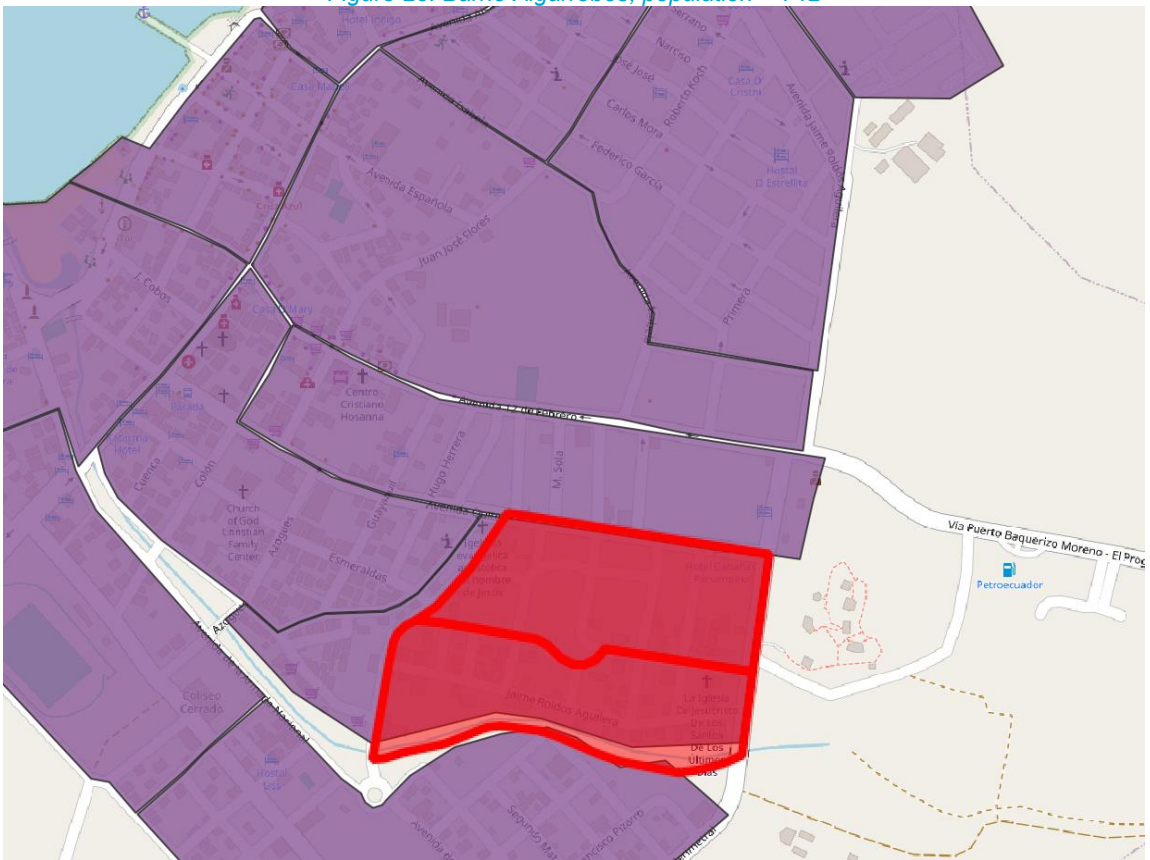


Figure 26: Barrio Fragata, population = 590

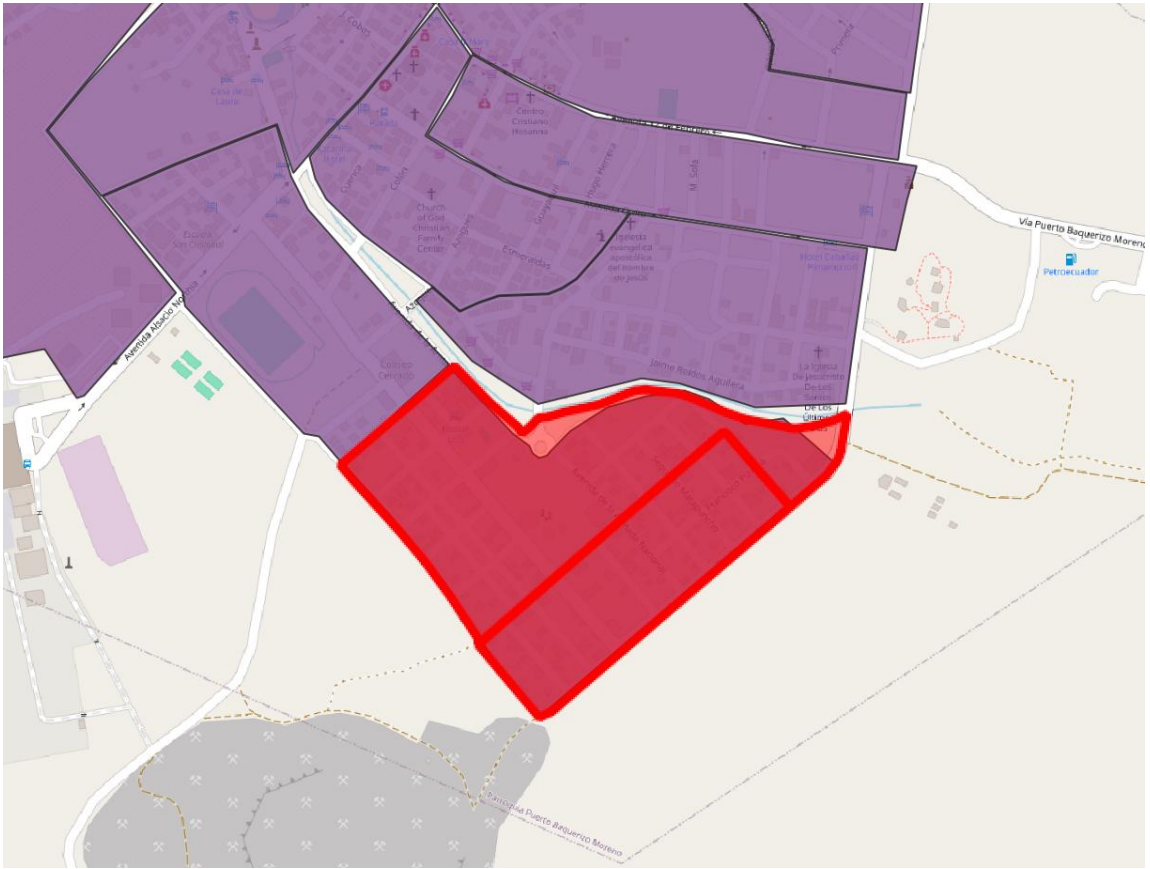


Figure 27: Barrio Estacion Terrena, population = 857

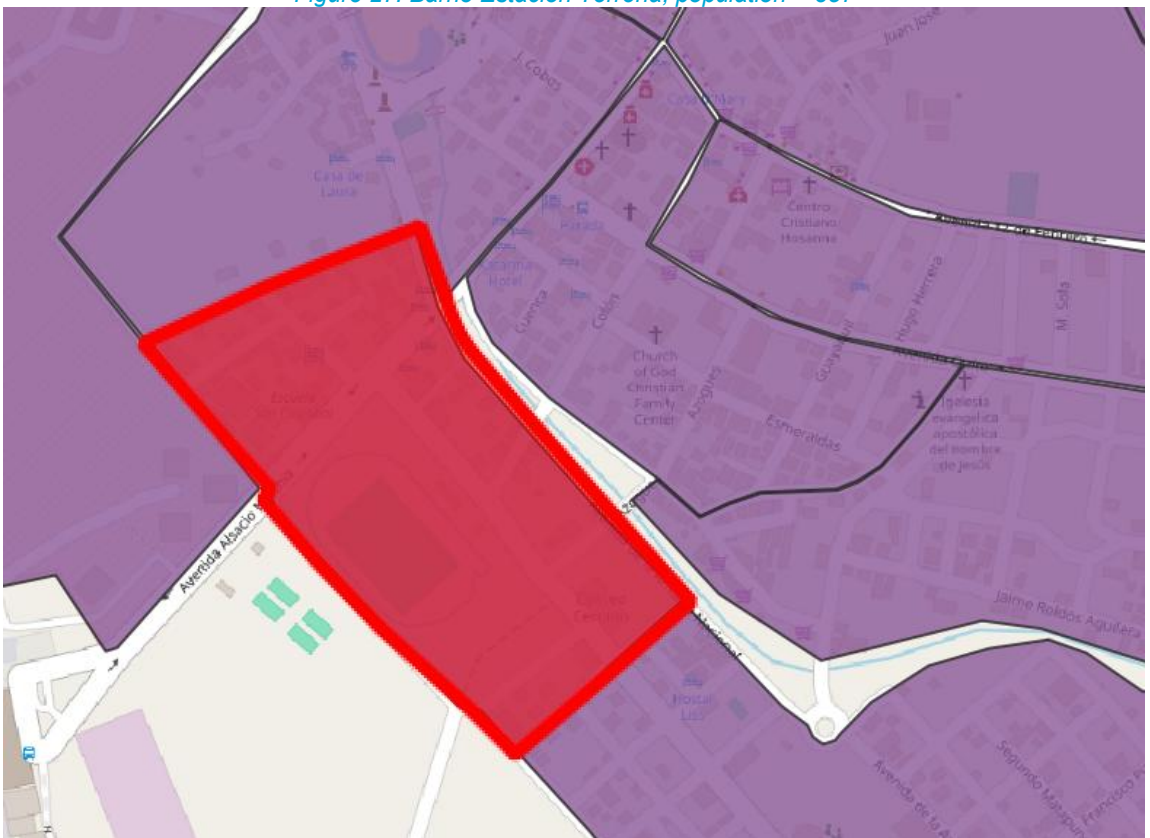


Figure 28: Barrio San Francisco, population = 221

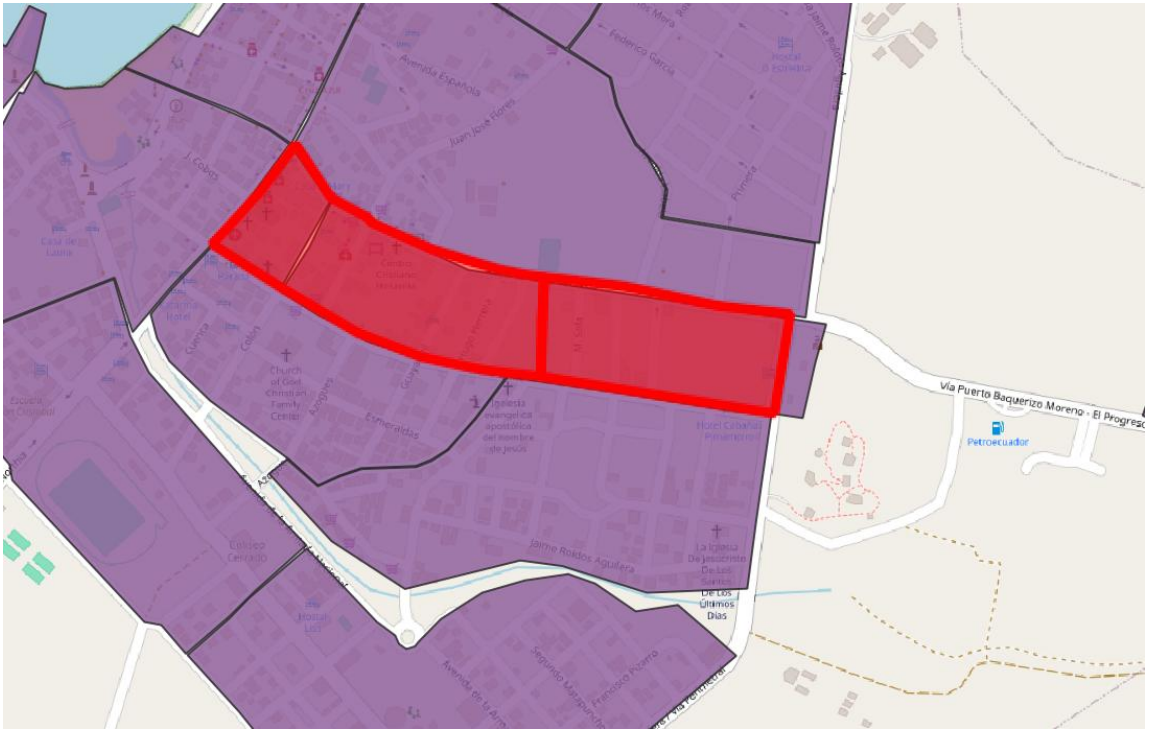


Figure 29: Barrio Albatros, population = 506

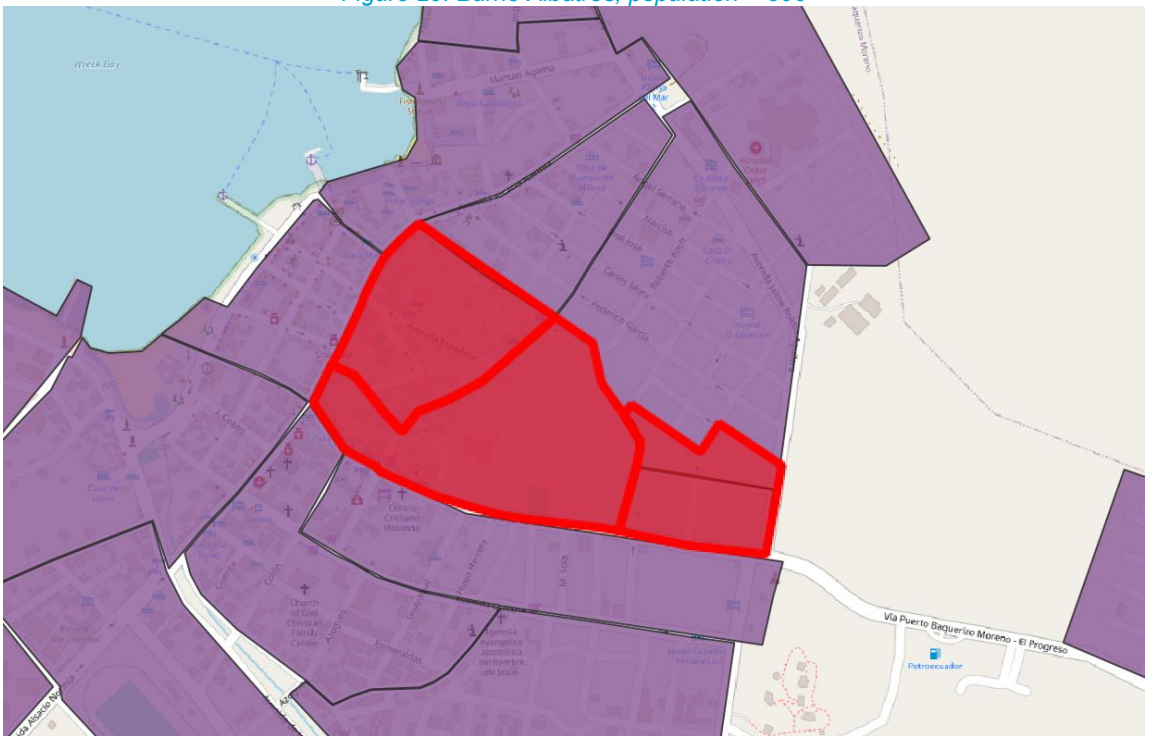


Figure 30: Barrio Cactus, population = 745

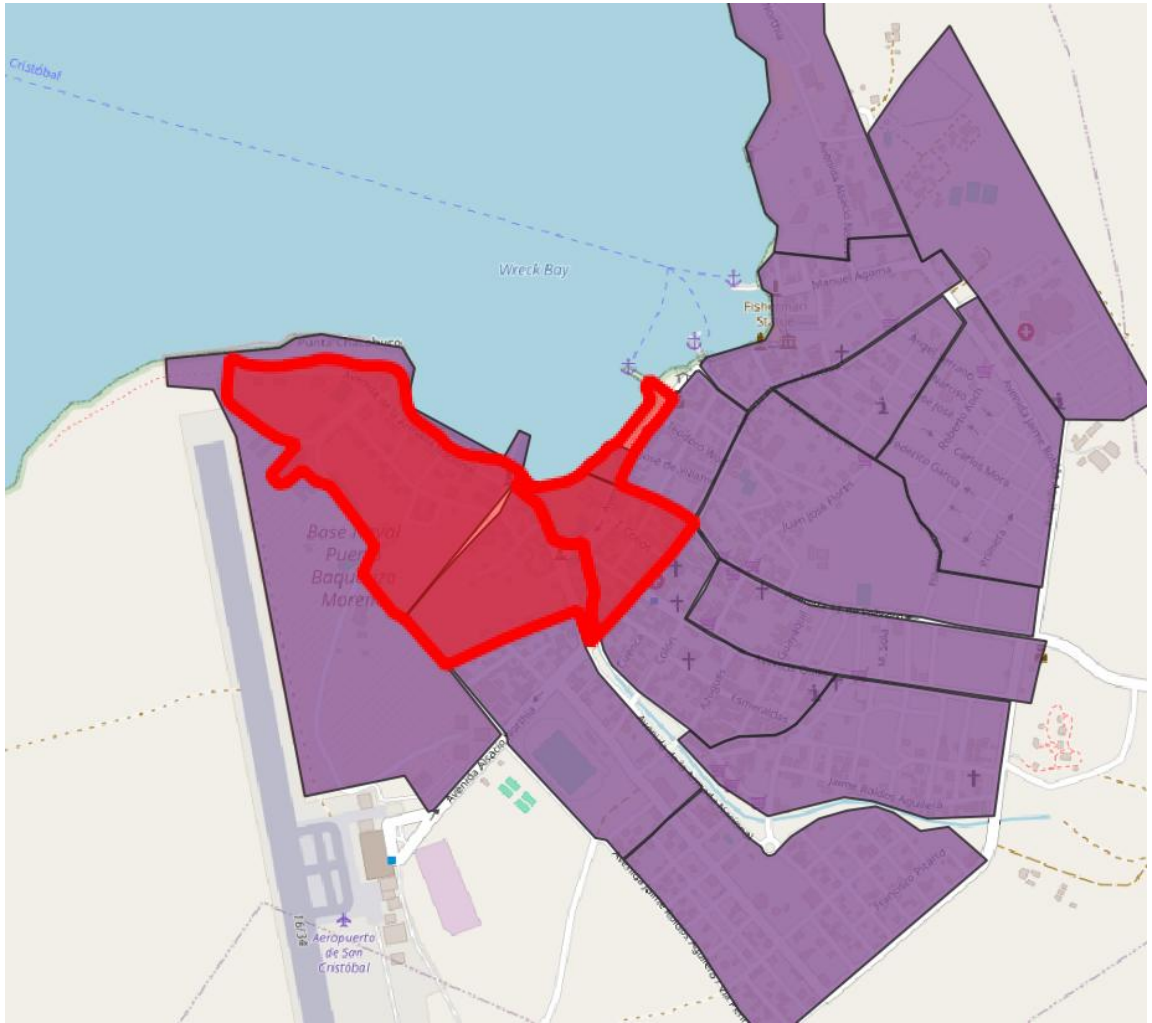


Figure 31: Barrio Frio, population = 374

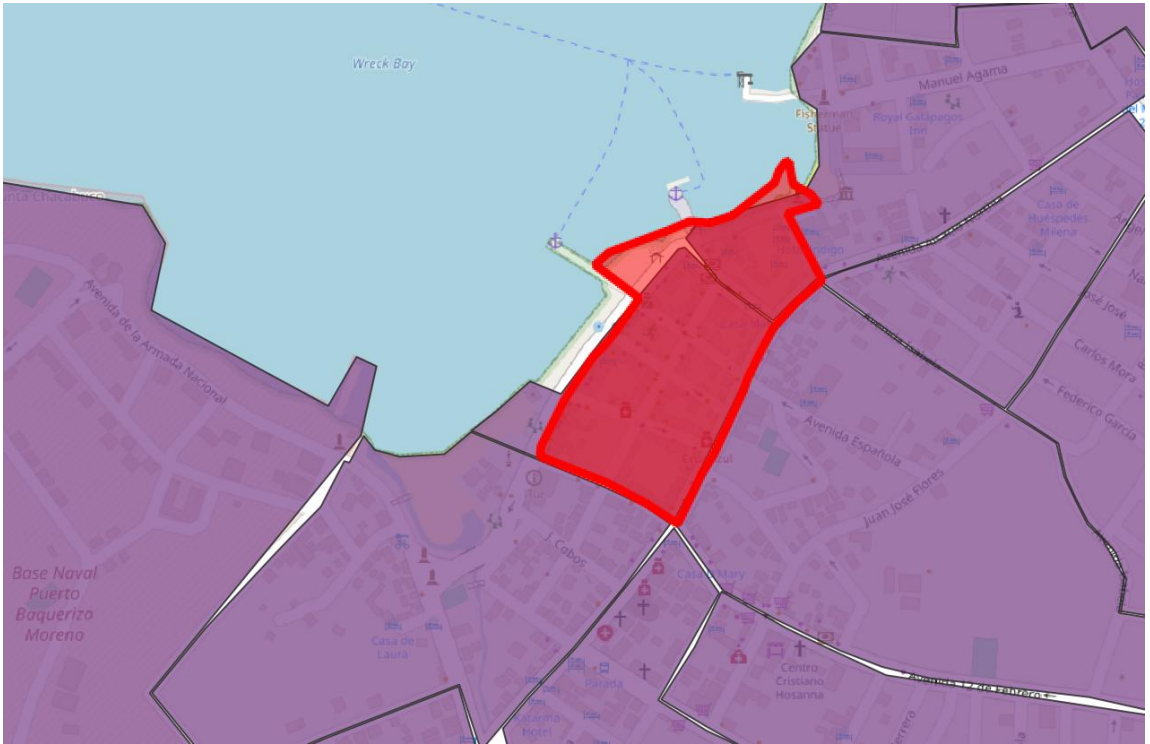


Figure 32: Barrio Central, population = 745

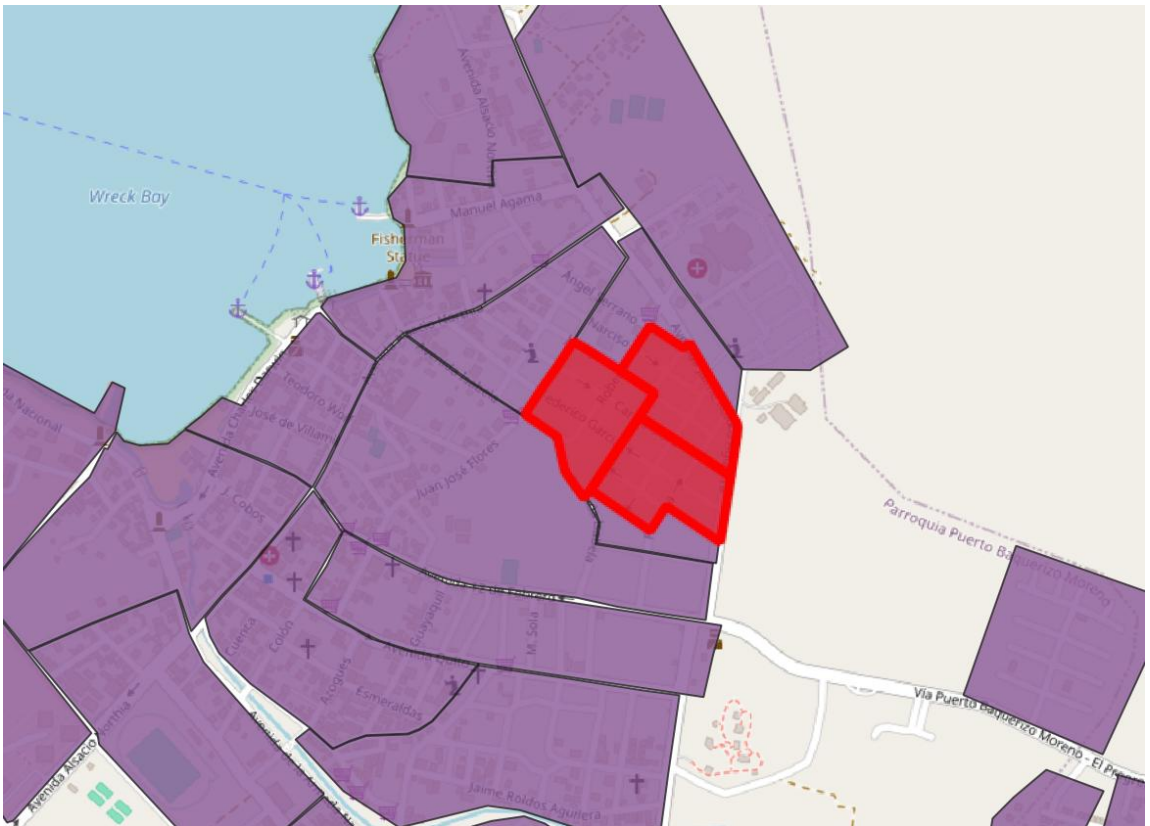


Figure 33: Barrio Peñas Altas, population = 888

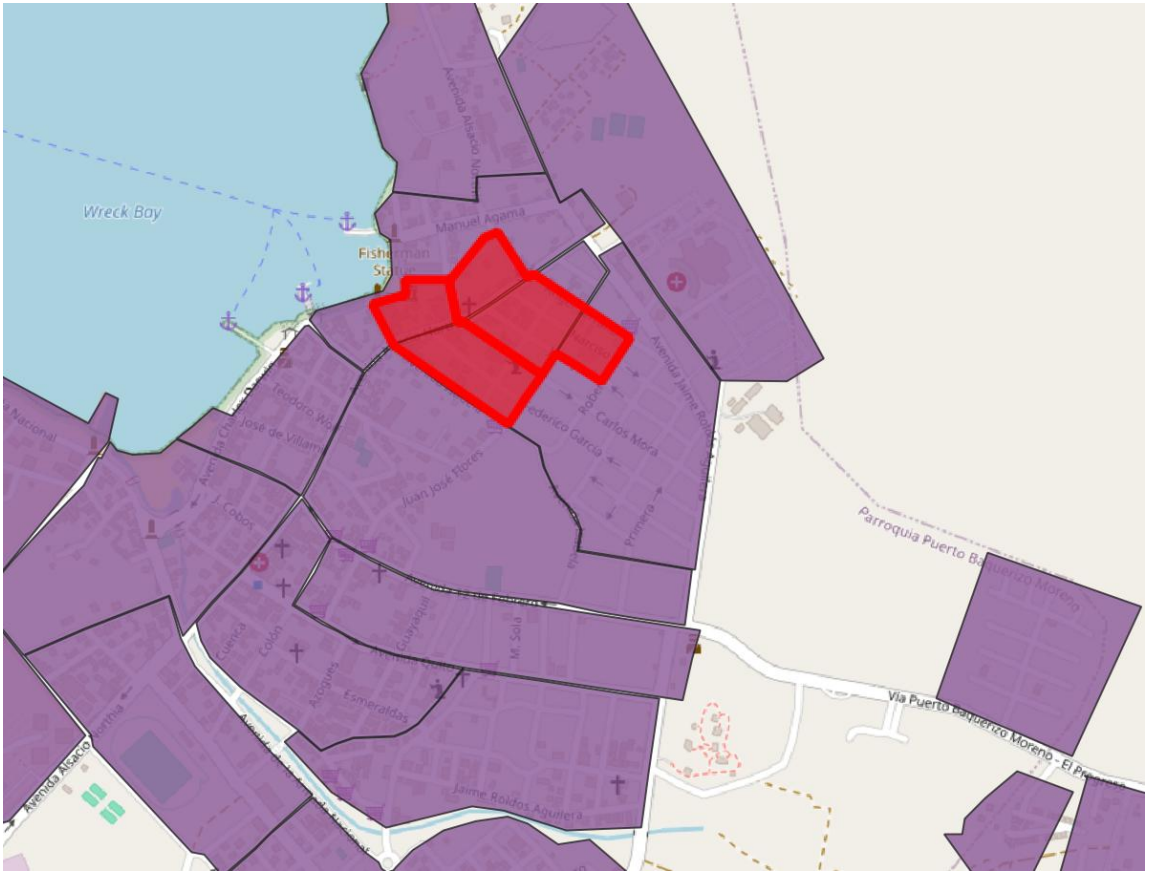


Figure 34: Barrio Peñas Bajas, population = 564

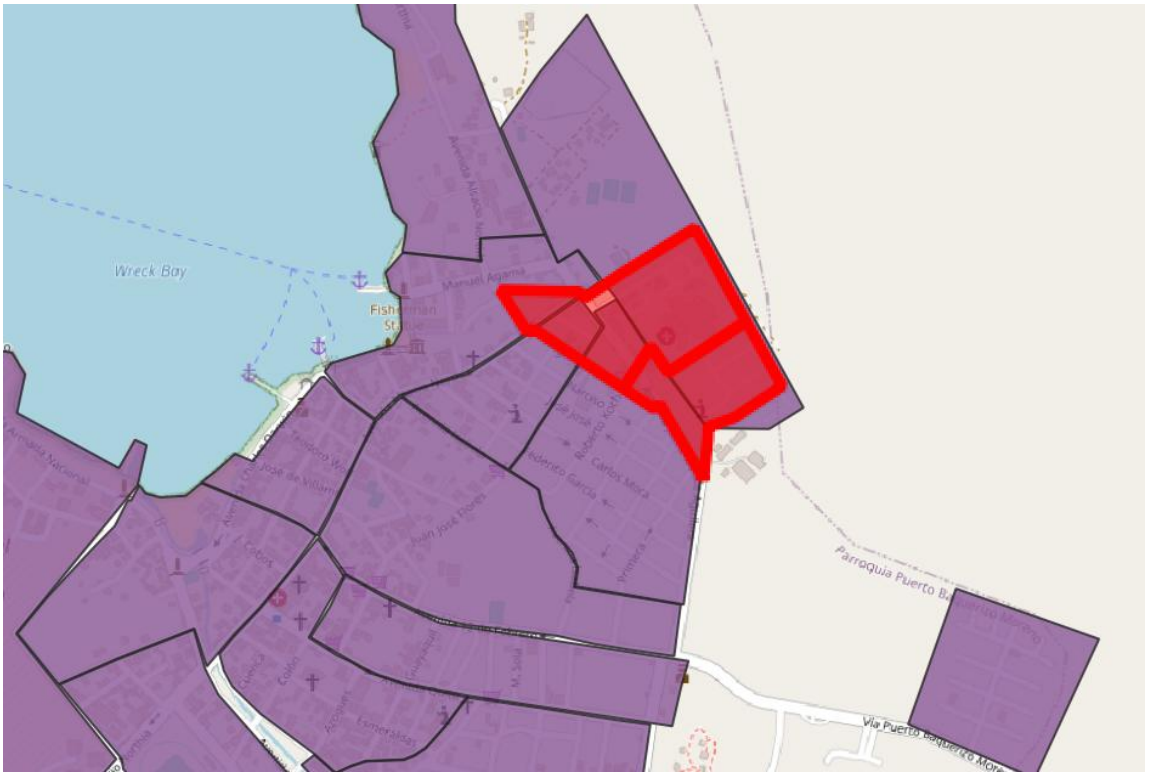


Figure 35: Barrio Divino Niño, population = 513

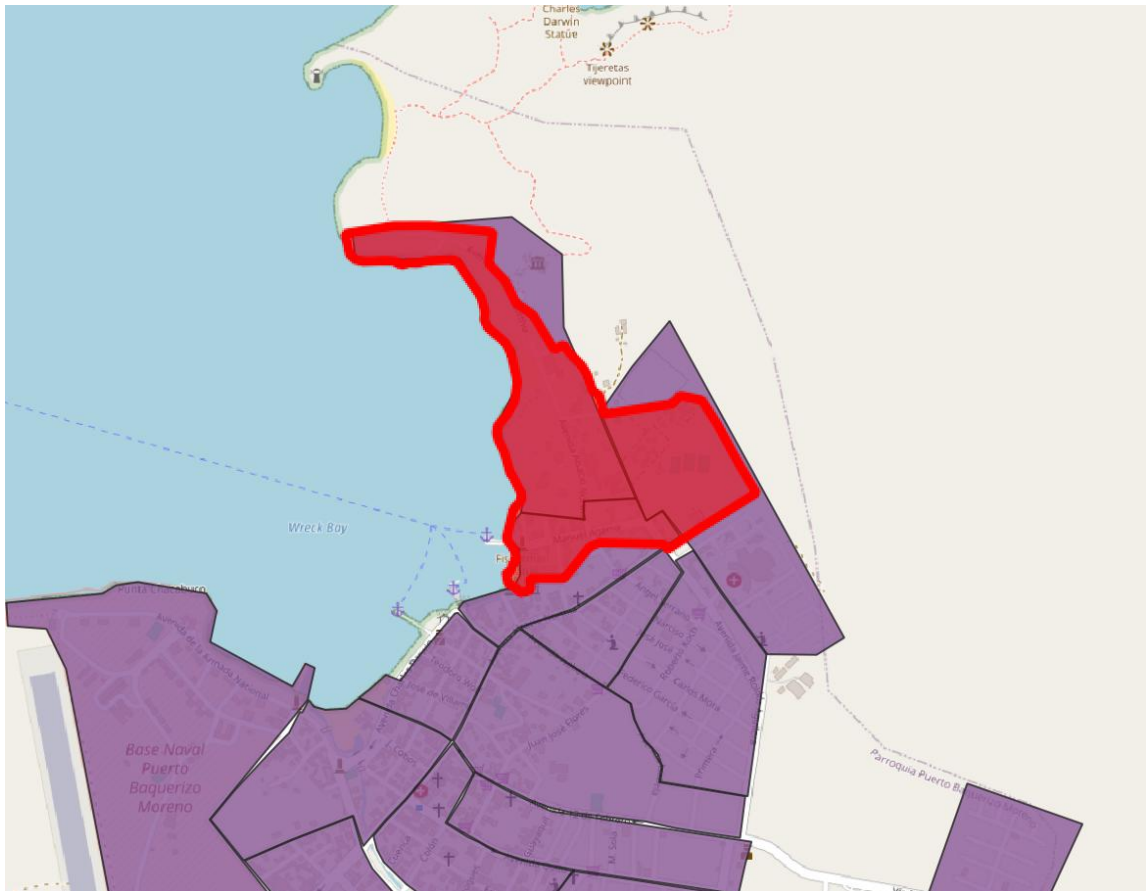


Figure 36: Barrios Playa de Oro, population = 208, and Playa Mann, population = 69

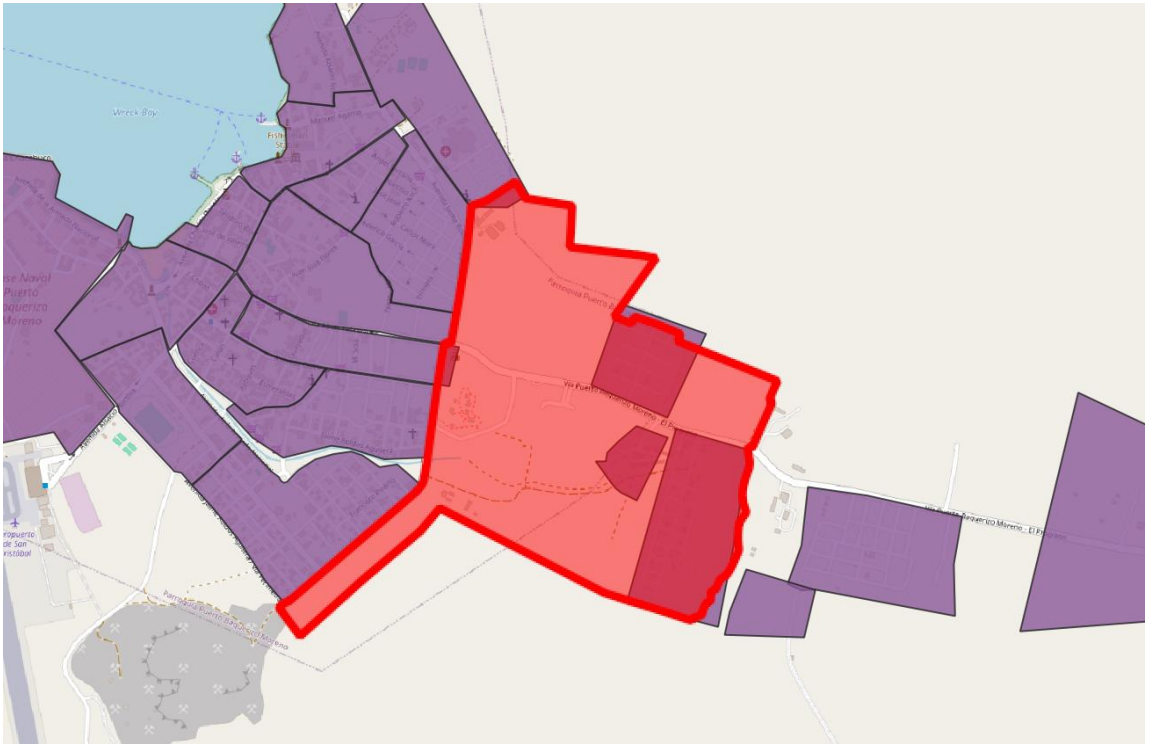


Figure 37: Barrios Gran Maestro, population = 140, Isla Sur, population = 94, and Manzanillo, population = 234

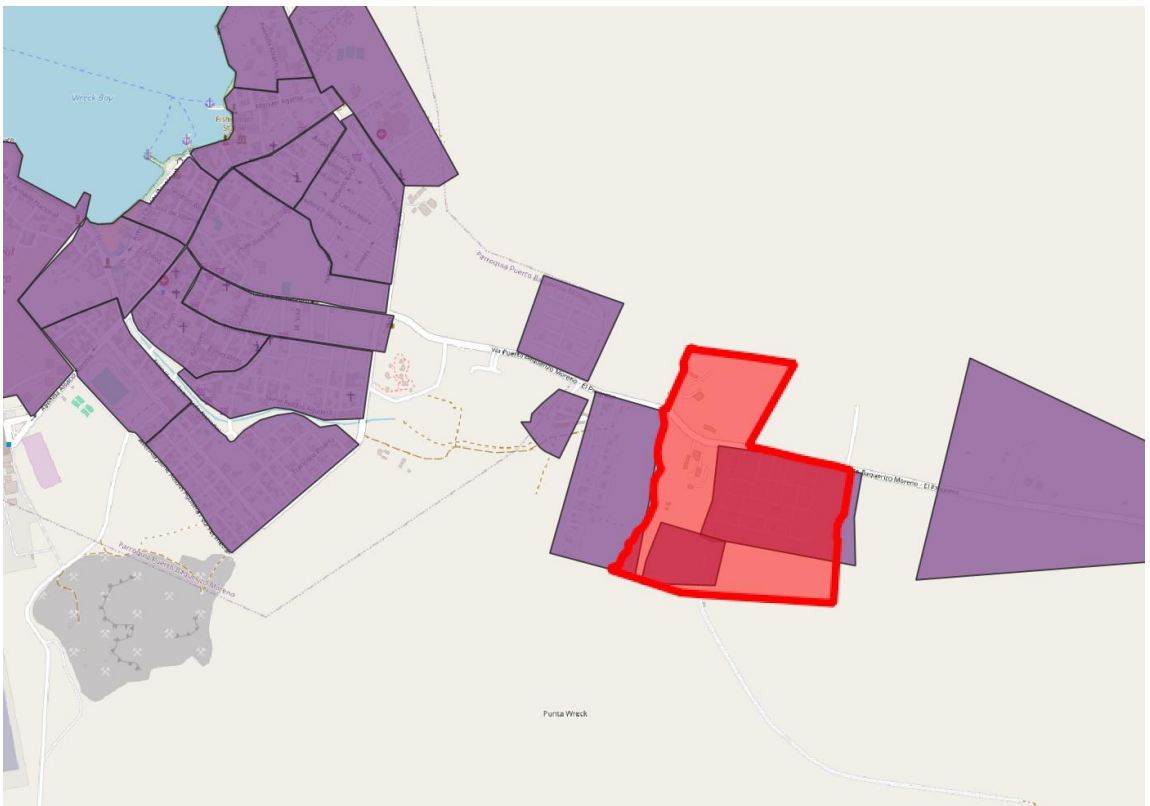


Figure 38: Barrios Arrayanes, population = 30, and Las Palmeras, population = 262

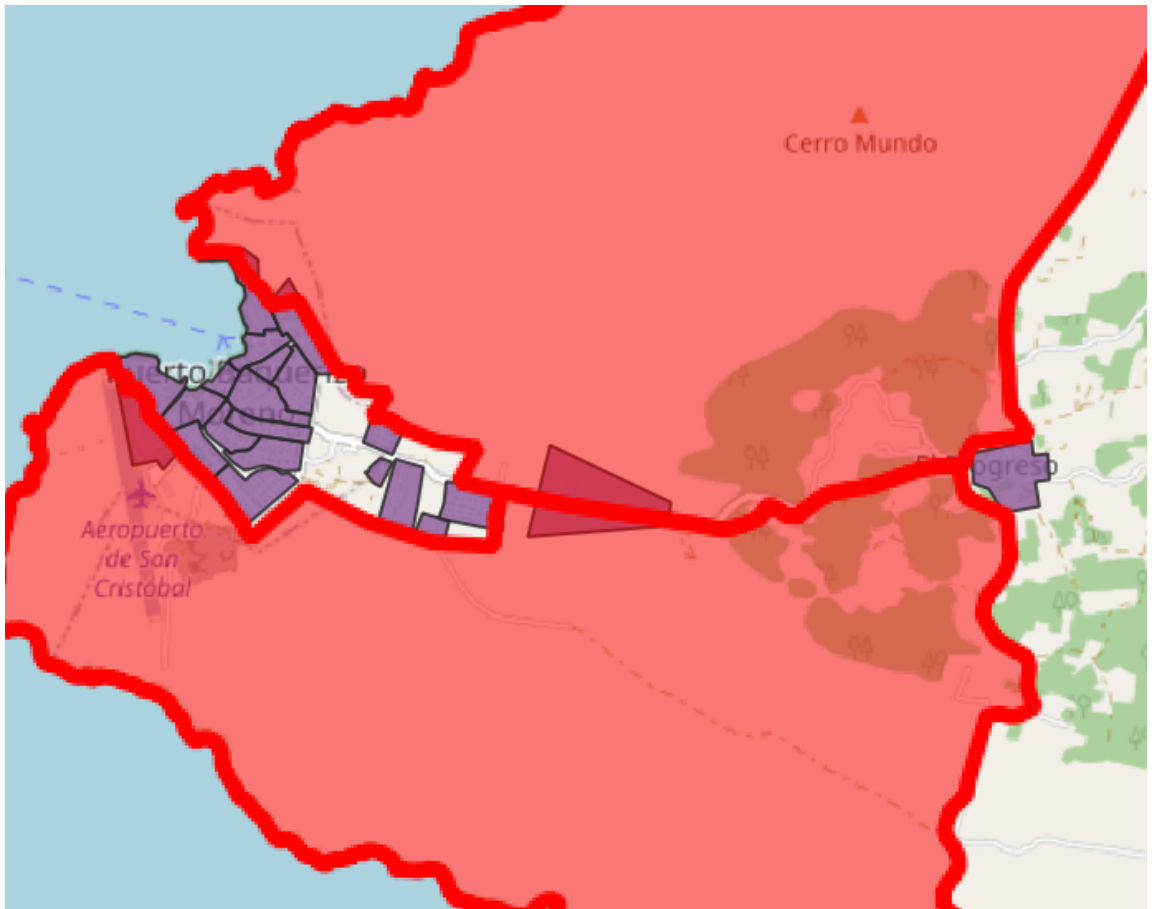


Figure 39: Barrios La Planada, population = 200, and 20% of Cabecera Parroquial El Progreso, population = 133

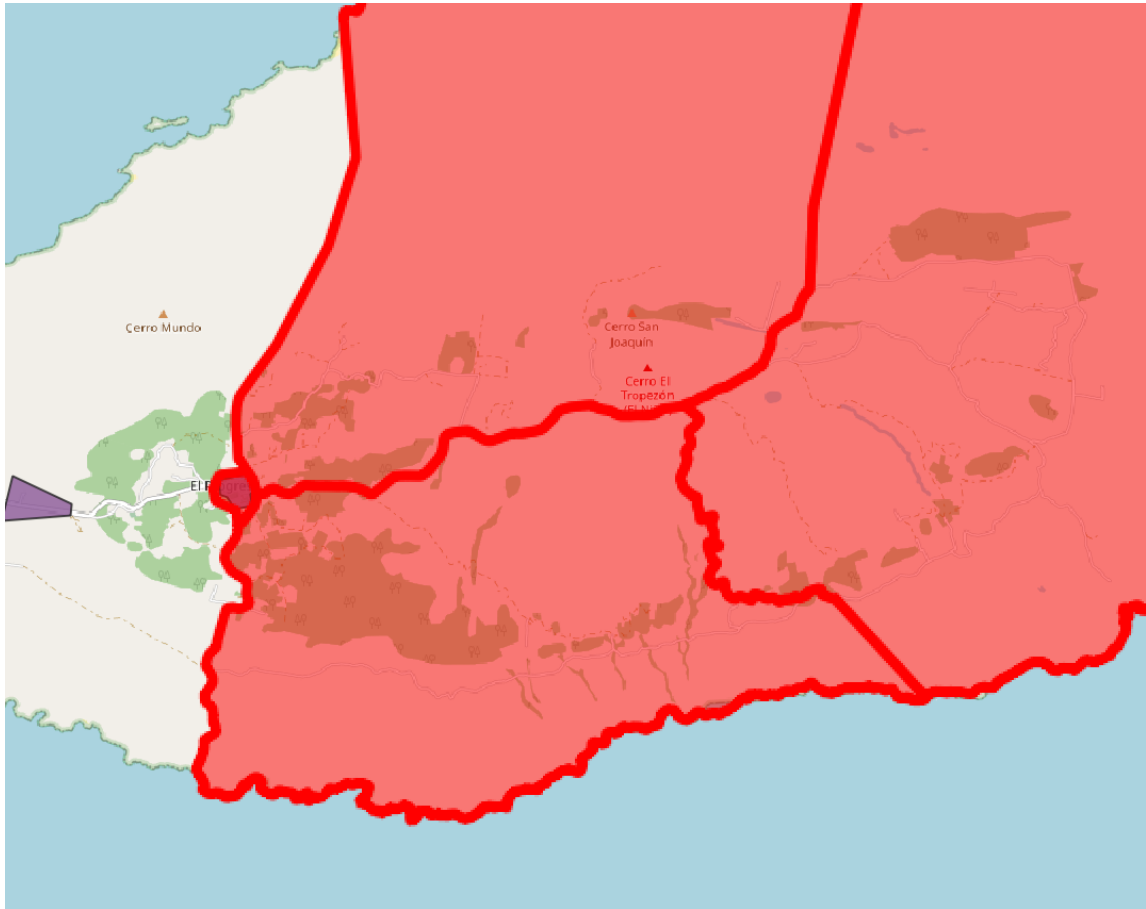


Figure 40: 80% of Cabecera Parroquial El Progreso, population = 534

The resulting estimation of the population per barrio is following:

Table 5: Population estimation for every Neighbourhood

Neighbourhood	Population
Albatros	506
Cactus	745
Algarrobos	742
San Francisco	221
Arrayanes	30
Gran Maestro	140
Isla Sur	94
La Palmeras	262
La Planada	200
Manzanillo	234
Cabecera Parroquial El Progreso	667
Central	253
Divino Niño	513

Neighbourhood	Population
Estación Terrena	857
Fragata	590
Frio	374
Peñas Altas	888
Peñas Bajas	564
Playa de Oro	208
Playa Mann	69
TOTAL	8157

Appendix C: Specification for spatial mapping

C-1 Types of water governance neighbourhood groups

The following table shows how the neighbourhoods were grouped. The grouping was based on spatial proximity, and similarities in neighbourhood characteristics, while aiming to keep the groups as distinct as possible.

Table 6: Grouping of the Neighbourhoods for the Types of water governance map.

Neighbourhood	#Interviews
Albatros	3
Cactus	4
Algarrobos	5
San Francisco	3
Arrayanes	2
Gran Maestro	1
Isla Sur	1
La Palmeras	3
La Planada	2
Manzanillo	2
High part of Puerto Baquerizo Moreno	11
Cabecera Parroquial El Progreso	8
Central	4
Divino Niño	5
Estación Terrena	6
Fragata	4
Frio	5
Peñas Altas	6
Peñas Bajas	4
Playa de Oro	4
Playa Mann	3
Playa de Oro + Playa Mann	7

C-2 Flood Risk neighbourhood groups

To merge neighbourhoods and ensure an acceptable sample size of 10 questionnaire per neighbourhood, two criteria were prioritized:

- the neighbourhoods border each other and have similar anecdotes and topographical altitudes
- had similar individual mean scores for Q7 (only used if $n > 5$)

The results of the grouping are shown in Table 7: Grouping of the neighbourhoods for the perceived and experienced flood-risk layers..

Table 7: Grouping of the neighbourhoods for the perceived and experienced flood-risk layers.

Neighbourhood	#Questionnaire	Mean score Q7
Albatros	9	3.00
Cactus	8	2.88
Albatros + Cactus	17	2.94
Algarrobos	9	4.00
San Francisco	3	4.33
Algarrobos + San Francisco	12	4.08
Arrayanes	3	4.67
Gran Maestro	2	4.00
Isla Sur	1	5.00
La Palmeras	7	2.86
La Planada	2	5.00
Manzanillo	2	3.00
High part of Puerto Baquerizo Moreno	17	3.71
Cabecera Parroquial El Progreso	13	3.38
Central	10	4.00
Divino Niño	12	3.25
Estación Terrena	11	3.20
Fragata	11	3.20
Frio	12	3.83
Peñas Altas	16	3.69
Peñas Bajas	10	3.67
Playa de Oro	7	3.57
Playa Mann	4	3.25
Playa de Oro + Playa Mann	11	3.45

C-3 Formal Governance and Perceived Satisfaction neighbourhoods groups

The following table presents the grouping of neighbourhoods used in the analysis. The grouping was determined based on three main criteria: the number of questionnaires collected, spatial proximity, and the number of municipal projects associated with each area. In practice, this means that where neighbourhoods present a high concentration of projects, these were kept as individual units to allow for a more direct comparison with the satisfaction index.

Table 8: Grouping of the neighbourhoods for the formal governance and perceived satisfaction neighbourhoods

Neighbourhood	#Questionnaire	Satisfaction Index	Number of plans	Plan number
Albatros	9	2.85	0	-
Cactus	8	2.92	0	-
Algarrobos	9	2.71	3	16, 7, 5
Cabecera Parroquial El Progreso	13	3.23	6	4, 6, 9, 12, 13, 15
Central	10	2.65	0	-
Divino Niño	12	2.88	2	3, 5
Fragata	11	3.14	3	5, 7, 16
Frio	12	3.06	5	5, 7, 8, 10, 16
Peñas Altas	16	2.61	0	-
Peñas Bajas	10	2.94	0	-
Estación Terrena	11	3.11	4	3, 7, 8, 16
San Francisco	3	3.29	3	5, 7, 16
Estación Terrena + San Francisco	14	3.15	5	3, 5, 7, 8, 16
Playa de Oro	7	2.49	3	3, 5, 8
Playa Mann	4	2.96	2	5, 8
Arrayanes	3	3.12	2	11, 14
Gran Maestro	2	2.88	2	2, 14
Isla Sur	1	2.00	0	-
La Palmeras	7	2.55	0	-
La Planada	2	2.83	2	4, 14
Manzanillo	2	3.92	1	14
High part of Puerto Baquerizo Moreno	17	2.85	4	2, 4, 11, 14

C-4 List of Municipal Investment Projects

The list of projects that were included in the map is displayed below, separated in 2020-2024 and 2024-2027. (GADMSC, 2024)

Table 9: Municipal investment plans from Plan of Desarrollo 2020-2024.

ID Plans	Plan (2020–2024)	Barrio	Investment
1	Construcción de la red de distribución de agua potable en el sector de Cerro Mundo, El Mango y vía La Soledad	Progreso	\$1.000.000,00
2	Construcción de muro de encauzamiento en el lado posterior a la ciudadela del Gran Maestro	Ciudadela del Gran Maestro	\$55.000,00
3	Construcción de muros de encauzamiento de aguas lluvias en el área urbana del cantón San Cristóbal	Playa de Oro, Divino Niño, Estación Terrena	\$280.000,00
4	Construcción de ducto cajón a la altura del cementerio en la cañada El Papo	La Planada	\$280.000,00
5	Mitigación del riesgo y mantenimiento preventivo (limpieza de cañadas, remoción de maleza y sedimentos)	Fragata, Algarrobos, San Francisco, Frío, Divino Niño, Playa Mann Playa Oro,	\$28.000,00
6	Construcción del ducto tipo alcantarilla “Segunda Etapa” parte baja del cementerio	El Progreso (parte baja del cementerio)	\$250.000,00

Table 10: Municipal investment plans from Plan of Desarrollo 2024-2027

ID	Plan (2024–2027)	Barrio	Investment
7	Plan Integral de Mantenimiento y remediación de la encañada, estuario marino-costero y playa de barrio Frío	Frío (bajo), Estación Terrena, Fragata, Algarrobos, San Francisco	\$250.000,00 (100.000 Frío,
8	Mantenimiento preventivo de la planta de tratamiento de aguas residuales y estaciones de bombeo	Frío, Playa de Oro, Estación Terrena, Playa Mann	\$500.000,00
9	Construcción de la Planta de Tratamiento de Aguas Residuales para la parroquia El Progreso	El Progreso	\$1.000.000,00
10	Construcción de un tanque de reserva de agua potable para el parque artesanal de San Cristóbal	Frío	\$200.000,00
11	Construcción de la línea de conducción principal de agua potable en los barrios Arrayanes y calle Guido Cobos	Arrayanes, calle Guido Cobos	\$95.552,00
12	Construcción de la red de distribución de agua potable en el sector Rural	El Progreso	\$150.000,00

ID	Plan (2024–2027)	Barrio	Investment
13	Cambio de tubería de conducción de agua en sectores aledaños de la Parroquia El Progreso	El Progreso	\$150.000,00
14	Consultoría para la ampliación del plan maestro de agua potable, alcantarillado sanitario y pluvial de los nuevos barrios de Puerto Baquerizo Moreno y la parroquia isla Santa María y El Progreso	El Progreso, Arrayanes, La Planada, manzanillo, GM.	\$50.000,00
15	Ejecución y construcción de los sistemas de alcantarillado de las parroquias de El Progreso y Santa María	El Progreso	\$2.500.000,00
16	Recuperación de la encañada del barrio Frío e implementación de un parque lineal	Frío, ET, FG, AG, SF	\$200.000,00

C-5 Specification for the spatial representation of projects in the investment plan layer

Marker sizes

Every project listed in Table 9 and Table 10 was represented in the *Formal Governance and Perceived Satisfaction* map layer as a point feature, whose size is proportional to the total investment amount. In this way, projects with larger budgets visually occupy a wider area on the map, symbolizing a broader potential spatial impact. The underlying idea is that the area covered by each symbol approximates the zone of influence or the territory likely affected by the corresponding investment.

Since the investment values vary greatly, from as little as USD 4,000 to several million, a direct linear scaling would have produced extreme size differences, making smaller projects nearly invisible and larger ones disproportionately dominant. To mitigate this effect, a non-linear transformation was applied in QGIS using the following formula:

$$\text{Size} = 2 + \frac{(\text{Investment})^{0.2}}{300}$$

This function applies a power transformation (raising the investment value to the power of 0.2) to compress the range of symbol sizes while preserving relative differences between projects. The constant “2” ensures that all symbols remain visible, while the divisor “300” controls the overall scaling of the points on the map.

Both parameters, the exponent (0.2) and the scaling factor (300), were manually adjusted through an iterative visual process to achieve a clear and balanced representation, ensuring that all projects are visible and comparable without overwhelming the spatial context.

Projects covering the entire city

Projects covering the entire city were excluded from the neighbourhood-level spatial analysis to maintain focus on geographically distinct interventions. These city-wide projects are listed in Table 11: Non-neighbourhood-specific projects.

Table 11: Non-neighbourhood-specific projects

Project	Objectives	Goal	Location	Collaboration	Budget (USD)	Source of Funding	Implementation Period
Strengthening of the Drinking Water Department	To reinforce the institutional capacity of the Drinking Water Department.	Hire a technical specialist for the Drinking Water Department for the period 2020–2024.	San Cristóbal	BDE (Development Bank of Ecuador)	500,000	Municipal GAD of San Cristóbal	2020–2024
Upgrading and Maintenance of the Water Treatment Plants of San Cristóbal	To upgrade and maintain the city's water treatment plants.	By 2024, 60% of San Cristóbal's population will benefit from access to quality drinking water.	San Cristóbal	Parish GADs, PNG (Galápagos National Park)	300,000	Municipal GAD of San Cristóbal	2020–2024
Construction of Channeling Walls in High-Risk Areas	To build channeling walls in zones exposed to natural hazards.	By 2024, five channeling walls will be constructed in areas vulnerable to natural risks caused by increased water flow through ravines.	San Cristóbal	SNGR (National Secretariat for Risk Management)	500,000	Municipal GAD of San Cristóbal	2020

Projects that appear in both development plans

Table 12: Projects which appear in both Plan Desarrollo 2020-2024 and 2024-2027 lists the projects that appear in both development plans. For these projects, the investment amounts were summed: when a project name is repeated, it indicates that the project remains unfinished and requires additional investment (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025).

Table 12: Projects which appear in both Plan Desarrollo 2020-2024 and 2024-2027

Project	Budget (USD)
Construction of the main potable water supply line in the Arrayanes and Guido Cobos neighbourhoods	45,552 (2020–2024) and 50,000 (2024–2027)
Replacement of water supply pipelines in areas surrounding El Progreso	90,000 (2020–2024) and 150,000 (2024–2027)

Projects that involve multiple neighbourhoods

For projects involving multiple neighbourhoods (projects 3, 5, 7, 8, 14, and 16 in Table 10), the total investment amount was generally divided equally among the affected areas. This proportional allocation was confirmed as appropriate by a representative of the municipal administration for the purposes of this research and for the qualitative layer being developed.

However, when a project explicitly indicated a stronger focus on a particular neighbourhood, a larger share of the investment was assigned to that area. For instance, in the case of project 7 (Table 10), an amount of USD 100,000 was allocated to Frío, while the remaining funds were evenly distributed among the neighbourhoods traversed by the canal, Estación Terrena, Fragata, Algarrobos, and San Francisco (*Técnico de La Unidad de Gestión de Riesgos*, personal communication, October 2025).

C-6 Participatory Weighting Method for the Dimensions of the Overall Satisfaction Index

Weights were defined using a pairwise comparison approach, a method widely recognized in decision-making research involving multiple criteria. This approach was selected because it is simple, transparent, and accessible for community members, ensuring genuine participation in every step of the project (Gang Kou, 2016).

Four individuals, selected from among the previously surveyed participants familiar with the study, were asked to compare the relative importance of each satisfaction dimension in the context of water infrastructure. During the conversation, the pairwise comparison table was completed reflecting their point of view. This participatory approach aligns with the objective of the study, to generate knowledge from the community and for the community.

It is important to acknowledge, however, the methodological limitations of this process. With only four respondents, the resulting weights may not fully capture the diversity of stakeholder perspectives, increasing the potential for bias, individual subjectivity, and reduced reliability of the results.

Weights were calculated for each table by summing the scores in each row and dividing each value by the total sum of all row sums, ensuring that the resulting weights sum to 1. The final weights were obtained by averaging the individual weights across all four participants (Table 17: Relative weights of satisfaction dimensions derived from the participatory weighting method, following a standard aggregation method (Krejčí & Stoklasa, 2018)). Nonetheless, this weighted arithmetic averaging

method introduces further constraints: it can be sensitive to outliers among decision-makers, dependent on the chosen normalisation procedure, and may at times distort the relative importance expressed in the original pairwise comparisons.

Table 13: Pairwise comparison matrix, participant 1.

Criteria	Efficiencia	Confiabilidad	Participacion	Comunicacion	Weights
Efficiencia	0.5	1	1	1	0.4375
Confiabilidad	0	0.5	1	1	0.3125
Participacion	0	0	0.5	1	0.1875
Comunicacion	0	0	0	0.5	0.0625

Table 14: Pairwise comparison matrix, participant 2.

Criteria	Efficiencia	Confiabilidad	Participacion	Comunicacion	Weights
Efficiencia	0.5	0	0	0	0.0625
Confiabilidad	1	0.5	1	1	0.4375
Participacion	1	0	0.5	0	0.1875
Comunicacion	1	0	1	0.5	0.3125

Table 15: Pairwise comparison matrix, participant 3.

Criteria	Efficiencia	Confiabilidad	Participacion	Comunicacion	Weights
Efficiencia	0.5	1	1	1	0.4375
Confiabilidad	0	0.5	1	1	0.3125
Participacion	0	0	0.5	0	0.0625
Comunicacion	0	0	1	0.5	0.1875

Table 16: Pairwise comparison matrix, participant 4.

Criteria	Efficiencia	Confiabilidad	Participacion	Comunicacion	Weights
Efficiencia	0.5	0	0	1	0.1875
Confiabilidad	1	0.5	0	1	0.3125
Participacion	1	1	0.5	0	0.3125
Comunicacion	0	0	1	0.5	0.1875

Table 17: Relative weights of satisfaction dimensions derived from the participatory weighting method

Dimension	Weight (%)
Reliability	34.38%
Efficiency	28.13%
Participation	18.75%
Communication	18.75%

This participatory approach helps ensure that the resulting satisfaction index reflects the community's own priorities rather than externally imposed assumptions. However, the pairwise comparison method presents certain inherent limitations. By design, it constrains the possible range of criterion weights: both minimum and maximum values are bounded by the structural parameters of the method. As a result, even when a criterion is substantially more (or less) important in practice, this difference may not be fully captured in the final weighting.

Appendix D: Social economic vulnerability indicators

D-1 Standard of Living Indicator

The Standard of Living indicator combines two observable sub-components assessed at both the household and street levels:

- Building Aesthetic Condition
- Quality of Road Infrastructure

Field observation served as the principal data collection method. Researchers systematically walked through each neighbourhood, recording visual notes and photographs while collectively discussing classifications to maintain inter-observer consistency. Each sub-indicator was evaluated using a five-point qualitative scale from “low” to “high”, where “low” represents the poorest condition observed and “high” the best. The classification categories were defined inductively, emerging from real conditions encountered in the field.

This direct, observation-based approach captures socio-economic differences through visible and tangible aspects of everyday life, such as the condition of buildings, roads, and surrounding infrastructure, which often reflect access to financial resources, public services, and maintenance capacity (Pradhan & Agrawal, 2025). A five-point qualitative scale was applied to enhance comparability and sensitivity, allowing for meaningful differentiation between neighbourhoods where variation was observed. The scale was therefore designed not to imply large disparities, but to support a systematic exploration of relative living conditions across the city.

The methodological choice was reviewed and approved by our client, who recommended this observation-based, relative scaling approach as the most appropriate means of representing socio-economic diversity in the local context.

Scoring System

(i) Building Aesthetic Condition

This sub-indicator captures the visible state of maintenance, aesthetic appearance of residential and mixed-use buildings. It serves as a proxy for household investment capacity, tenure stability, and general neighbourhood upkeep. The scoring was based on direct field observation, using the following qualitative categories:

Table 18: Qualitative 5 points scale to assess the Building Aesthetic Condition indicator

Score	Category neighbourhoods	Description observations
0) Low	Deteriorated area	Almost all of the buildings show clear signs of physical decay (cracked walls, damaged roofs, peeling paint), poorly maintained; missing walls, with occasional missing elements

Score	Category neighbourhoods	Description observations
		(walls, windows) and signs of makeshift or outdoor facilities (e.g., outdoor kitchens)
0.25) Low-mid	Undermaintained area	Majority of the buildings appear irregularly maintained; There is visible wear and outdated materials, the general impression is of low maintenance and limited resources for upkeep.
0.5) Mid	Moderately maintained	Buildings are structurally sound with moderate upkeep; maintenance appears occasional rather than systematic; surroundings generally clean but lack signs of consistent care or recent improvement.
0.75) Mid-high	Regularly maintained / well kept	Most buildings are in good repair, showing evidence of routine maintenance and attention. Paint, roofs, and facades are in decent condition, clean surroundings are common.
1) High	Highly maintained / luxurious area	Buildings appear recently built or renovated, with no visible deterioration. Façades and roofs are intact, and aesthetic and design features (landscaping, signage, decorative elements) reflect active investment and higher material well-being

(ii) Road Condition

This sub-indicator assesses the physical state and accessibility of local road networks, which directly influence mobility, safety, and neighbourhood connectivity. Conditions were evaluated based on pavement quality and pedestrian infrastructure:

Table 19: Qualitative 5 points scale to assess the Road Condition Indicator

Score	Category neighbourhood	Description observations
0) Low	Unserviced network	The majority of roads are unpaved, uneven, and full of potholes. There are no sidewalks, and access is difficult for both vehicles and pedestrians. Main roads become unusable during the rainy season each year
0.25) Low-mid	Low accessibility	Paved segments are fewer than unpaved ones. Road quality is low, with significant wear and frequent potholes. Most roads lack sidewalks, or existing ones are narrow, obstructed, or damaged. Some roads become unusual during rain events.
0.5) Mid	Partially improved network	The majority of roads are paved and include sidewalks, though sidewalk quality is limited (narrow, obstructed, or with holes). Visible wear and cracking are common
0.75) Mid-high	Maintained but imperfect network	Roads are paved and largely functional. Sidewalks are present but vary in width and condition across segments, with occasional cracks or uneven surfaces

Score	Category neighbourhood	Description observations
1) High	Fully serviced network	All roads are fully paved, clean, and well-maintained. Sidewalks are in very good conditions: continuous and wide,

Figure 41 illustrates a typical house commonly found across the neighbourhoods of Frío, corresponding to the “high” category described in Table 18: Qualitative 5 points scale to assess the Building Aesthetic Condition indicator. In contrast, the presence of houses and buildings such as the one shown in Figure 42: picture of a typical house in Estacion Terrena led to the evaluation of Estación Terrena as “low” category in Table 18: Qualitative 5 points scale to assess the Building Aesthetic Condition indicator. Neighbourhoods falling between these two extremes were assessed based on the relative presence of structures similar to those shown in Figure 41, Figure 42: picture of a typical house in Estacion Terrena, following the five-point scale defined in Table 18: Qualitative 5 points scale to assess the Building Aesthetic Condition indicator. For instance, Figure Z presents a representative building in the neighbourhood of Albatros, which received a “mid” score on the scale. The same procedure and logic were applied when evaluating the sub-indicator for road quality conditions.



Figure 41: picture of a typical house in Frío



Figure 42: picture of a typical house in Estacion Terrena



Figure 43: picture of a typical house in Albatross.

Scores assigned

Table 20: Scores for each neighbourhood for the Building Aesthetic Condition and Road Condition Indicator

Neighbourhood	Building Aesthetic Condition	Quality of Road Infrastructure
Algarrobos	0.5	0.5
Playa de Oro	1.0	1.0

Neighbourhood	Building Aesthetic Condition	Quality of Road Infrastructure
San Francisco	0.75	0.25
Frío	1.0	0.75
Peñas Altas	0.5	0.75
Peñas Bajas	0.75	0.75
Divino Niño	0.0	0.5
Manzanillo	0.5	0.25
Las Palmeras	0.5	0.25
Cactus	0.75	0.5
Albatros	0.5	0.5
Fragata	0.5	0.5
Estación Terrena	0.0	0.5
Central	1.0	1.0
Playa Mann	0.75	0.75
El Progreso	0.25	0.25
La Planada	0.5	0.25
Arrayanes	0.75	0.0
Isla Sur	0.25	0.0
Gran Maestro	0.75	0.5

D-2 Community Infrastructure Indicator

The Community Infrastructure indicator measures the availability and diversity of public facilities that enhance collective well-being and social resilience. These spaces are recognized as anchors of community life (McShane & Coffey, 2022), promoting interaction, access to services, and local cohesion, all of which contribute to lower socio-economic vulnerability.

Table 1.4.8 of Plan de Desarrollo 2020–2024 assess the presence of the different community infrastructure categories. Neighbourhoods were assigned one point for each facility present. To account for the different sizes of the neighbourhoods, the raw scores for community infrastructure were by divided by the population size determined in B-2 Population estimation.

This adjustment prevents small neighbourhoods with few facilities from being disproportionately penalized; however, it may also lower the scores of larger neighbourhoods that, despite hosting numerous facilities, serve higher populations. This limitation should be taken into account when interpreting the resulting map.

The resulting values were then standardized using min–max normalization, rescaling all scores to a 0–1 range to allow comparability with other indicators (Savelberg et al., 2025).

To avoid unfairly penalizing very small neighbourhoods which naturally have fewer facilities, like Arrayanes with roughly 20 residents, a minimum baseline score of 0.2 was applied. This adjustment

preserves the proportionality between neighbourhoods' size and service provision, acknowledging scale limitations while still reflecting meaningful differences in infrastructure availability.

Table 21: Community infrastructure (Plan of Desarrollo 2020-2024) and score by neighbourhood

Neighbourhood	Schools & Educational Centres	Sports Facilities	Parks & Green Spaces	Community Centre	Score	Standard Score
Peñas Bajas	No	Yes	Yes	No	2	0,17191
Central	Yes	Yes	Yes	Yes	4	1
Divino Niño	Yes	Yes	No	Yes	3	0,32734
Playa Mann	Yes	No	No	No	1	0,91104
Barrio Frío	Yes	Yes	Yes	Yes	4	0,65463
Playa de Oro	No	No	Yes	No	1	0,2571
San Francisco	Yes	Yes	Yes	No	3	0,84905
Estación Terrena	No	Yes	Yes	No	2	0,09005
Algarrobos	No	No	Yes	No	1	0,02348
Fragata	No	No	Yes	No	1	0,04692
Manzanillo	No	No	Yes	No	1	0,22103
Albatros	No	No	Yes	No	1	0,06592
Palmeras	No	No	Yes	No	1	0,19019
Cactus	Yes	No	Yes	Yes	3	0,20437
Peñas Altas	No	No	Yes	Yes	2	0,08455
Arrayanes	No	No	No	No	0	0,38262
Sector La Planada	No	No	No	No	0	0
Ciudadela del Maestro	No	No	Yes	No	1	0,41477
El Progreso	Yes	Yes	Yes	Yes	4	0,3374
Isla Sur	No	No	No	No	0	0,07614

D-3 Integration of Indicator and Visualisation

The calculation and integration of the indicators followed the INFORM methodology, which adopts a hierarchical structure for composite indices (Savelberg et al., 2025). In this framework, all indicators are first standardized to a 0–1 scale to ensure comparability. Subsequently, indicators within the same dimension are equally weighted, so that each contributes proportionally to the final composite index (Figure 44).

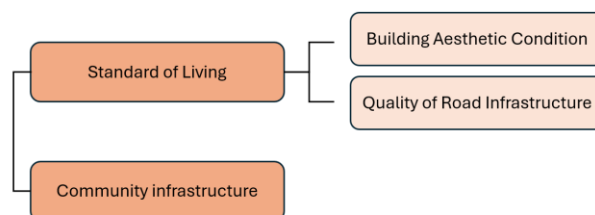


Figure 44: Hierarchical structure of indicators to determine socio-economic vulnerability map.

For the Standard of Living indicator, the two sub-indicators, Building Aesthetic Condition and Road Quality, were averaged to produce a single score representing material well-being at the neighbourhood level. The resulting values are presented in Table 22.

Table 22: Calculation of the Standard of Living Indicator by averaging the scores of the two sub-indicators.

Neighbourhood	Building Aesthetic Condition	Quality of Road Infrastructure	Standard of Living
Algarrobos	0.5	0.5	0.5
Playa de Oro	1.0	1.0	1.0
San Francisco	0.75	0.25	0.5
Frío	1.0	0.75	0.875
Peñas Altas	0.5	0.75	0.625
Peñas Bajas	0.75	0.75	0.75
Divino Niño	0.0	0.5	0.25
Manzanillo	0.5	0.25	0.375
Las Palmeras	0.5	0.25	0.375
Cactus	0.75	0.5	0.625
Albatros	0.5	0.5	0.5
Fragata	0.5	0.5	0.5
Estación Terrena	0.0	0.5	0.25
Central	1.0	1.0	1.0
Playa Mann	0.75	0.75	0.75
El Progreso	0.25	0.25	0.25
La Planada	0.5	0.25	0.25
Arrayanes	0.75	0.0	0.375
Isla Sur	0.25	0.0	0.125
Gran Maestro	0.75	0.5	0.625

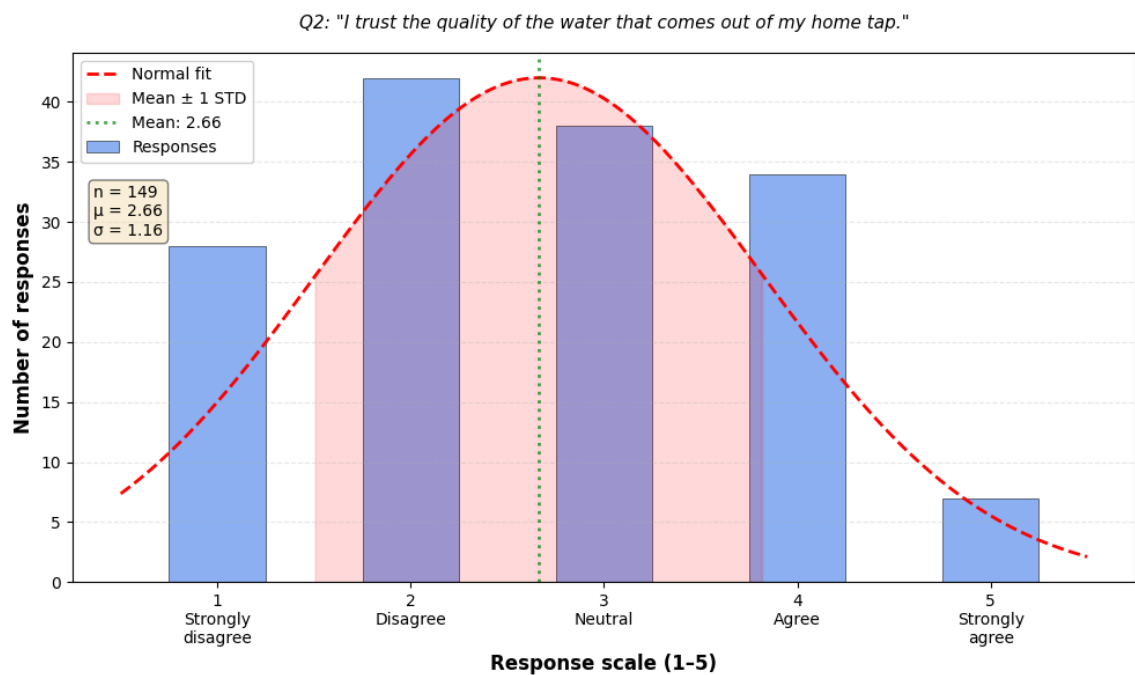
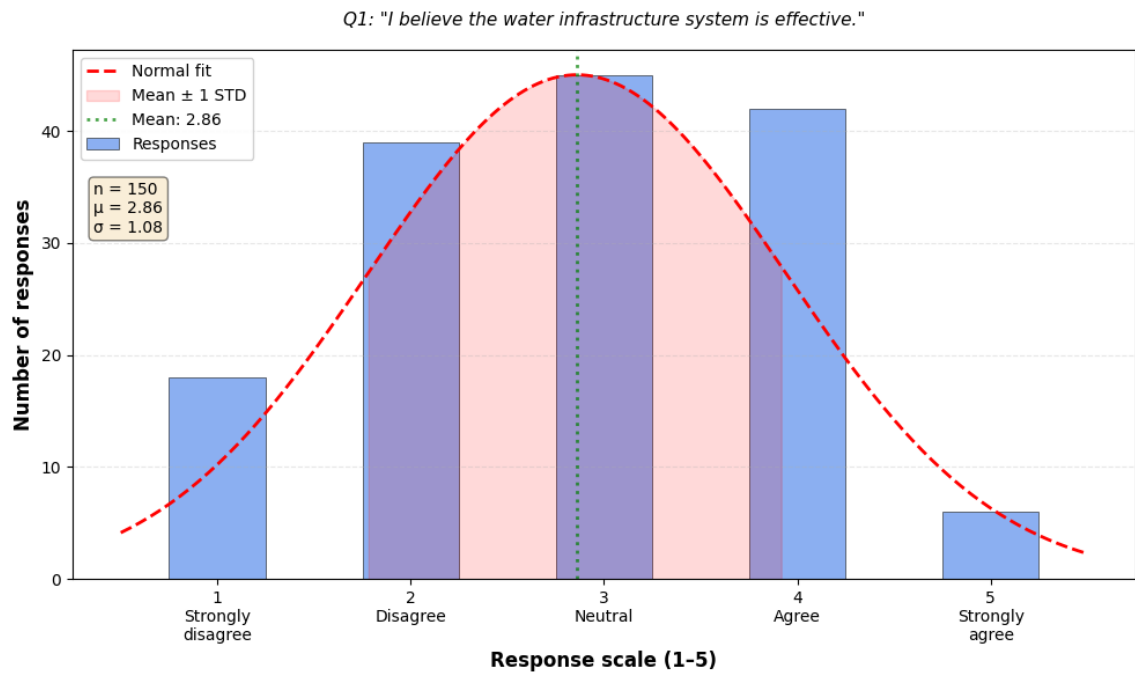
To integrate the two main dimensions, Standard of Living and Community Infrastructure, an overlay analysis was performed in QGIS (Schürmann et al., 2024). Both indicators were assigned equal weights (50%), consistent with the INFORM framework. In the visualization, this weighting was expressed through a 50% transparency level, enabling both individual and combined observation of the layers.

The final composite map employs a red colour gradient, where darker tones represent higher relative socio-economic vulnerability. This dual visualization approach allows for both the exploration of individual dimensions and the interpretation of their cumulative effect across neighbourhoods.

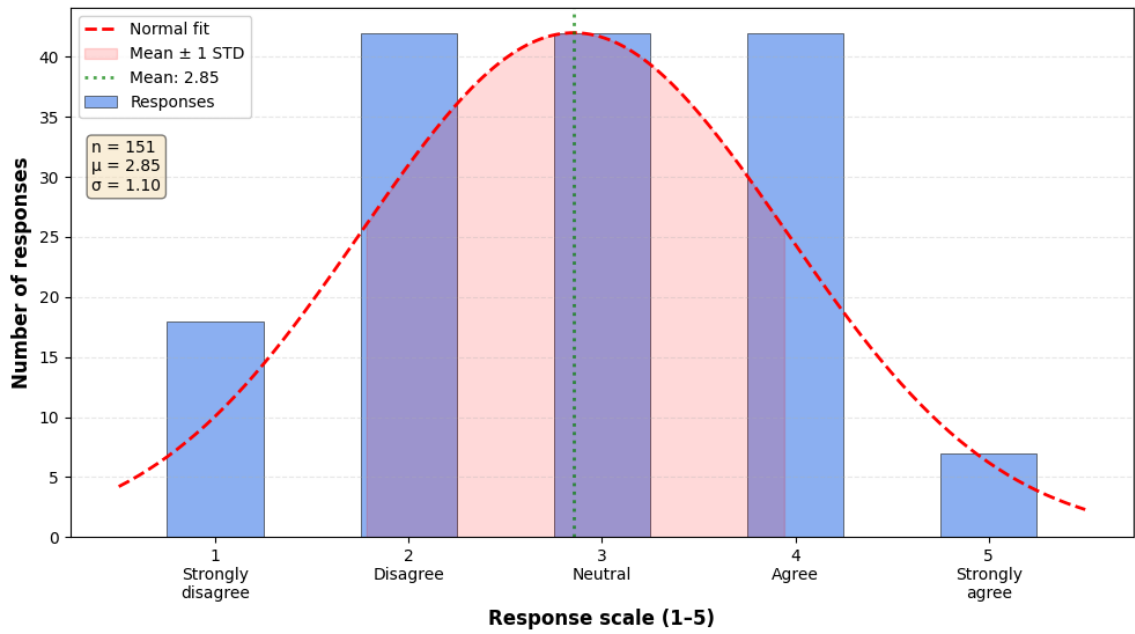
Appendix E: Questionnaire Analysis

Following are the distributions of responses to the questionnaire that was floated by the research team to augment the semi-structured interviews. They provide an understanding of the broad sentiment of the people towards issues like water governance, infrastructure and flood risk.

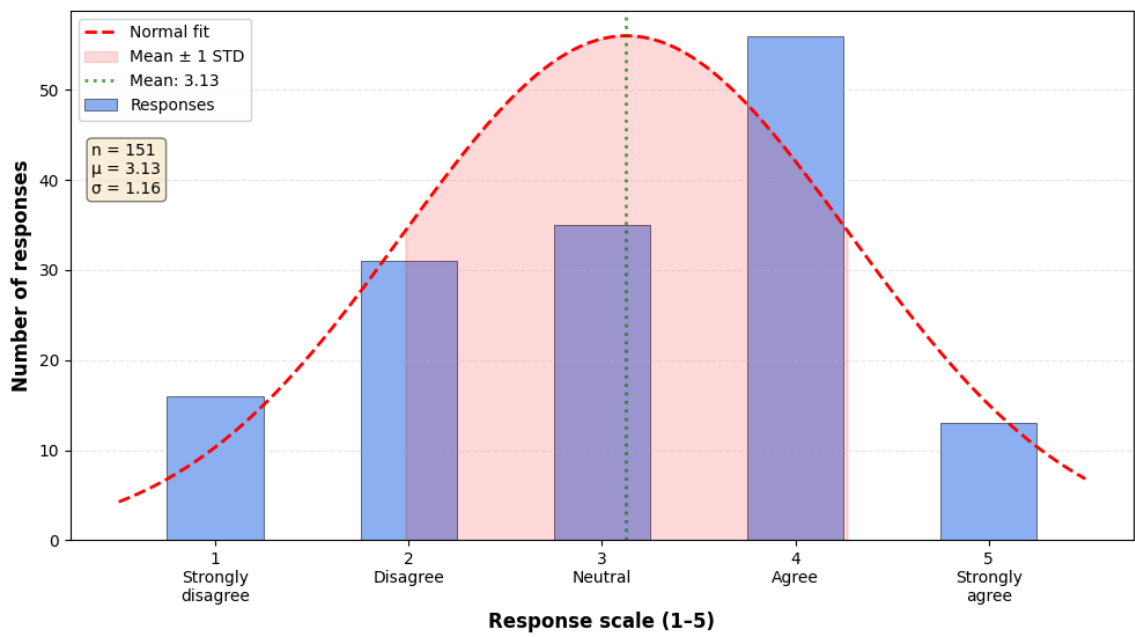
Figure 45: Gallery of distributions of responses to all questionnaire questions across all neighbourhoods.



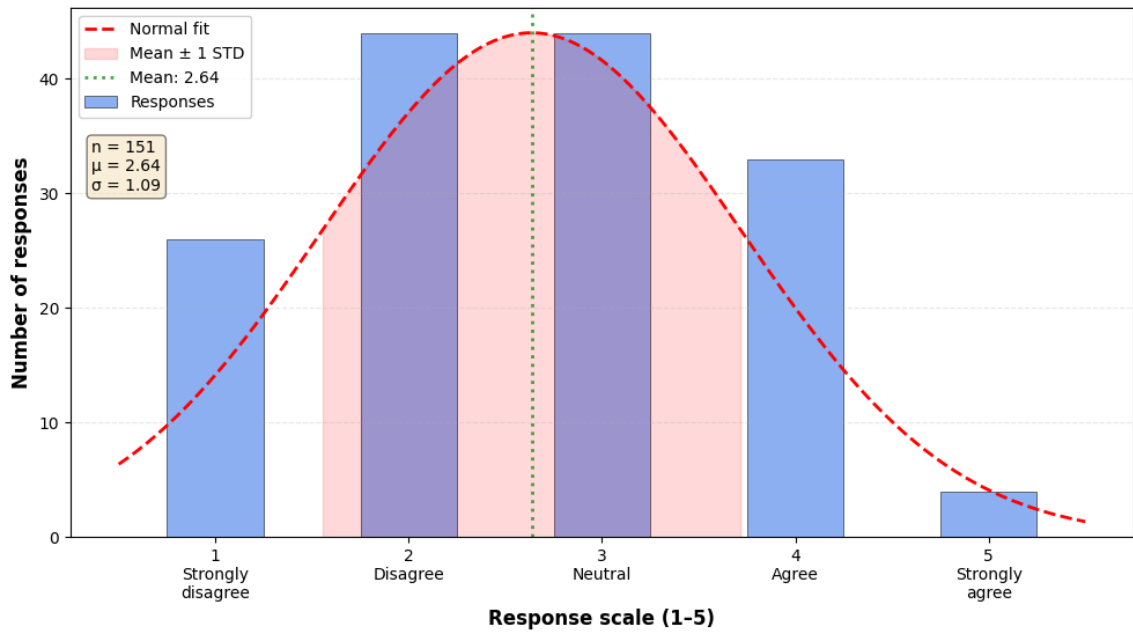
Q3: "I trust the quality of the water that reaches the city from the El Progreso plant."



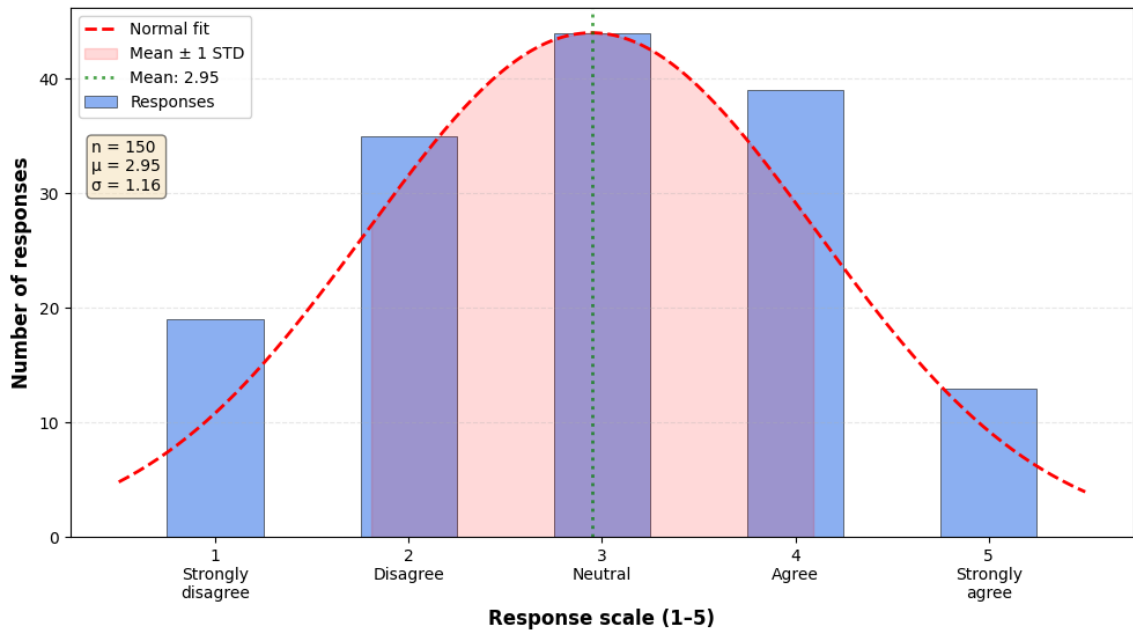
Q4: "I believe that water infrastructure plans include community participation."



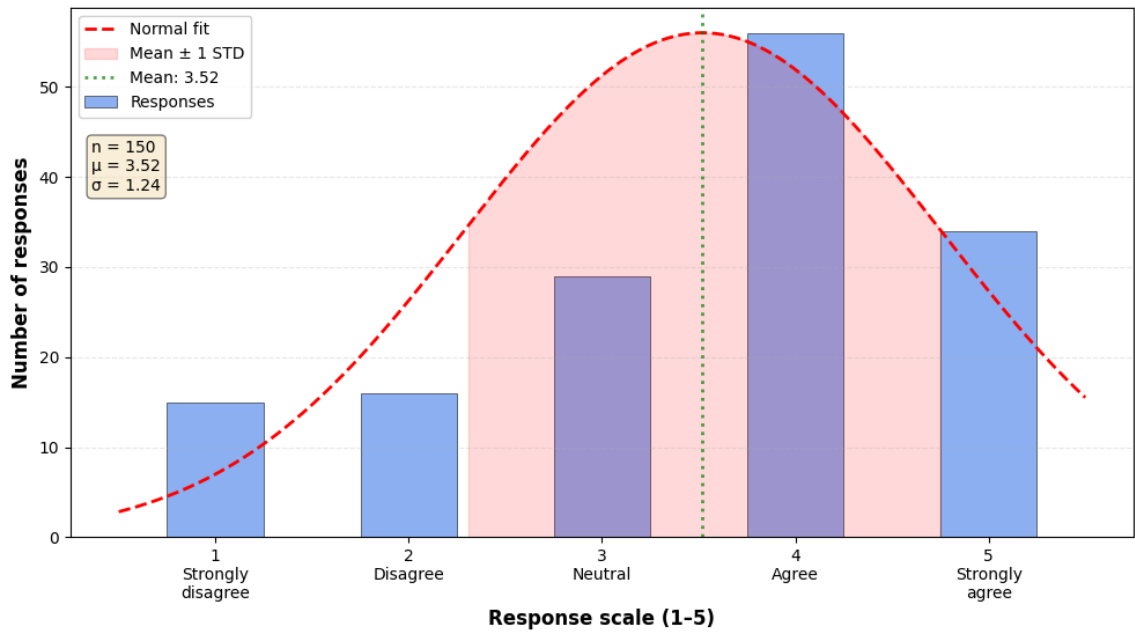
Q5: "I believe the municipality clearly communicates the water infrastructure plans."



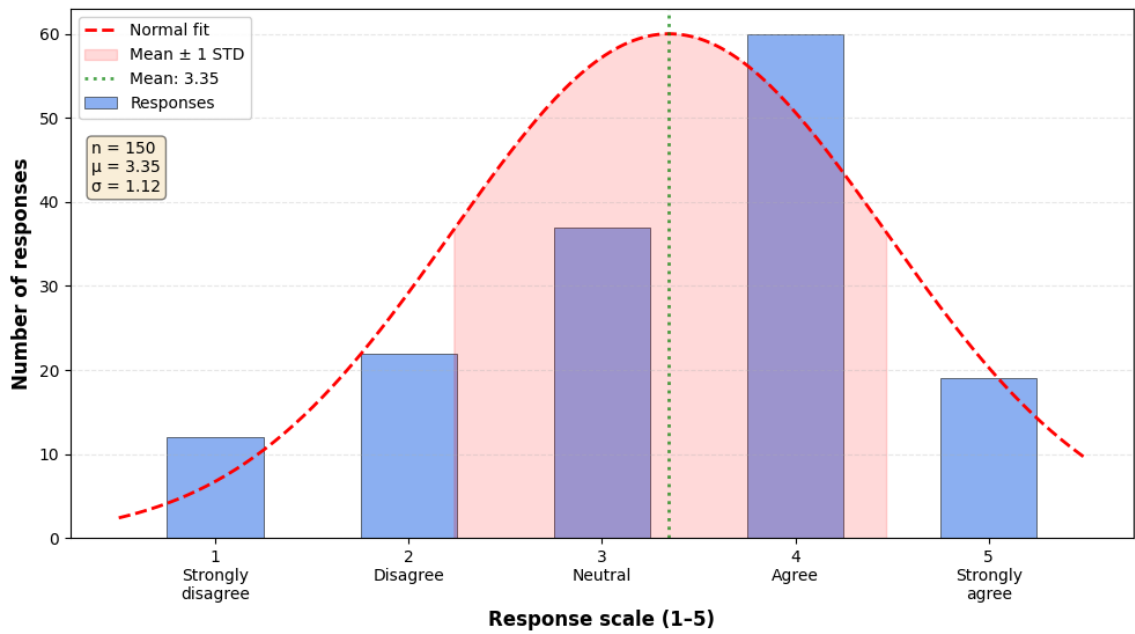
Q6: "When something breaks, the municipality fixes it immediately."



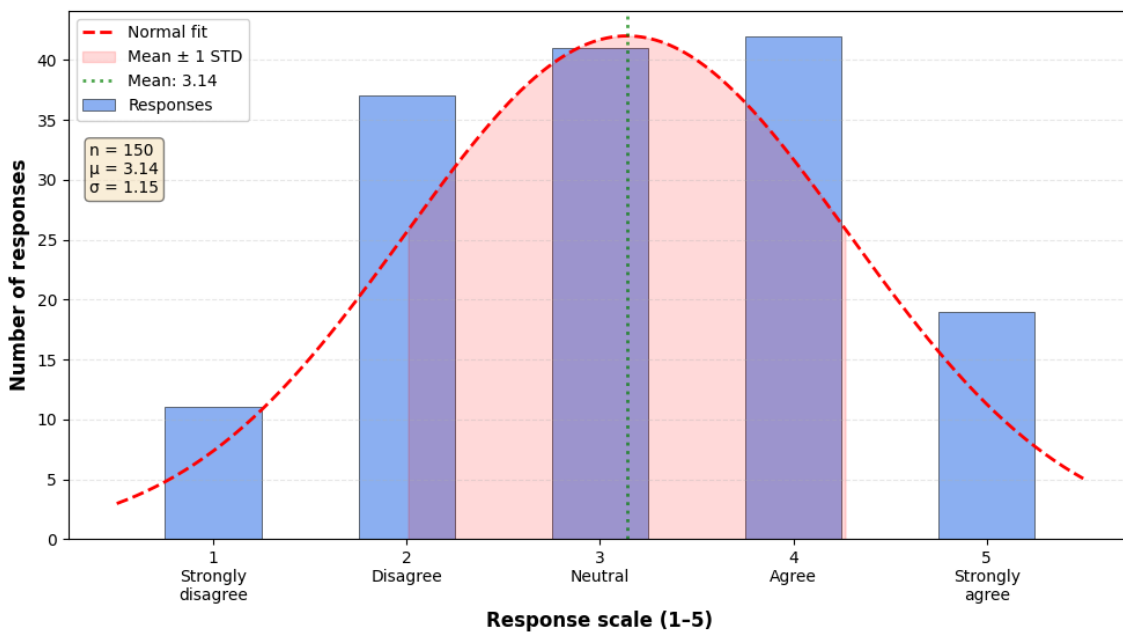
Q7: "I am concerned about flooding in my neighborhood during the rainy season."



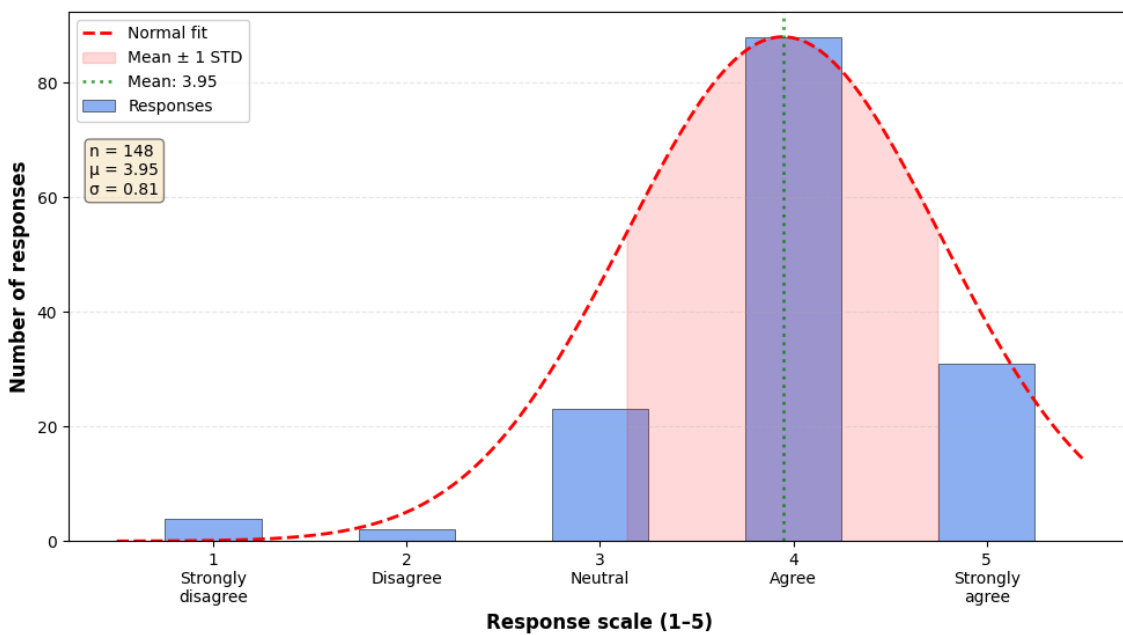
Q8: "I am afraid of rocks or other objects that fall during floods."



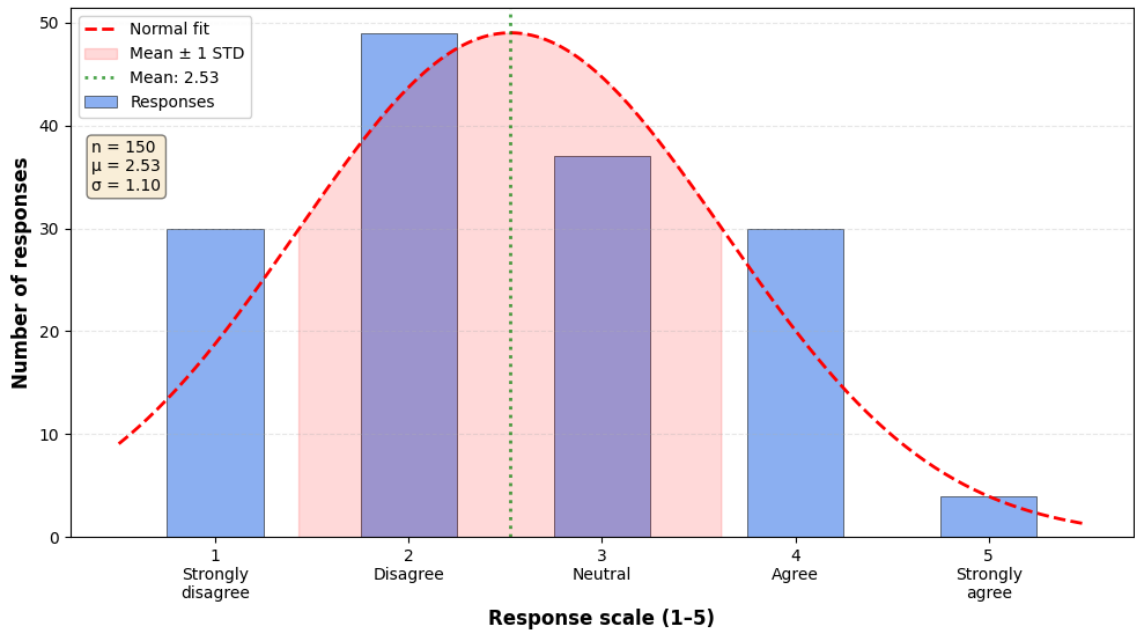
Q9: "I believe that floods are a normal part of life in San Cristóbal."



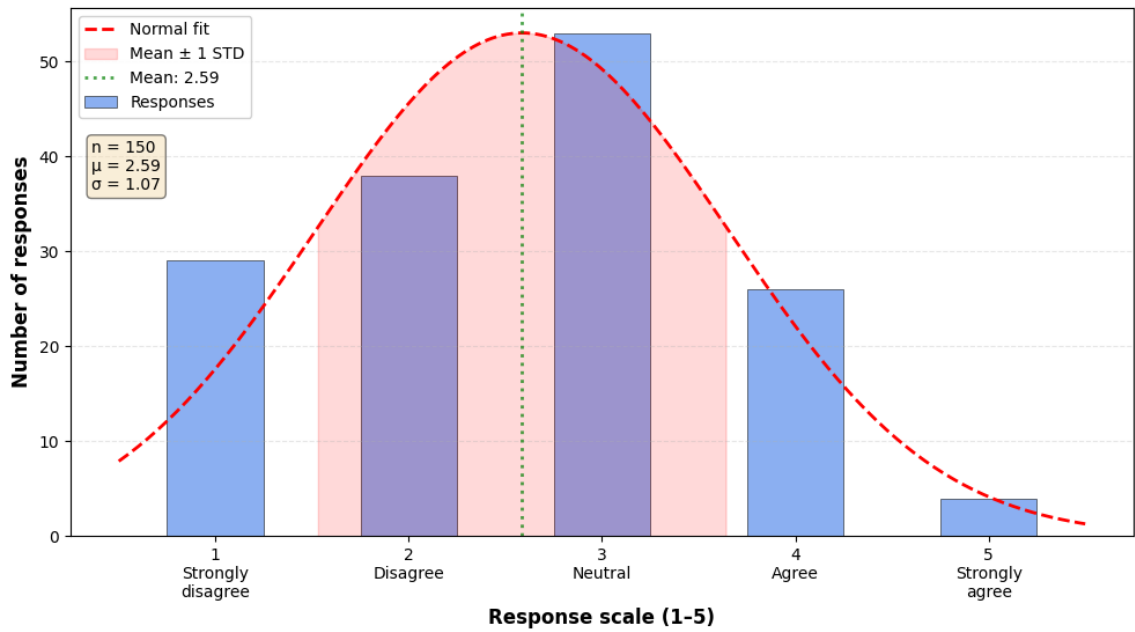
Q10: "Are you willing to invest in or collaborate on projects to protect against flooding?"



Q11: "When there is a flood, my house suffers a lot of damage."



Q12: "I believe that San Cristóbal's infrastructure is effective in preventing floods."



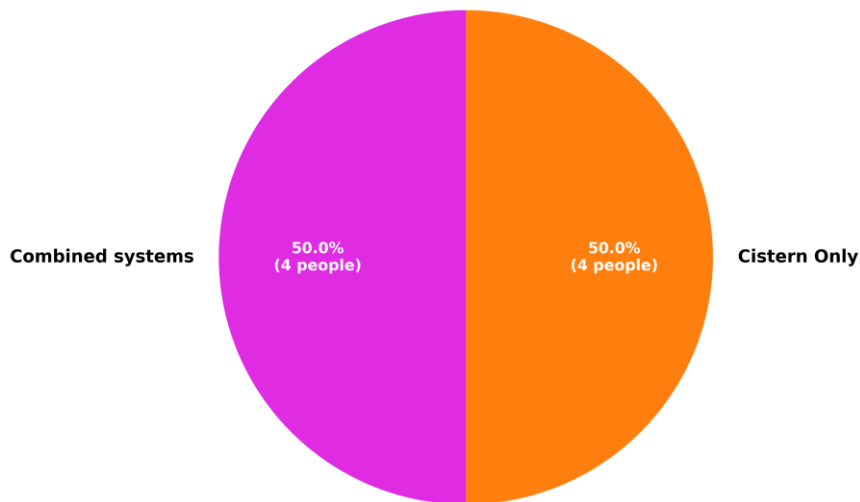
Appendix F: Results

F-1: Self-Organized Water Governance Practices

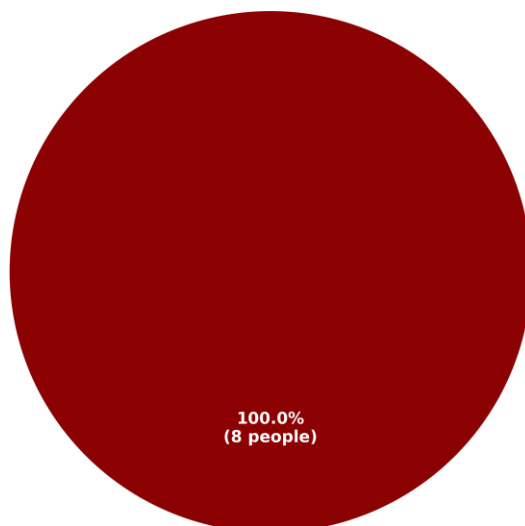
Reported below are the pie charts illustrating water storage types, cleaning frequencies, and drinking water sources for each neighbourhood or neighbourhood group.

Figure 46 Gallery of pie charts illustrating water storage types, cleaning frequencies, and drinking water sources for each neighbourhood or neighbourhood group in Puerto Baquerizo Moreno and Cabecera Parroquial El Progreso

**Water Storage Infrastructure - Albatros
Total: 8 people**

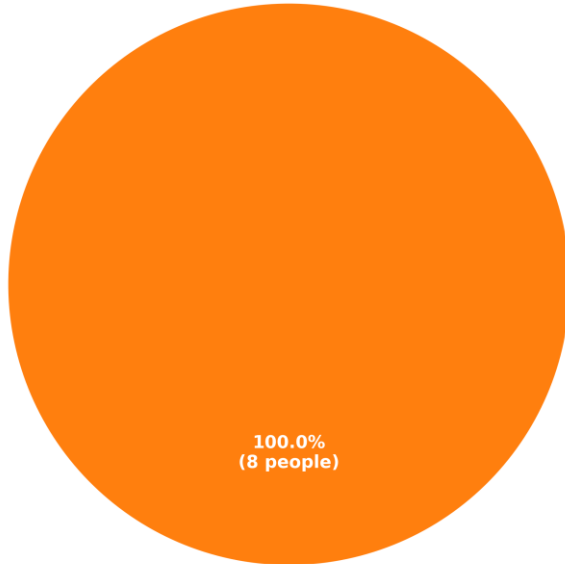


**Tank/Cistern Cleaning Frequency - Albatros
Total: 8 people**



Non-cleaners

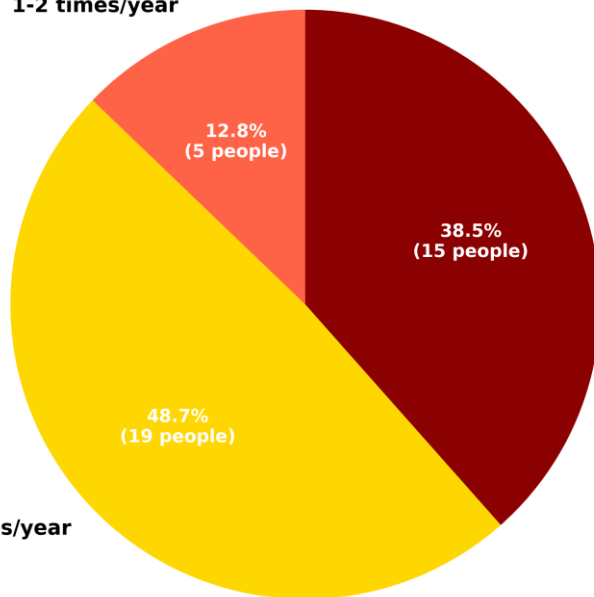
Drinking Water Methods - Albatros
Total: 8 people



Boil Water

Tank/Cistern Cleaning Frequency - Algarrobos
Total: 39 people

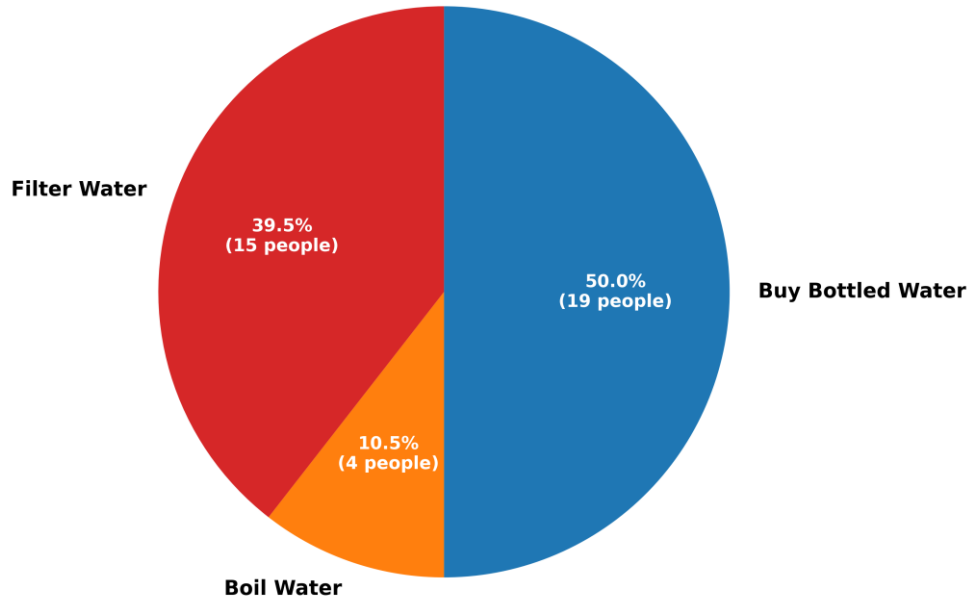
1-2 times/year



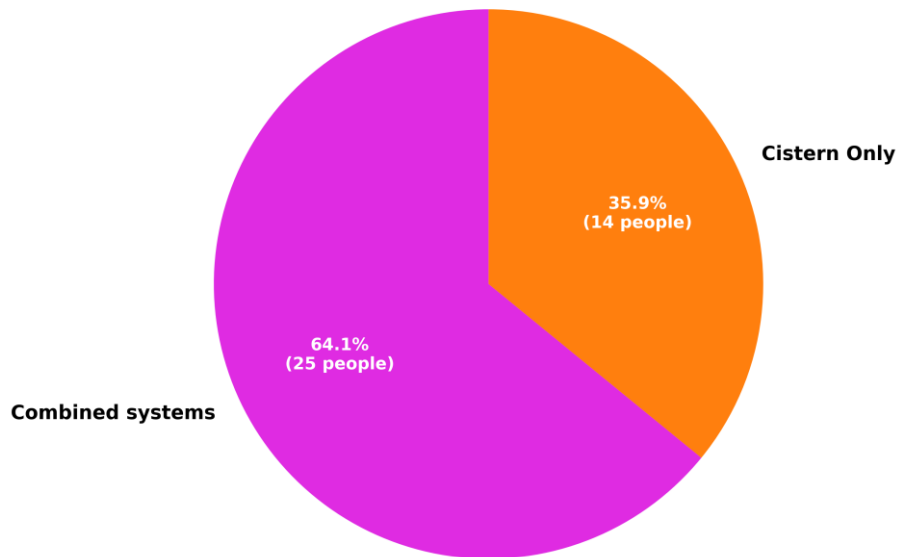
Non-cleaners

2-4 times/year

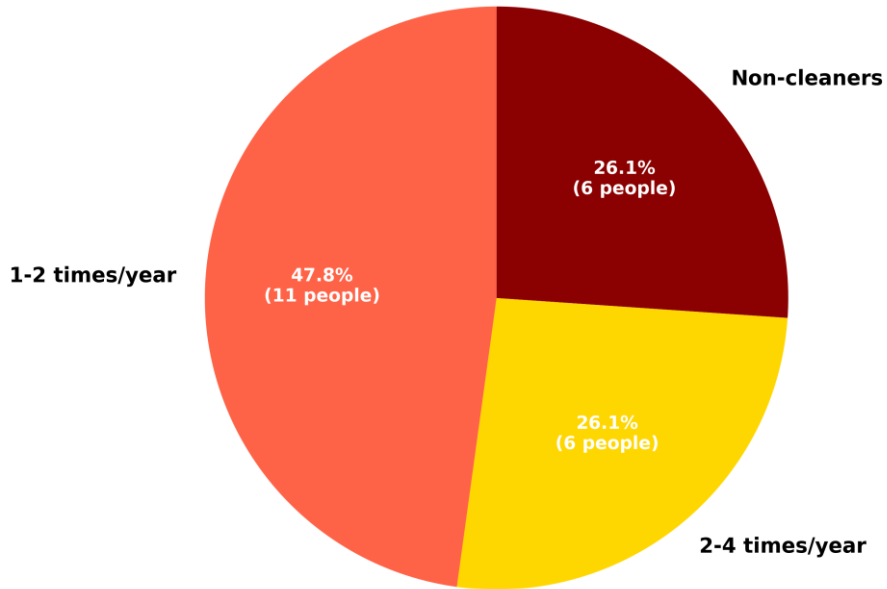
Drinking Water Methods - Algarrobos
Total: 38 people



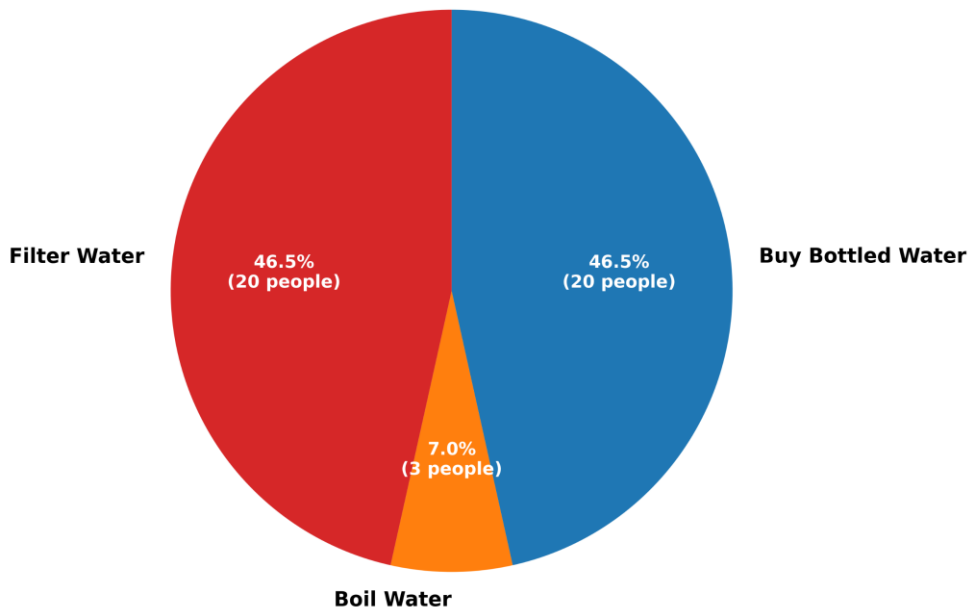
Water Storage Infrastructure - Algarrobos
Total: 39 people



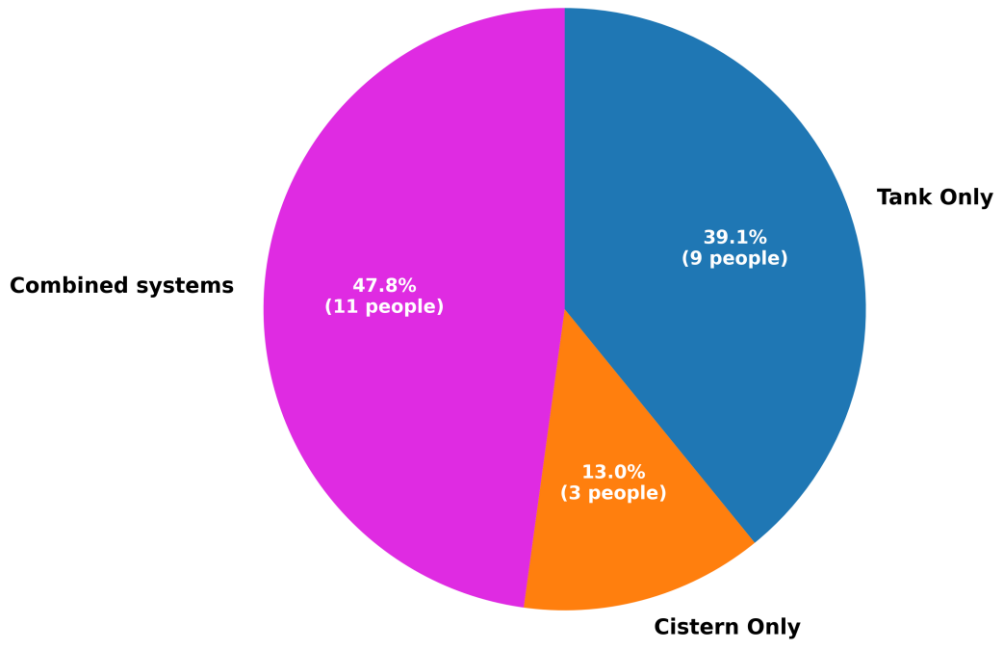
Tank/Cistern Cleaning Frequency - Cactus
Total: 23 people



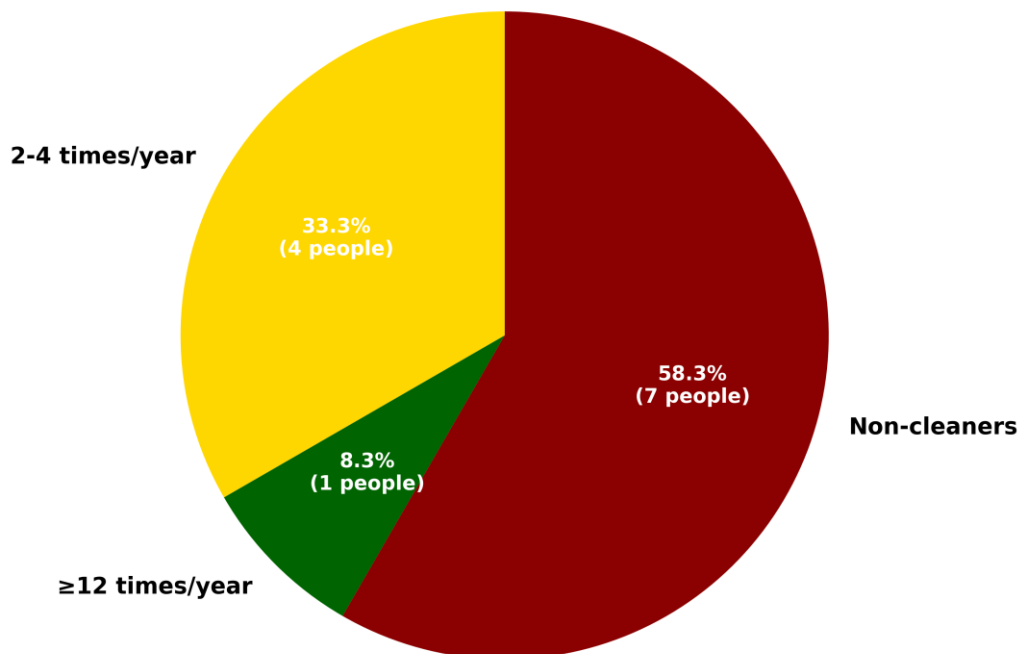
Drinking Water Methods - Cactus
Total: 43 people



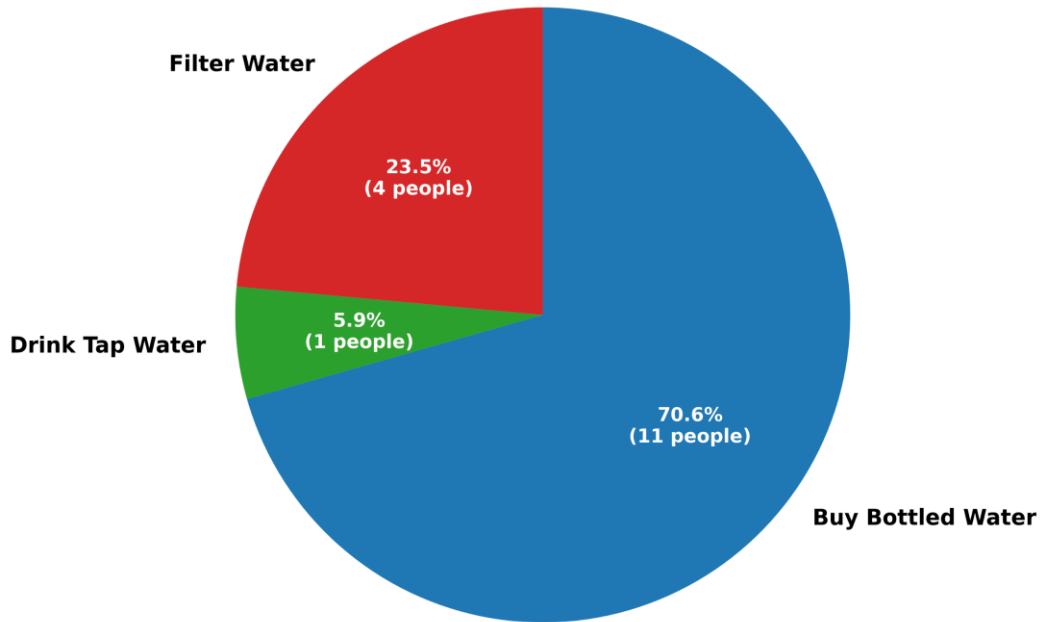
Water Storage Infrastructure - Cactus
Total: 23 people



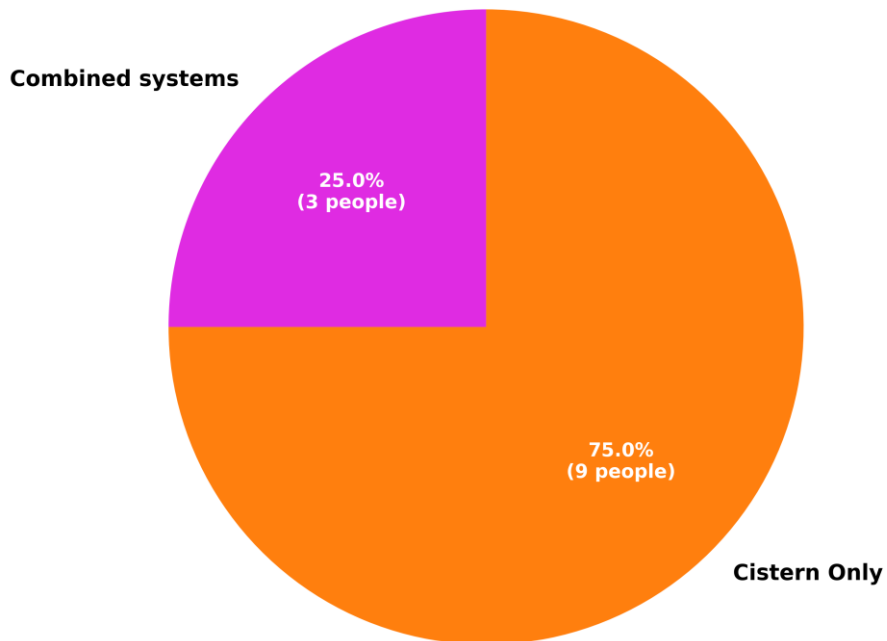
Tank/Cistern Cleaning Frequency - Centrale
Total: 12 people



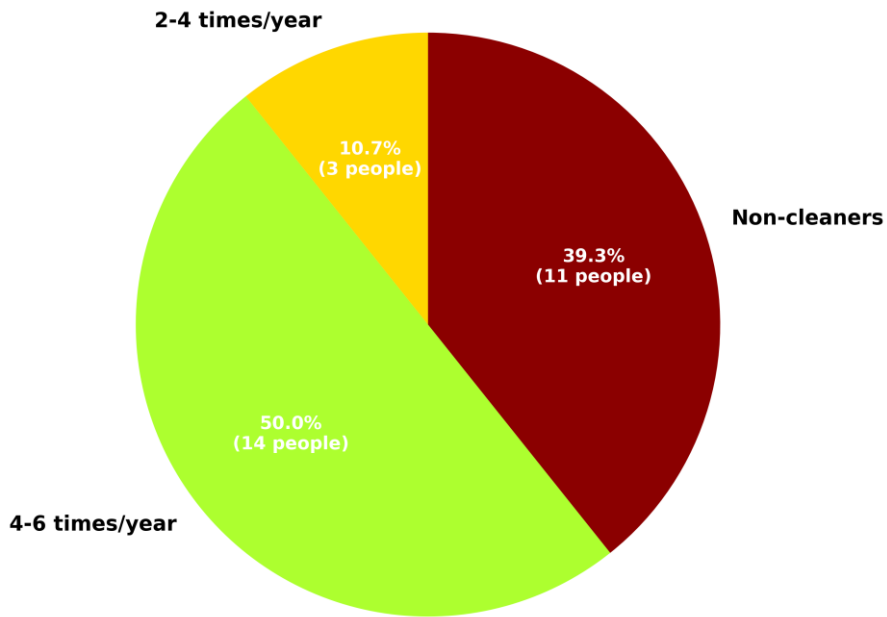
Drinking Water Methods - Centrale
Total: 17 people



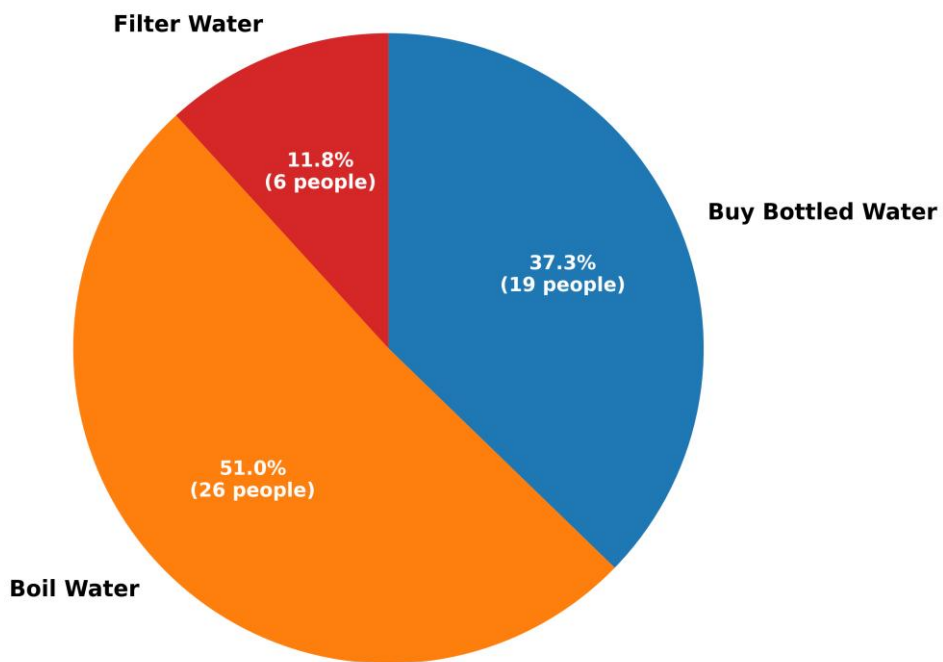
Water Storage Infrastructure - Centrale
Total: 12 people



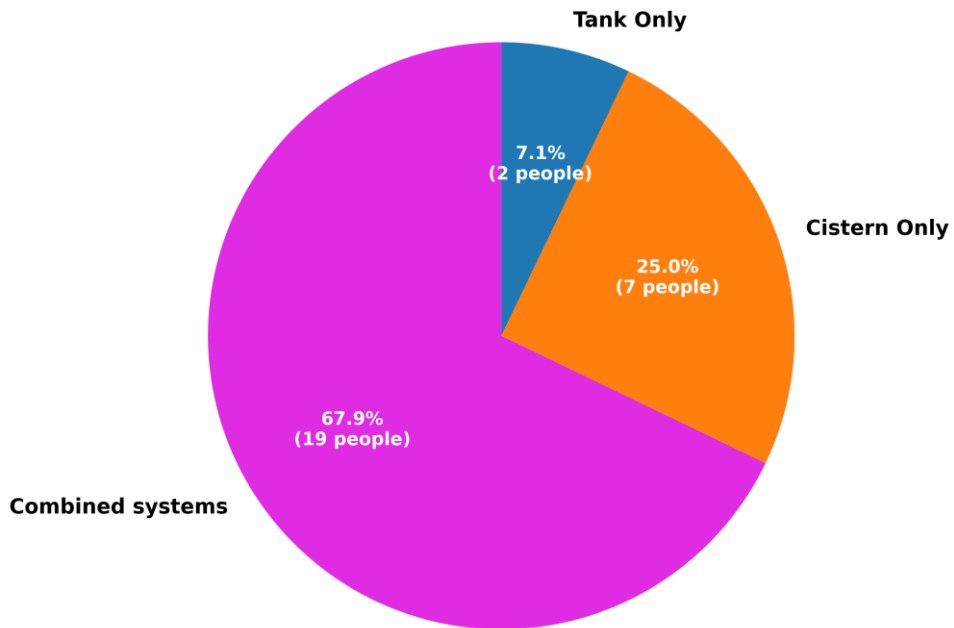
Tank/Cistern Cleaning Frequency - DivinoNino
Total: 28 people



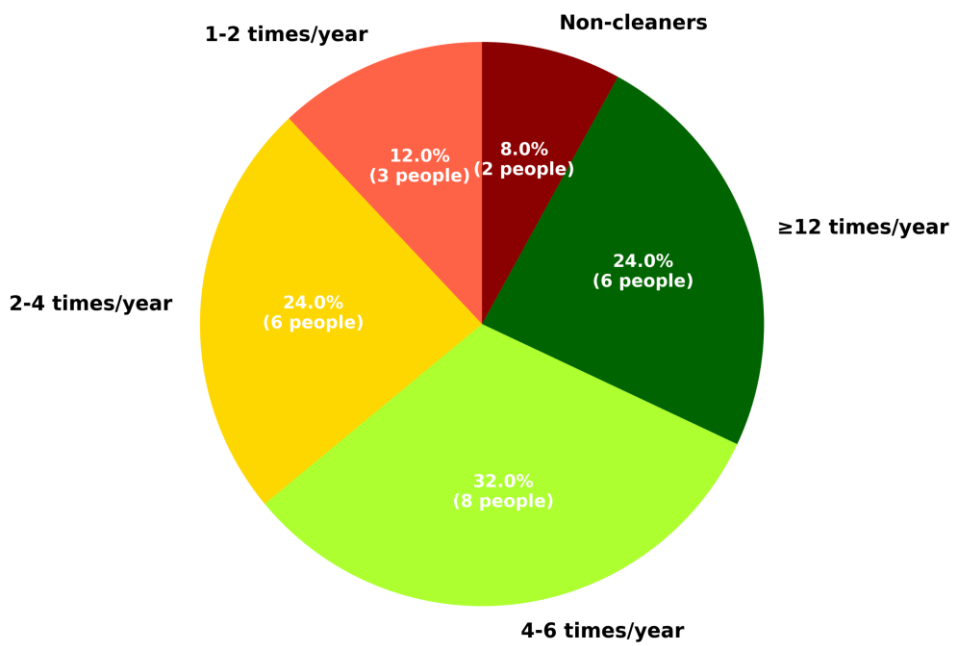
Drinking Water Methods - DivinoNino
Total: 51 people



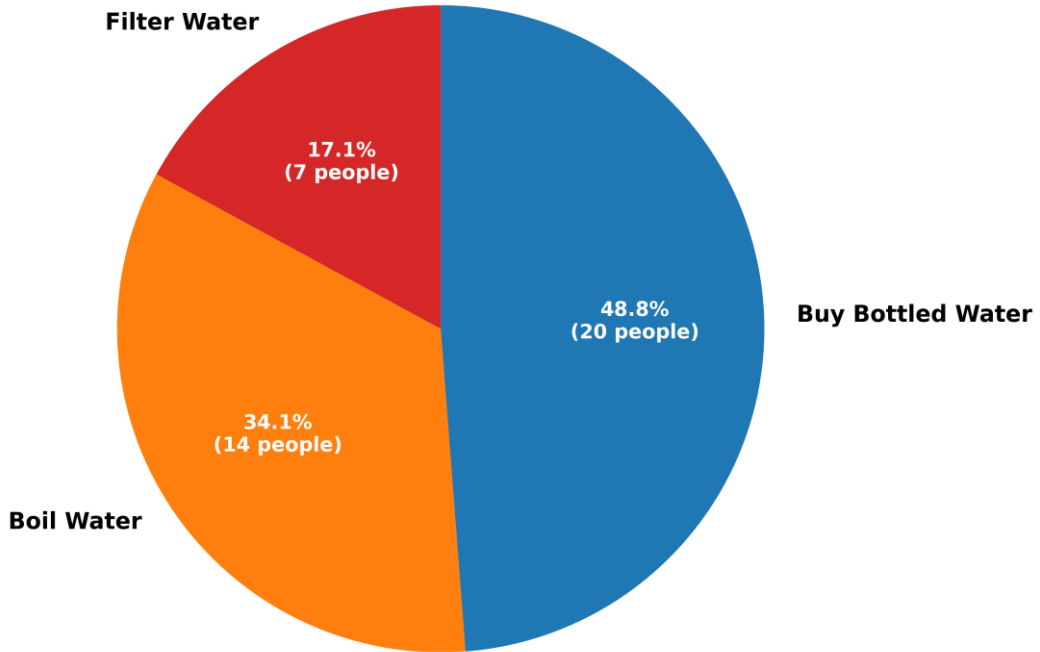
Water Storage Infrastructure - DivinoNino
Total: 28 people



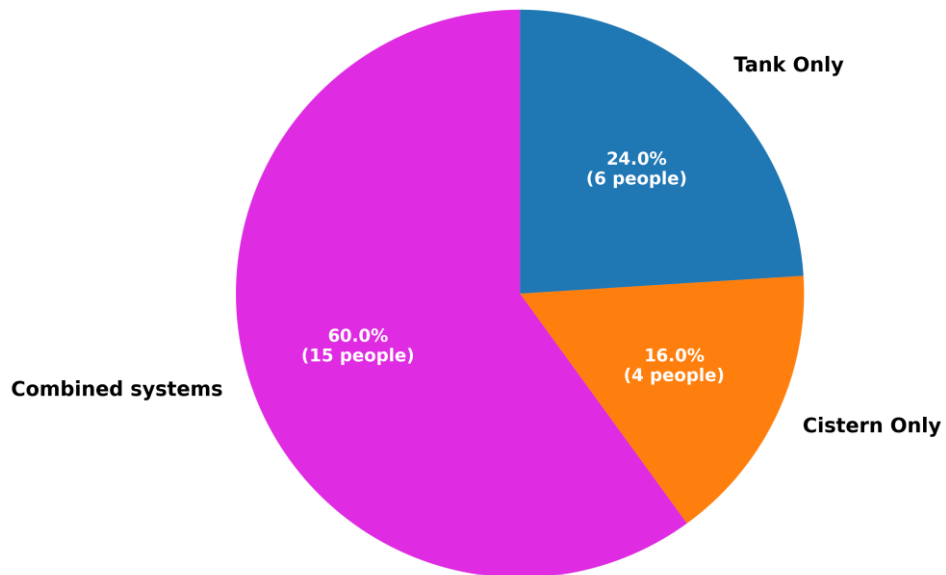
Tank/Cistern Cleaning Frequency - ElProgreso
Total: 25 people



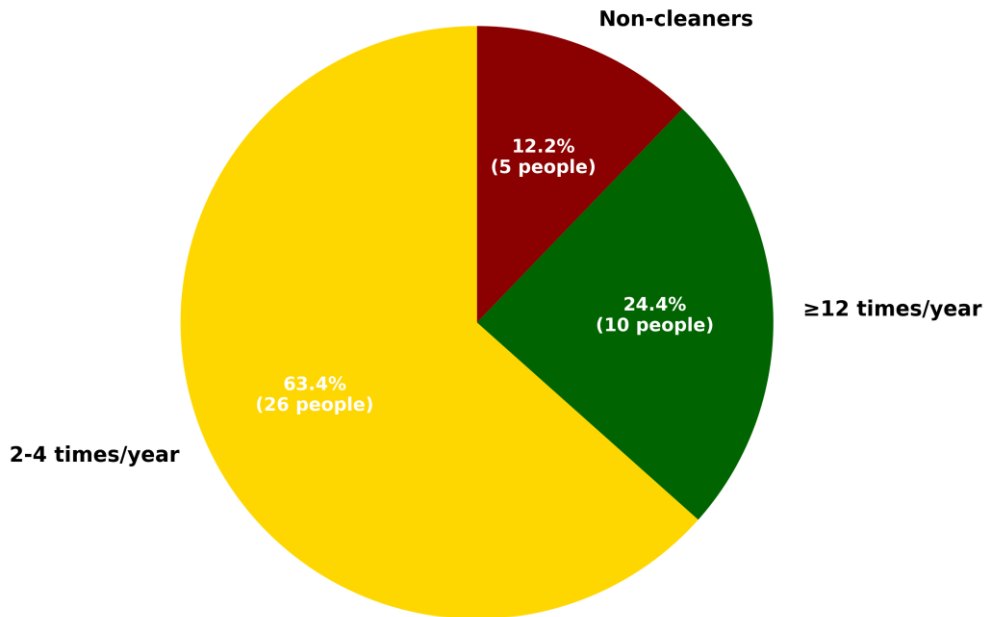
Drinking Water Methods - EIProgreso
Total: 41 people



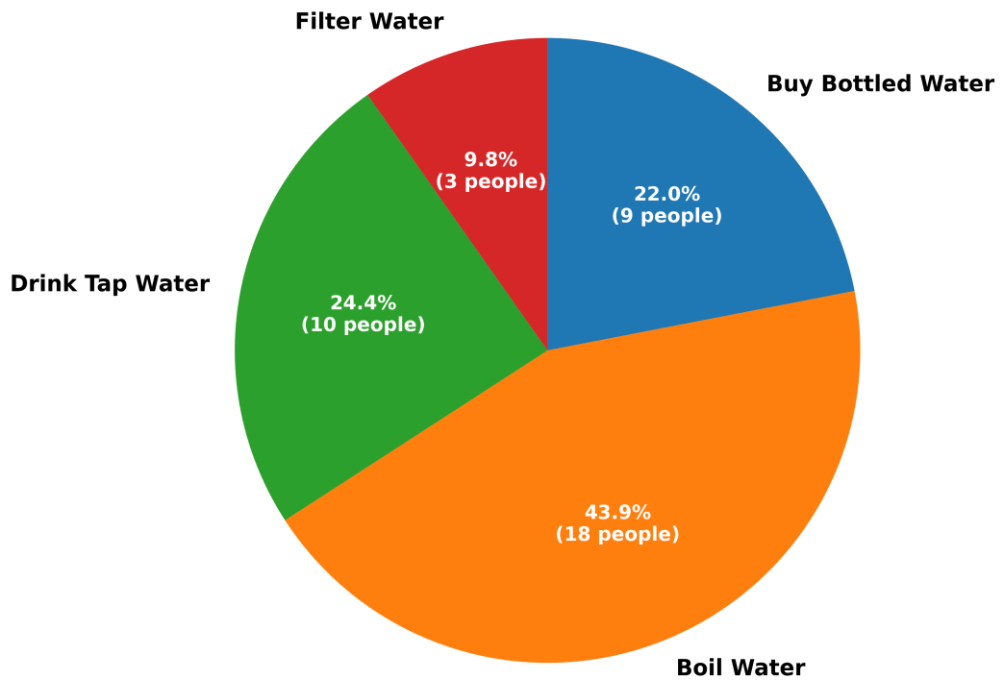
Water Storage Infrastructure - EIProgreso
Total: 25 people



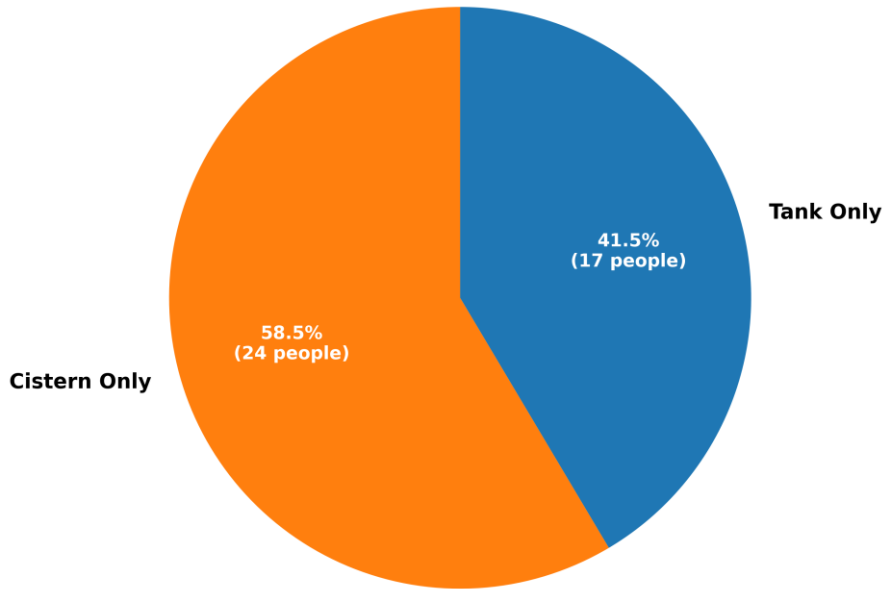
Tank/Cistern Cleaning Frequency - Estacion_Terrena
Total: 41 people



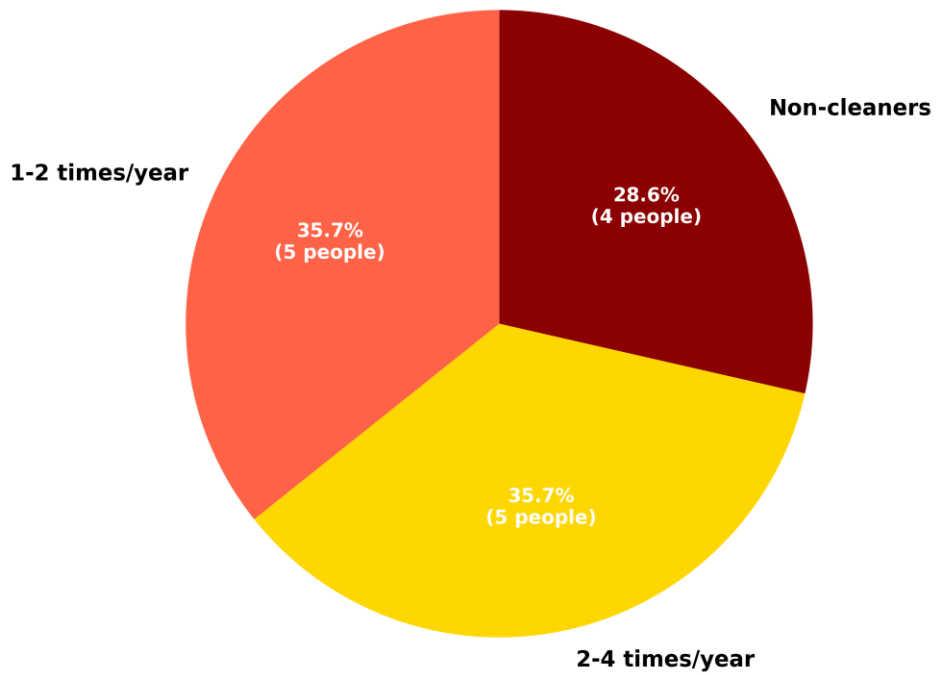
Drinking Water Methods - Estacion_Terrena
Total: 41 people



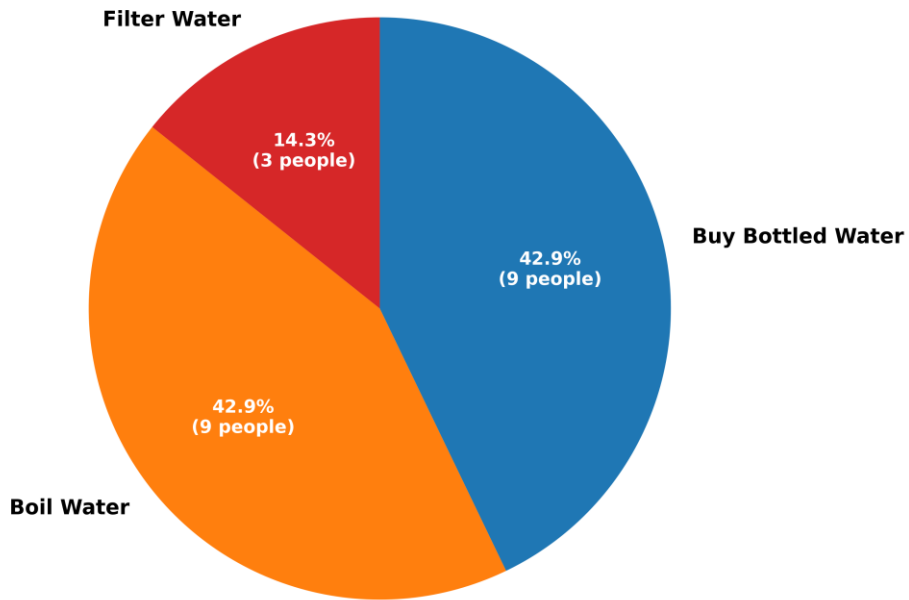
Water Storage Infrastructure - Estacion_Terrena
Total: 41 people



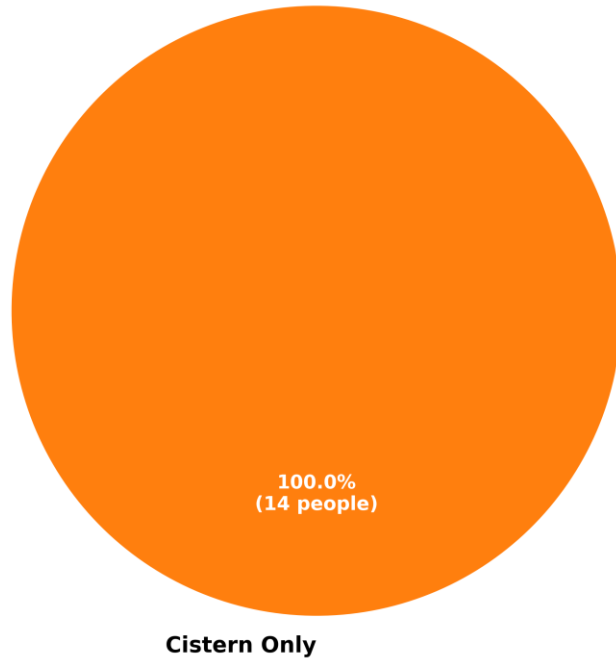
Tank/Cistern Cleaning Frequency - Fregatas
Total: 14 people



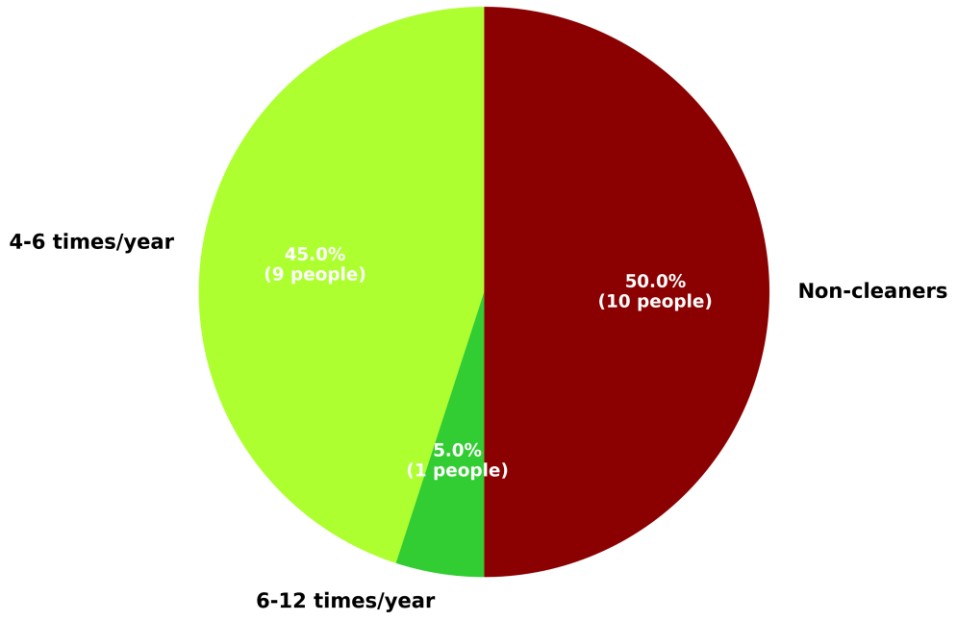
Drinking Water Methods - Fregatas
Total: 21 people



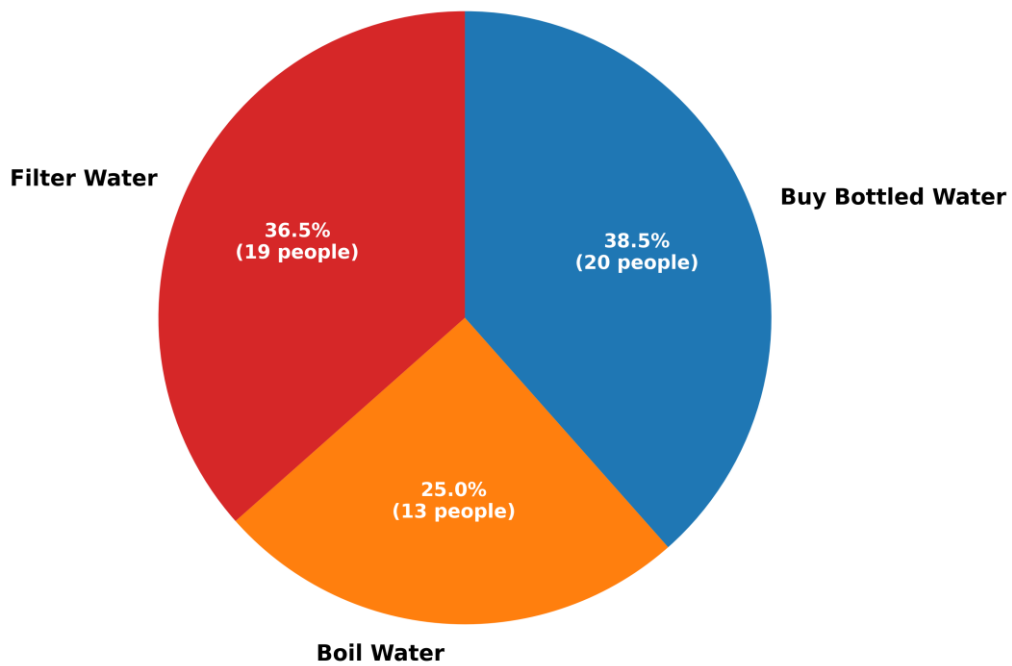
Water Storage Infrastructure - Fregatas
Total: 14 people



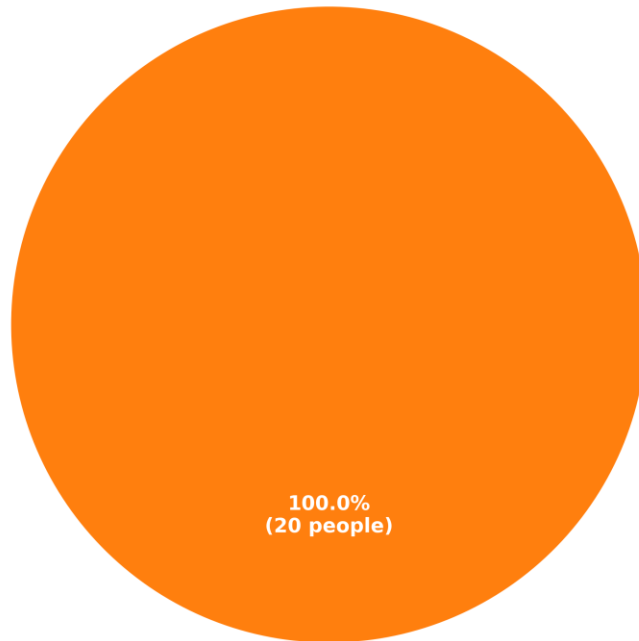
Tank/Cistern Cleaning Frequency - Frio
Total: 20 people



Drinking Water Methods - Frio
Total: 52 people

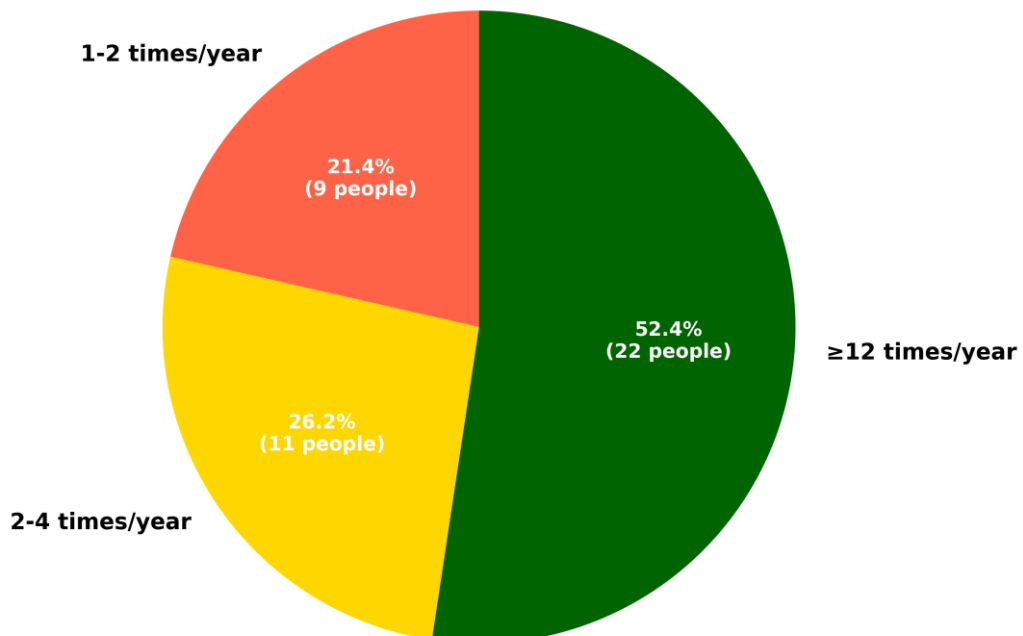


**Water Storage Infrastructure - Frio
Total: 20 people**

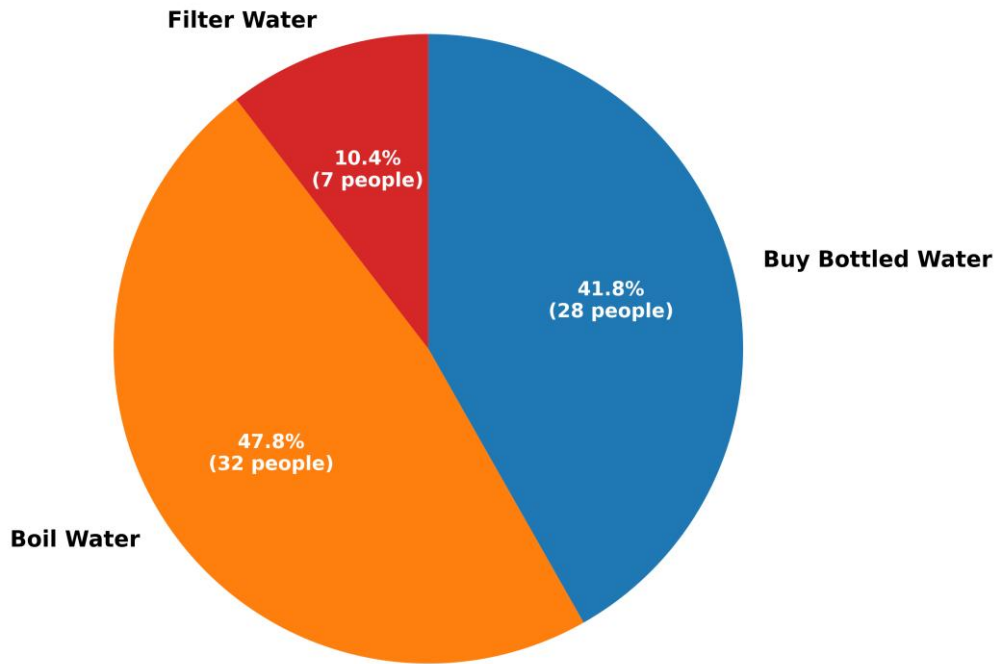


Cistern Only

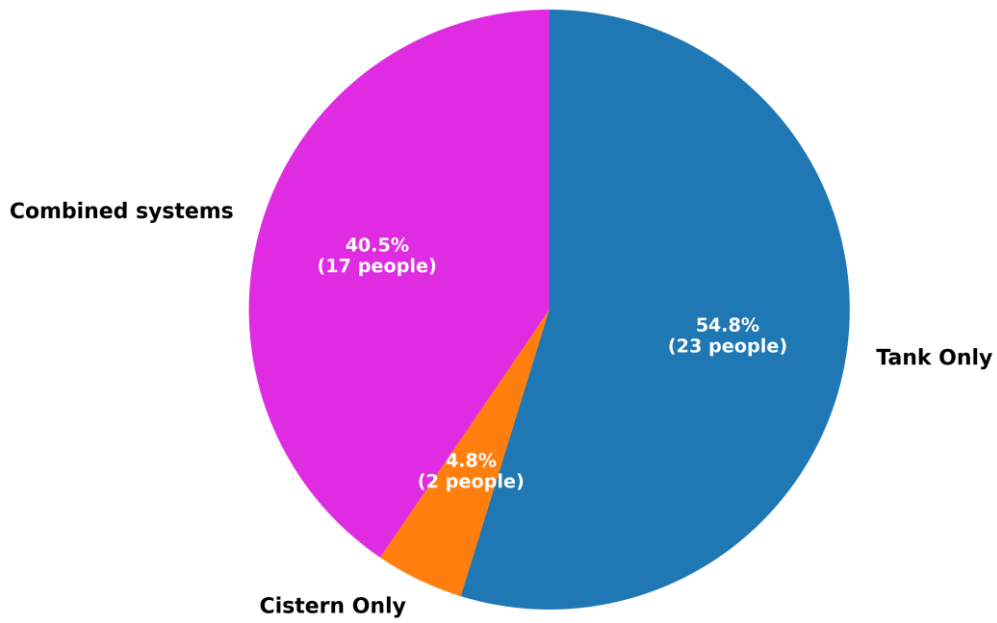
**Tank/Cistern Cleaning Frequency - Las Palmeras group
Total: 42 people**



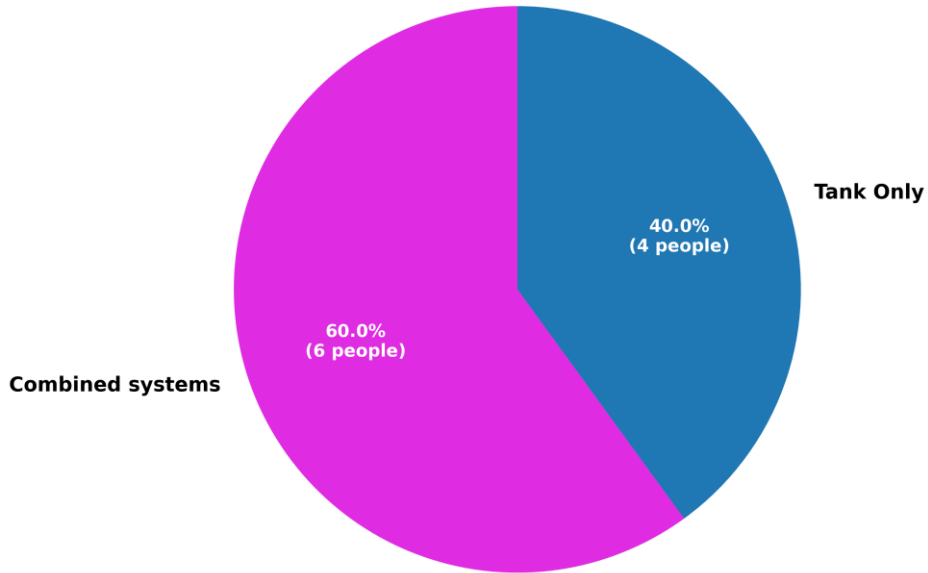
Drinking Water Methods - Las Palmeras group
Total: 67 people



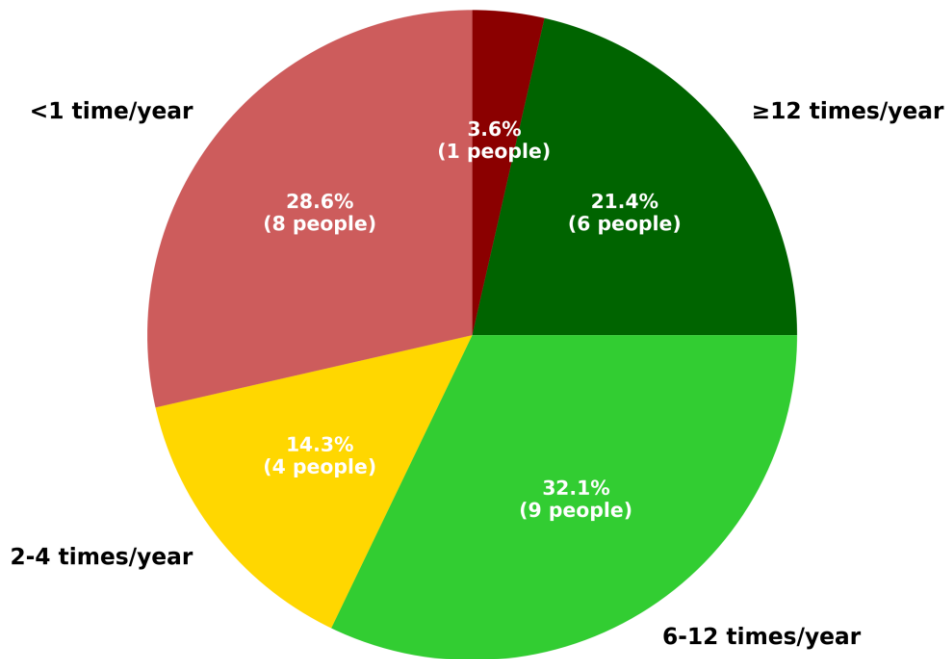
Water Storage Infrastructure - Las Palmeras group
Total: 42 people



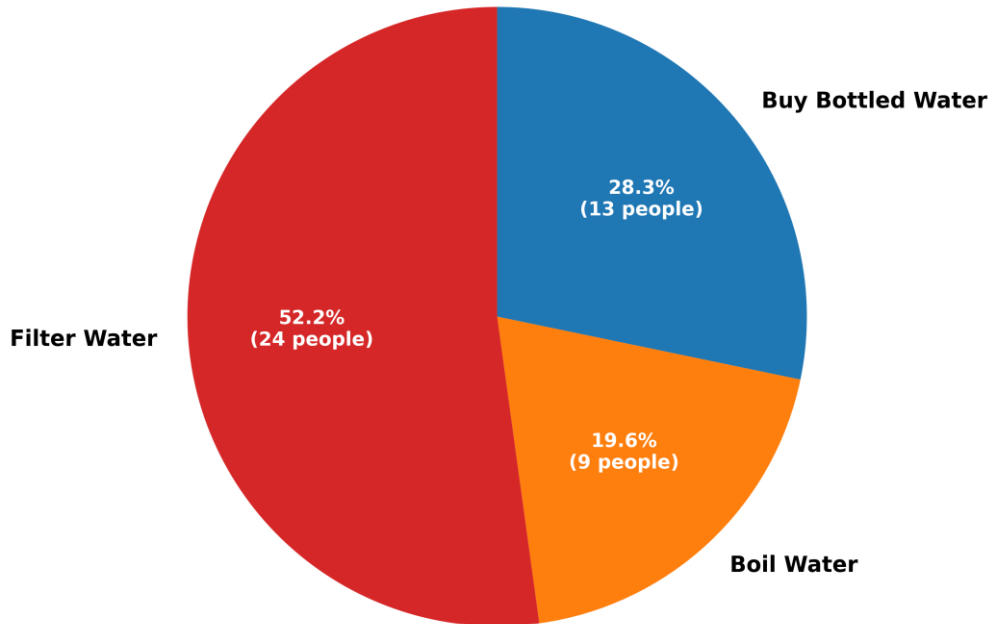
Water Storage Infrastructure - Las_Palmeras
Total: 10 people



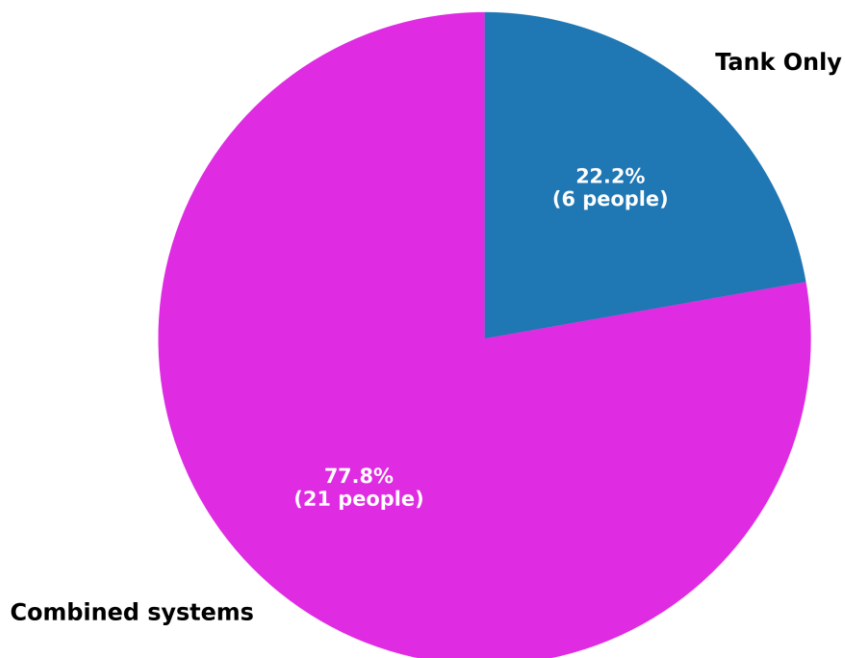
Tank/Cistern Cleaning Frequency - Penas_Altas
Total: 28 people
Non-cleaners



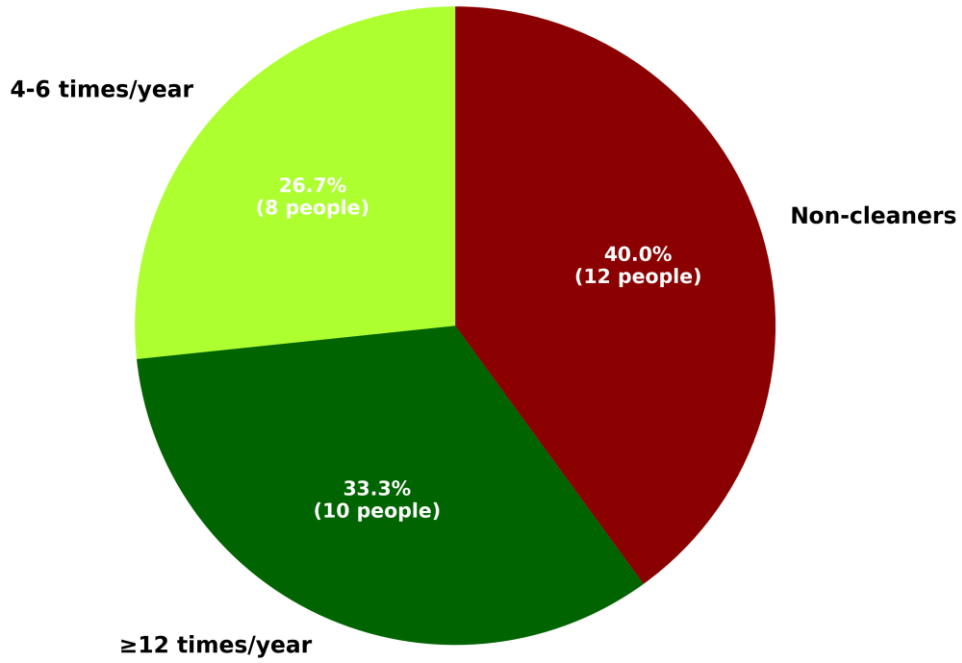
Drinking Water Methods - Penas_Altas
Total: 46 people



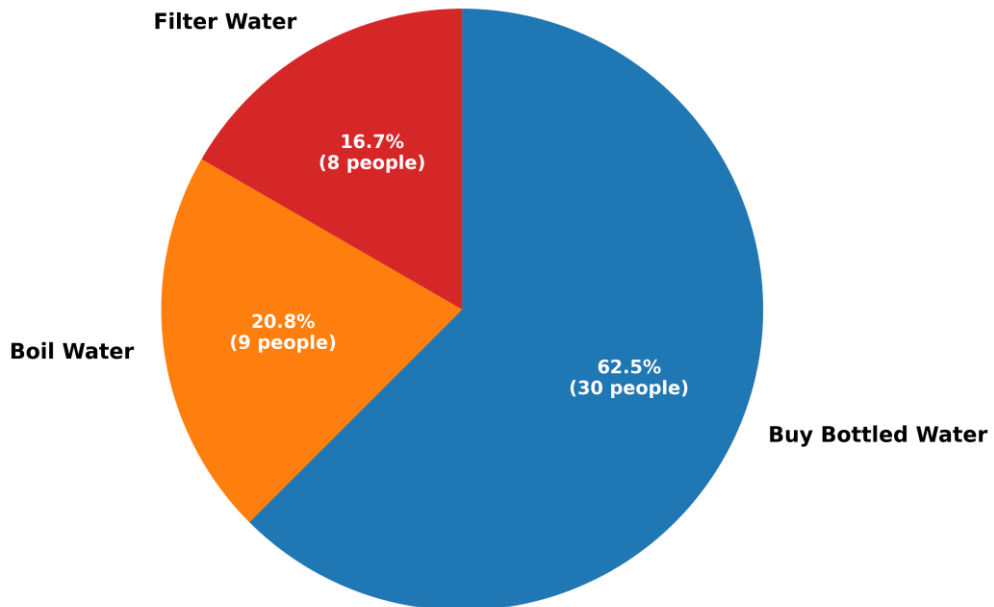
Water Storage Infrastructure - Penas_Altas
Total: 27 people



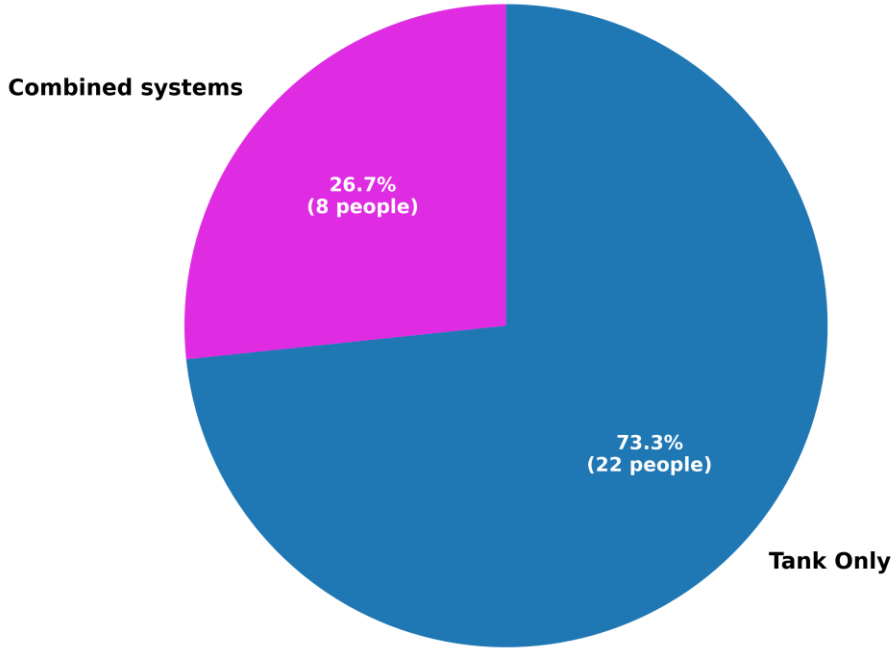
Tank/Cistern Cleaning Frequency - Penas_Bajas
Total: 30 people



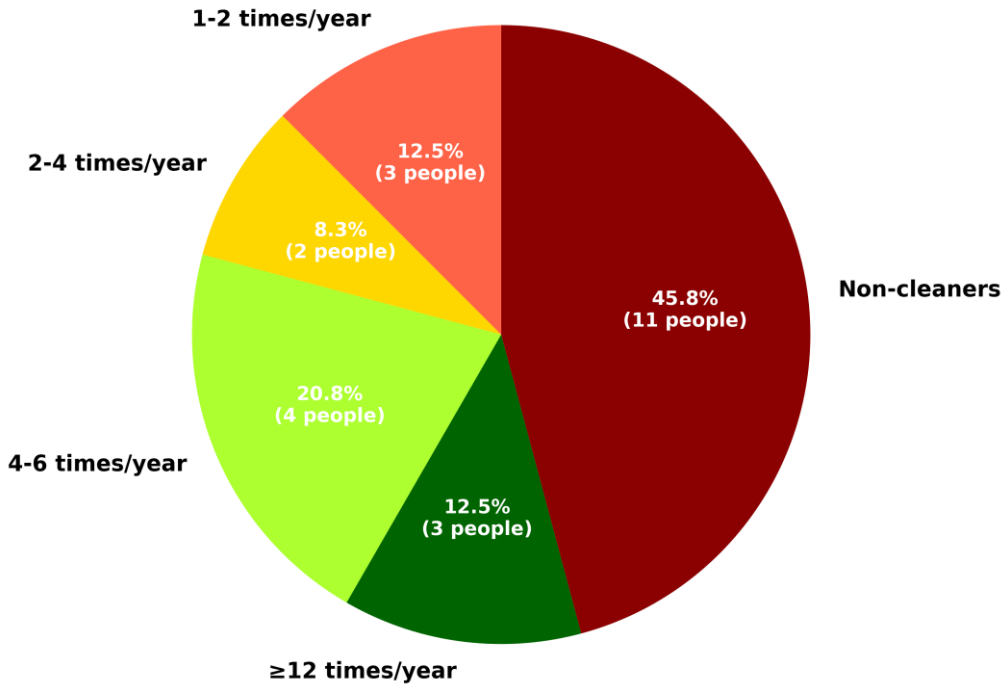
Drinking Water Methods - Penas_Bajas
Total: 48 people



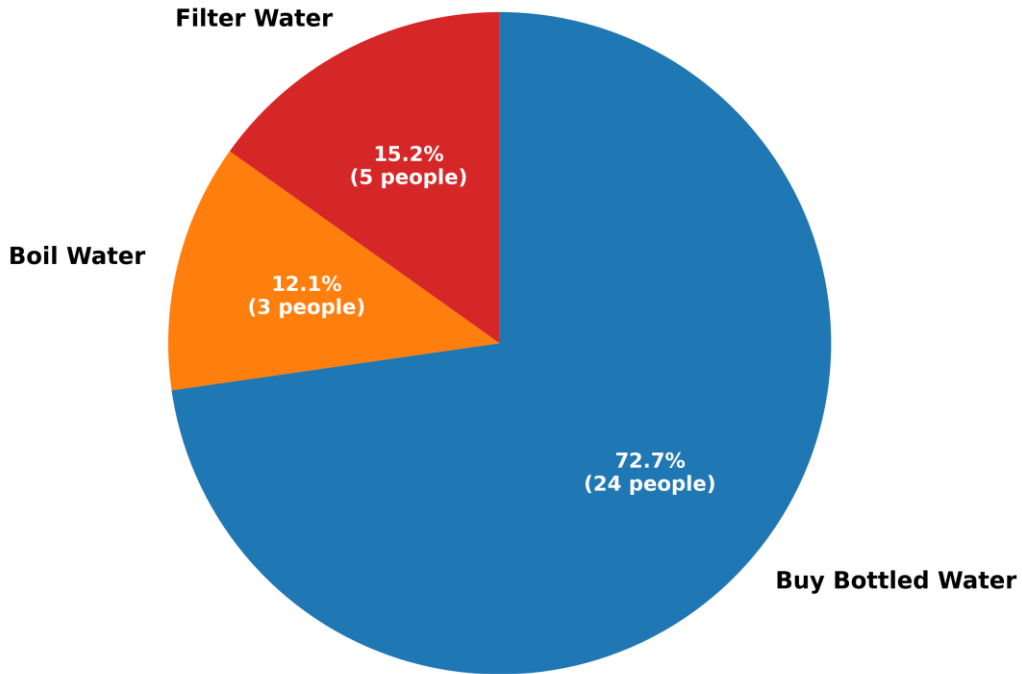
Water Storage Infrastructure - Penas_Bajas
Total: 30 people



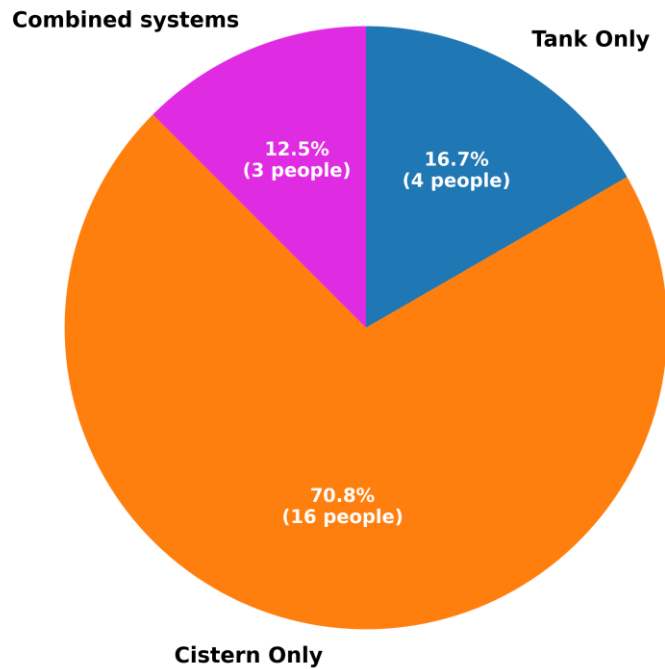
Tank/Cistern Cleaning Frequency - Playa Oro & Playa Mann
Total: 24 people



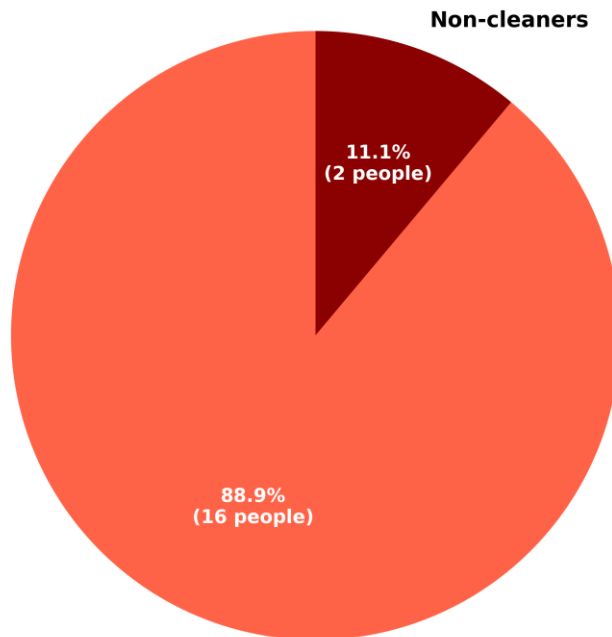
Drinking Water Methods - Playa Oro & Playa Mann
Total: 33 people



Water Storage Infrastructure - Playa Oro & Playa Mann
Total: 24 people

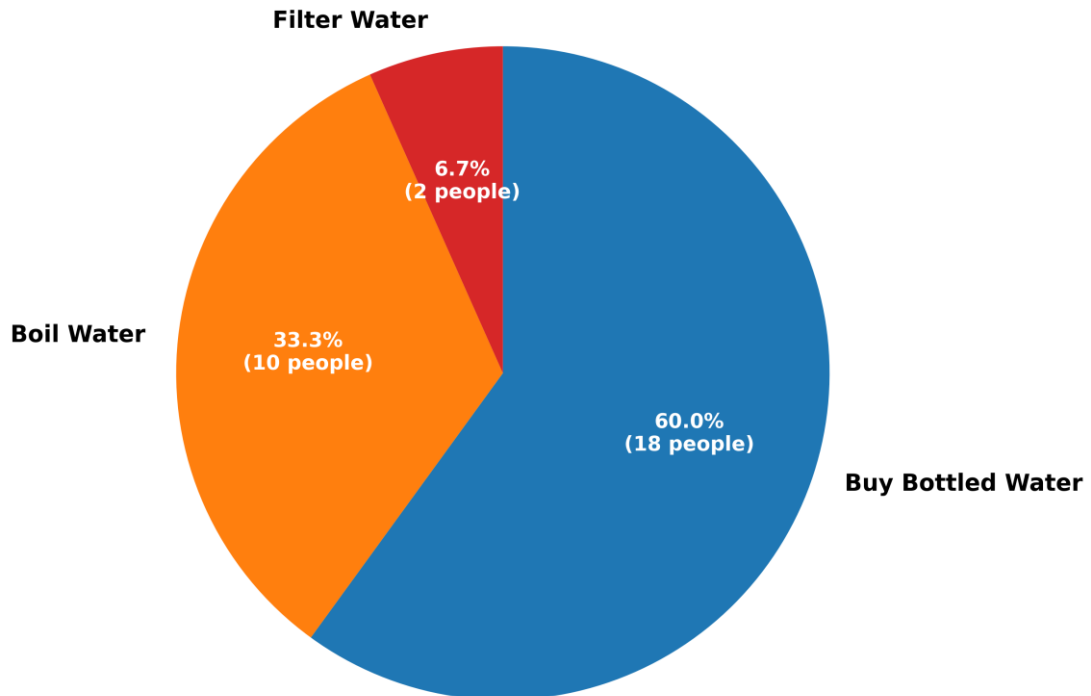


Tank/Cistern Cleaning Frequency - San_Francisco
Total: 18 people

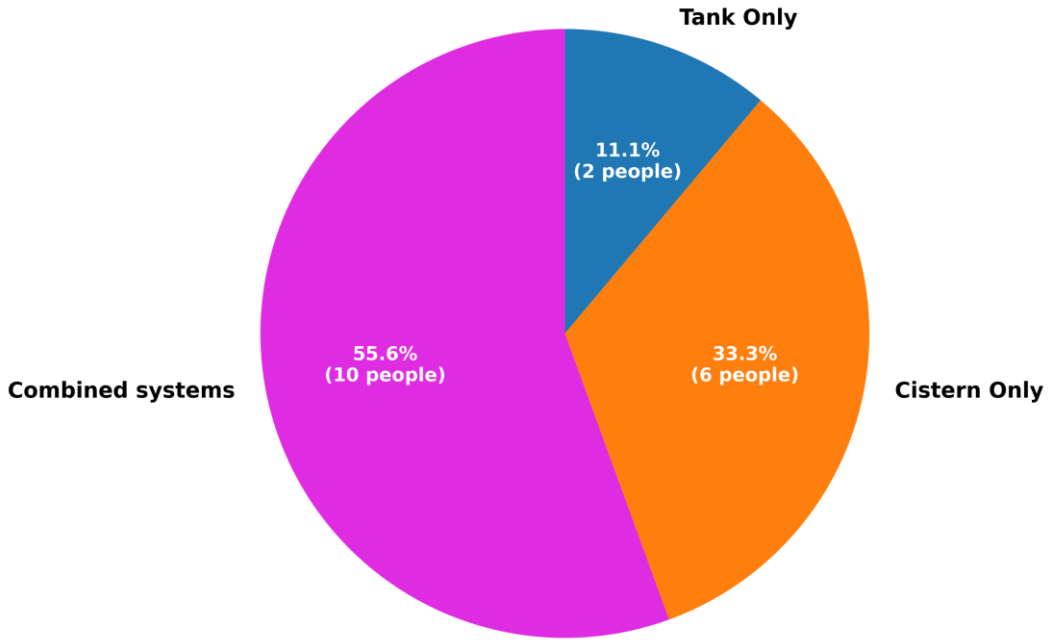


1-2 times/year

Drinking Water Methods - San_Francisco
Total: 30 people



Water Storage Infrastructure - San Francisco
Total: 18 people



Pearson coefficient map confronting water storage type and cleaning frequency.

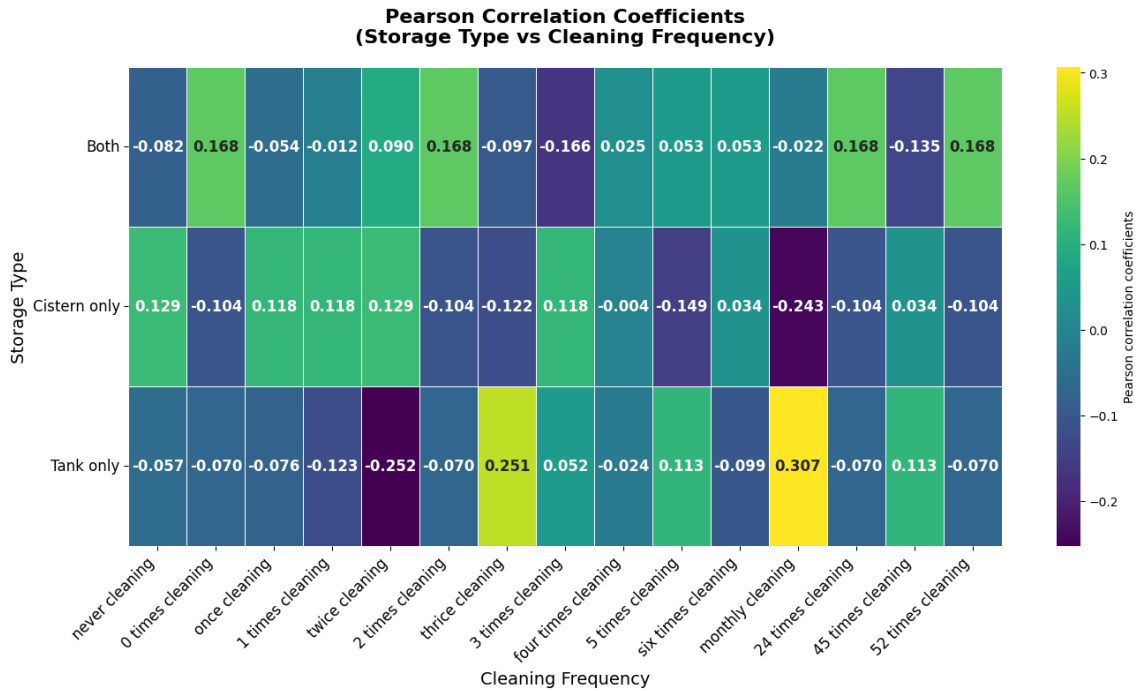


Figure 47: Pearson correlation map comparing water storage type and cleaning frequency.

F-2: Table of relative annual water consumption per neighbourhood (2025)

Table 23: Relative water consumption per neighbourhood per person.

Neighbourhood	Relative water consumption (m ³ /person)
Albatros	52,186
Cactus	44,413
Algarrobos	49,348
San Francisco	120,208
Arrayanes	15,300
Gran Maestro	21,886
Isla Sur	9,436
La Palmeras	56,557
La Planada	20,100
Manzanillo	39,521
Cabecera Parroquial El Progreso	2,370
Central	110,004
Divino Niño	24,326
Estación Terrena	42,595

F-3: Correlations between experienced issues and storage type

Analysis results of transcribed and translated interviews:

[water clarity]: mentioned by 58% (of total interviews)

88% the municipality or government, 12% the person themselves (private problem)

21% <1 day, 5% ≤3 days, 5% ≤1 week, 0% ≤2 weeks, 2% ≤30 days, 2% >30 days, 65% Not mentioned.

23% more than once a month, 2% once a month, 5% between once a year and once a month, 21% once a year, 7% approximately less than once a year, 0% don't happen anymore, 42% not mentioned.

[water shortage]: mentioned by 62% (of total interviews)

98% the municipality or government, 2% the person themselves (private problem)

15% <1 day, 22% ≤3 days, 20% ≤1 week, 4% ≤2 weeks, 4% ≤30 days, 4% >30 days, 30% Not mentioned.

4% more than once a month, 4% once a month, 4% between once a year and once a month, 30% once a year, 22% approximately less than once a year, 0% don't happen anymore, 35% not mentioned.

[water-related health issues]: mentioned by 26% (of total interviews)

100% the municipality or government, 0% the person themselves (private problem)

5% <1 day, 0% ≤3 days, 0% ≤1 week, 0% ≤2 weeks, 0% ≤30 days, 0% >30 days, 95% Not mentioned.

0% more than once a month, 0% once a month, 0% between once a year and once a month, 5% once a year, 11% approximately less than once a year, 0% don't happen anymore, 84% not mentioned.

[pipe leakage]: mentioned by 59% (of total interviews)

84% the municipality or government, 16% the person themselves (private problem)

20% <1 day, 20% ≤3 days, 14% ≤1 week, 0% ≤2 weeks, 5% ≤30 days, 2% >30 days, 39% Not mentioned.

7% more than once a month, 0% once a month, 2% between once a year and once a month, 16% once a year, 18% approximately less than once a year, 0% don't happen anymore, 57% not mentioned.

Overall: 89% of interviews mentioned at least one problem.

People reporting >1 problem type: 65% of total interviews.

Co-occurrence of problem types per person (count and % of all interviews)

	water clarity	water shortage	water-related health issues	pipe leakage
water clarity	43 (58%)	34 (46%)	16 (22%)	30 (41%)
water shortage	34 (46%)	46 (62%)	11 (15%)	31 (42%)
water-related health issues	16 (22%)	11 (15%)	19 (26%)	13 (18%)
pipe leakage	30 (41%)	31 (42%)	13 (18%)	44 (59%)

Top keywords in descriptions (per type)

water clarity:

treatment (8), dirt (8), during (8), has (8), arrives (6), tank (5), quality (5), plant (5), after (4), always (4)

water shortage:

during (14), requiring (12), shortage (11), cistern (8), hours (8), without (8), pipes (7), drought (7), runs (6), truck (6)

water-related health issues:

people (7), have (5), get (5), problems (5), quality (5), related (5), drinking (4), sick (4), food (3), stomach (3)

pipe leakage:

pipes (26), pipe (18), municipality (12), causing (10), breaks (9), fix (7), problems (5), occur (5), during (5), repairs (5)

Median time to resolution (days) where stated:

water clarity: 5.25

water shortage: 7.0

water-related health issues: —

pipe leakage: 3.5

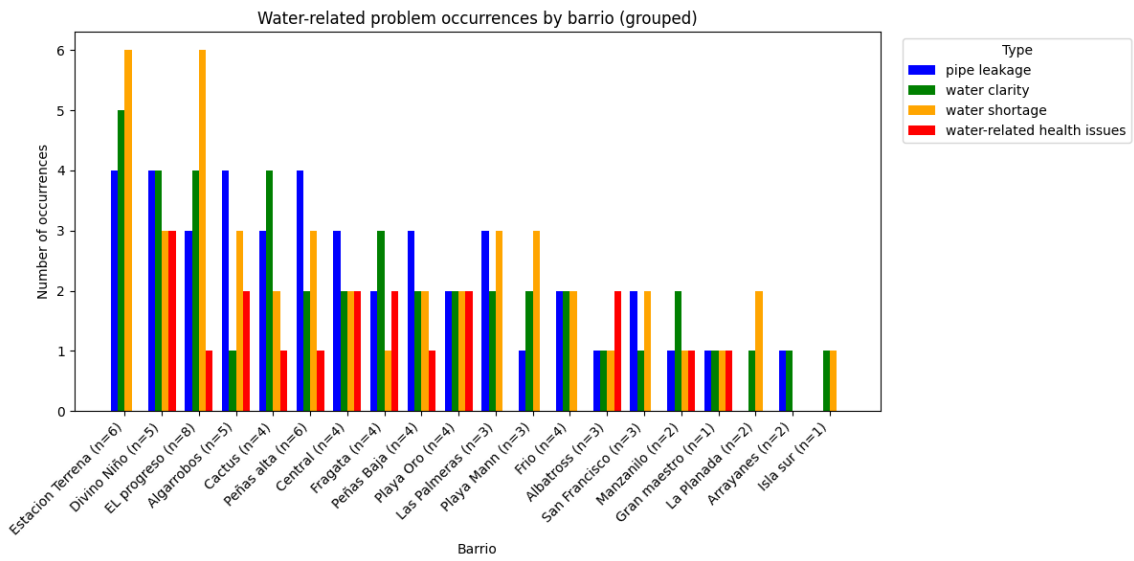
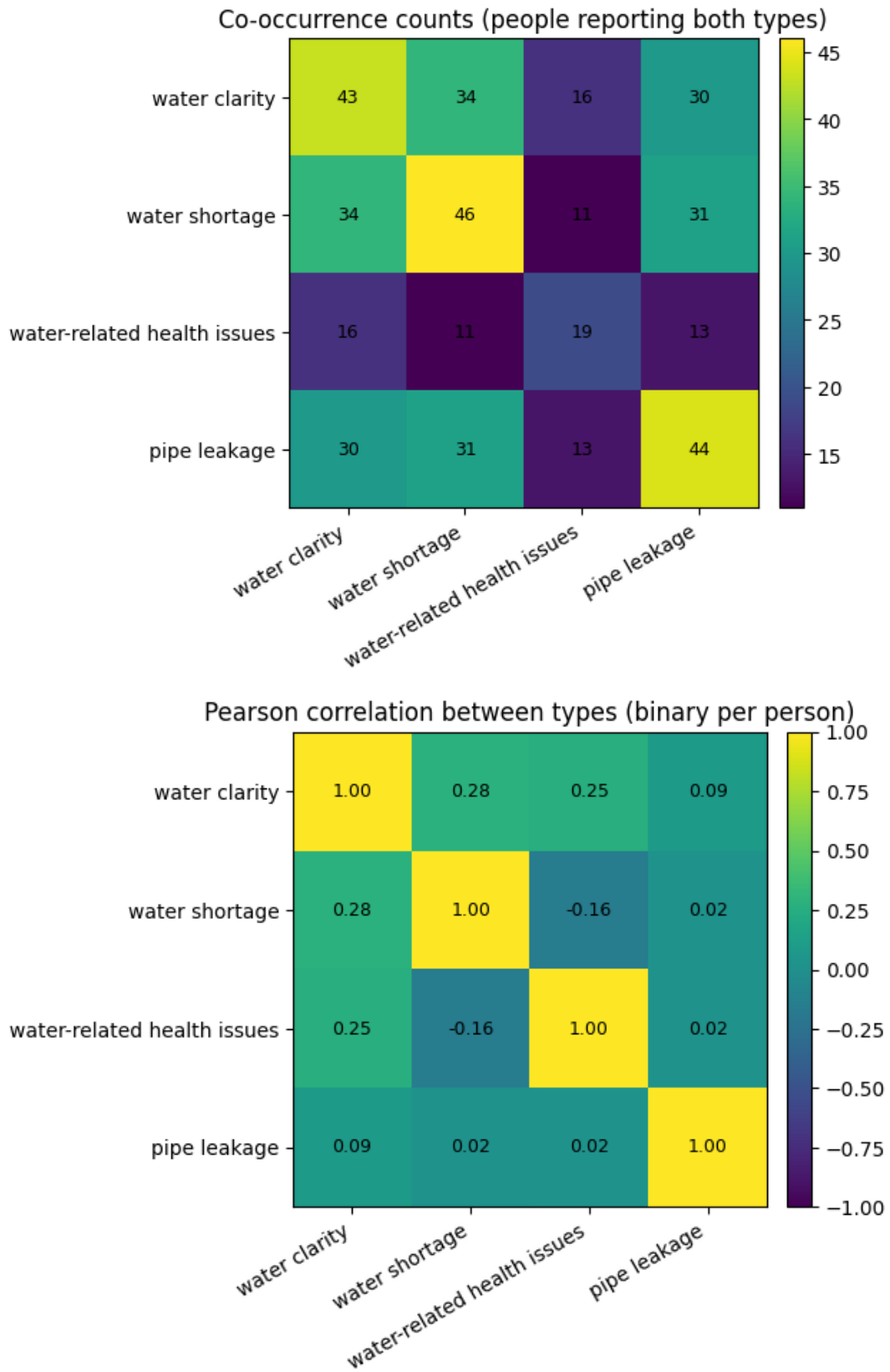
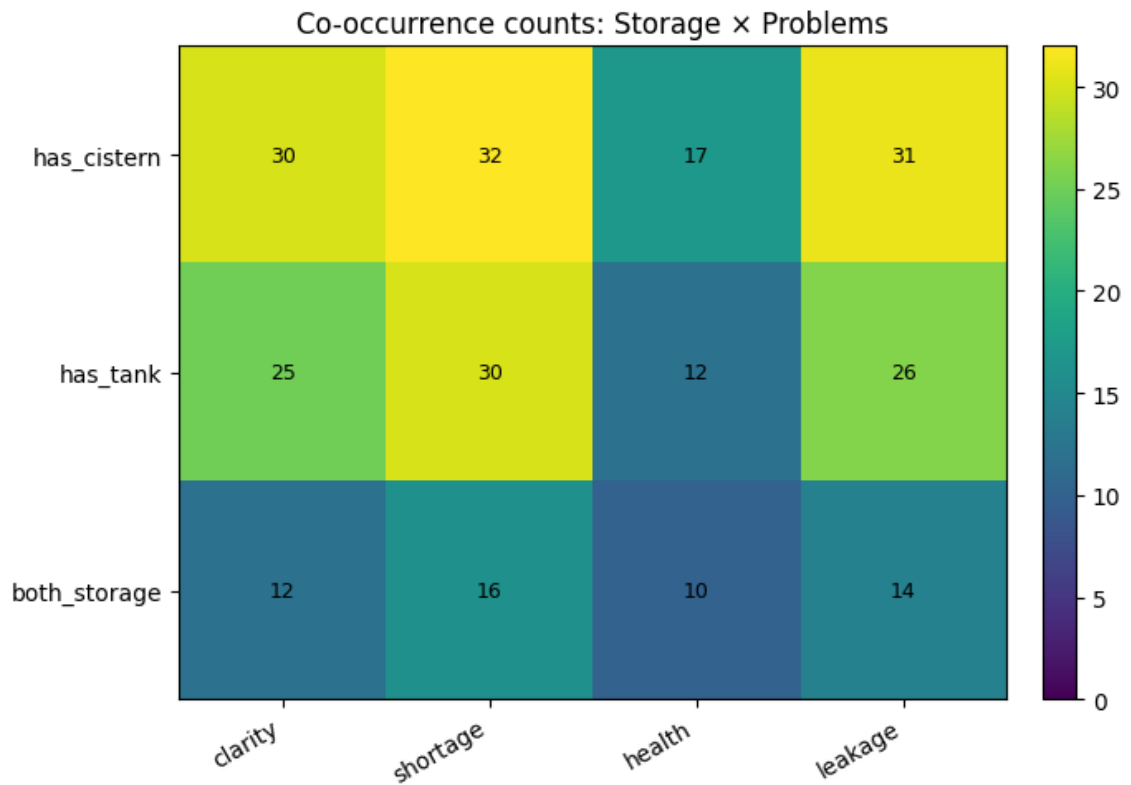
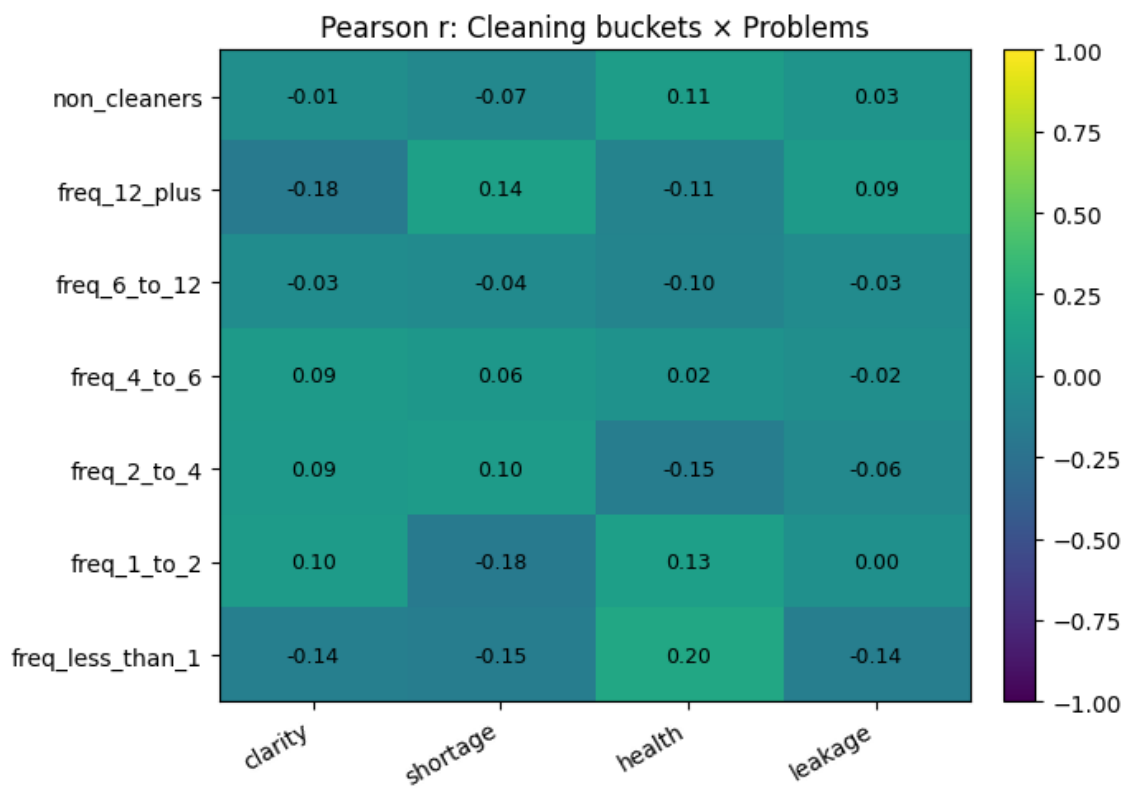
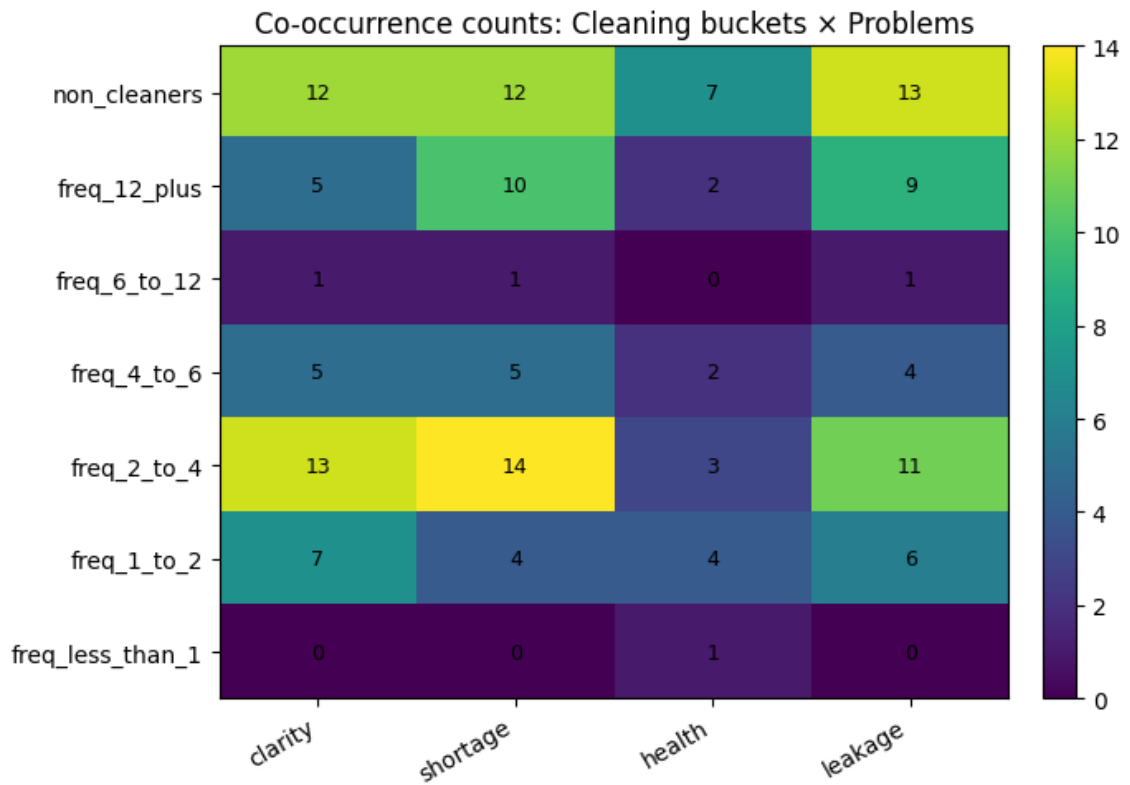


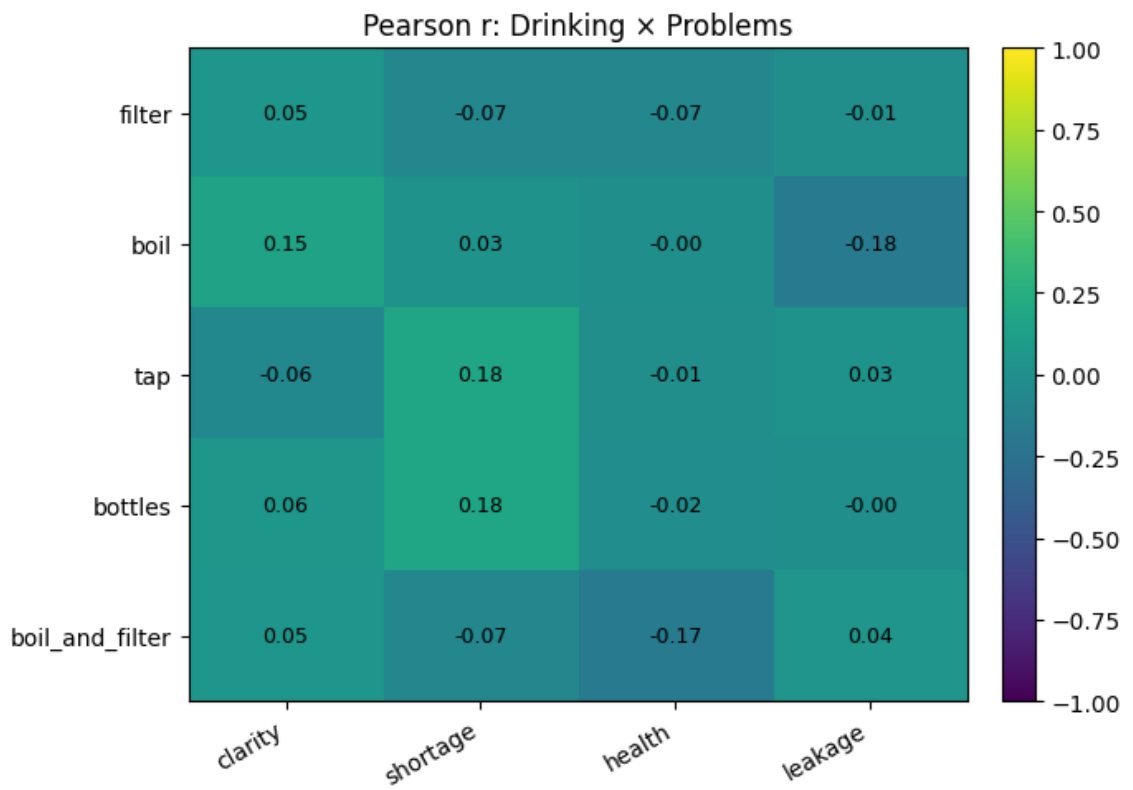
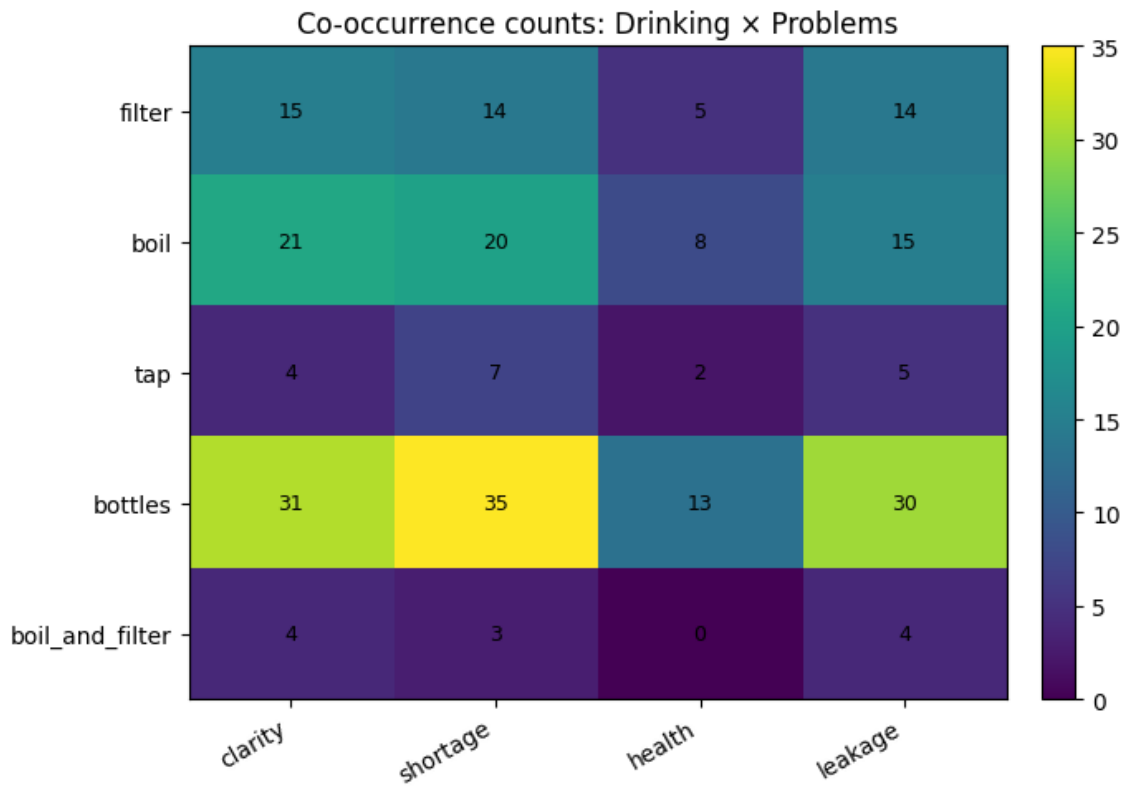
Figure 48: Barchart of water related problem occurrences by barrio.

Figure 49: Gallery of correlation matrices of water related problem occurrences.





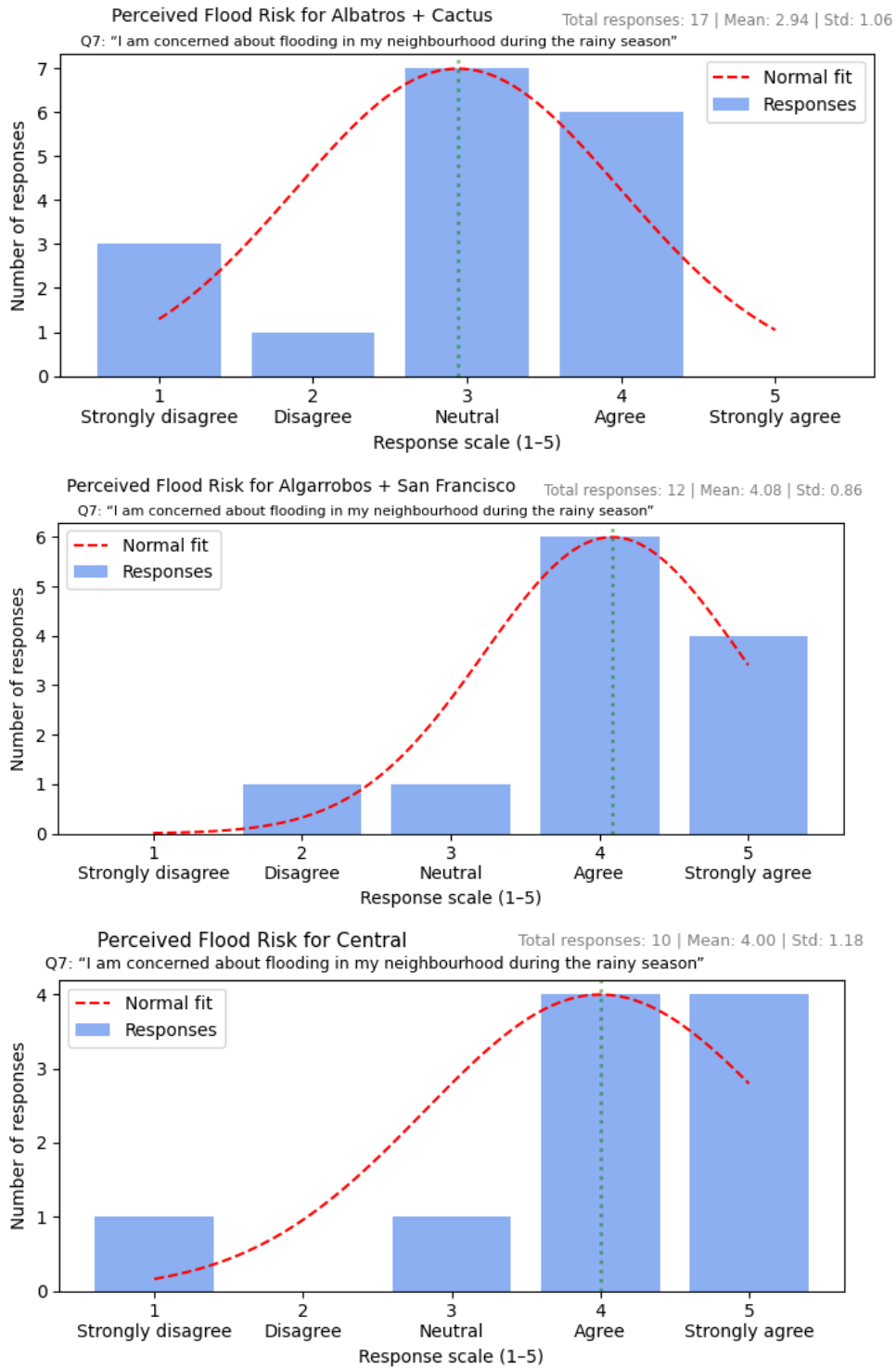


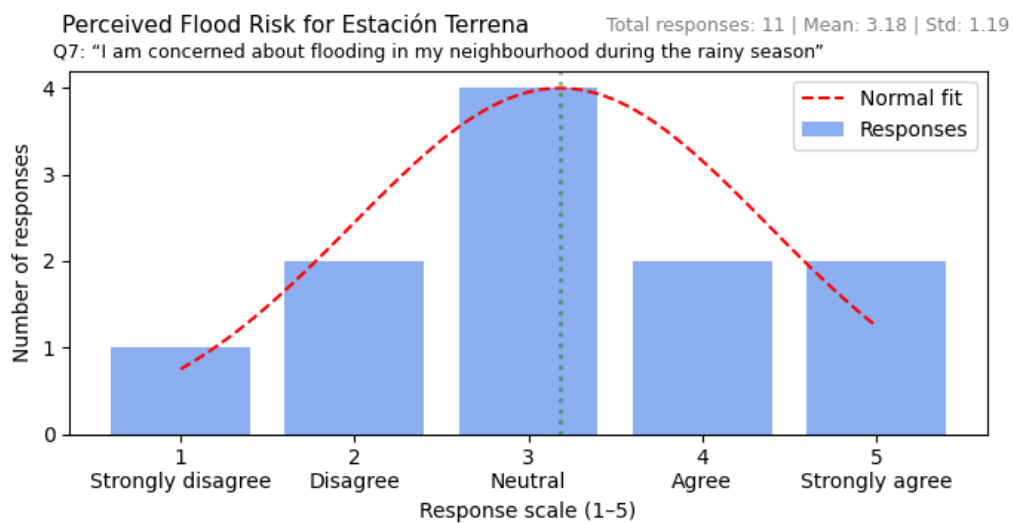
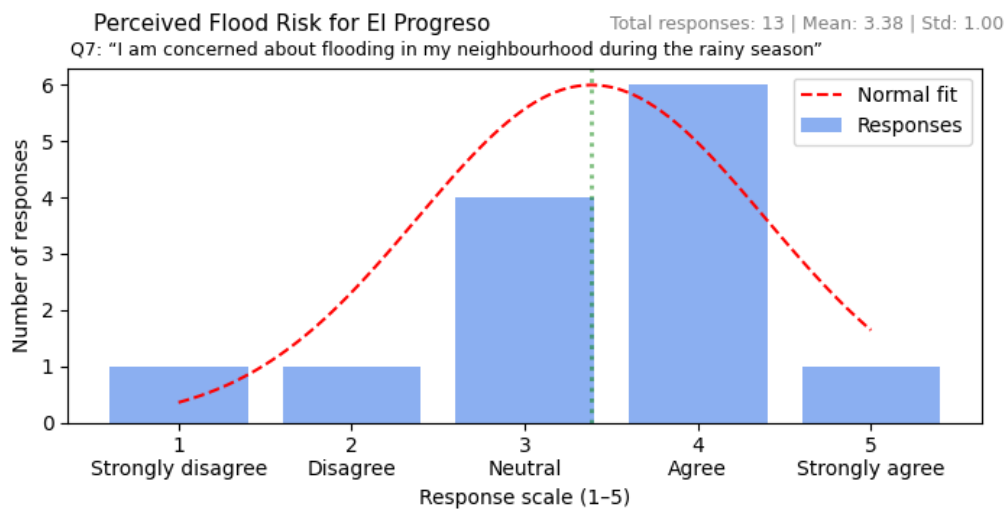
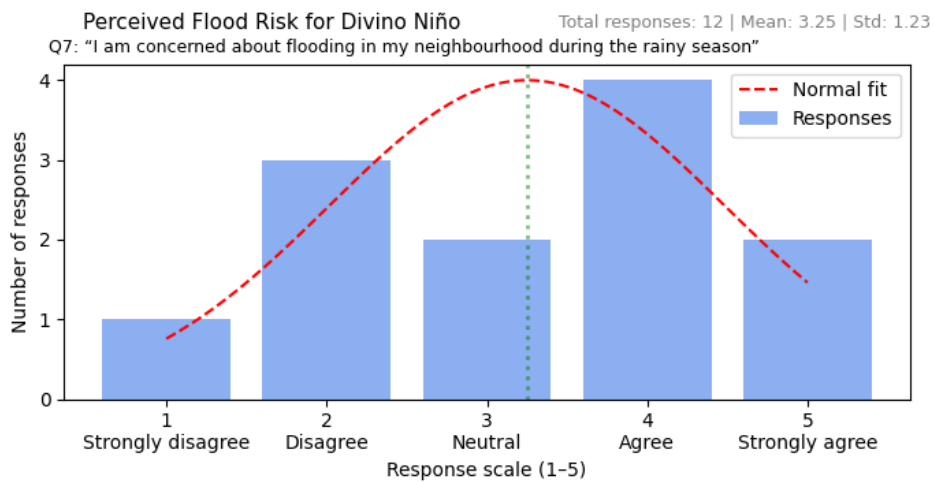


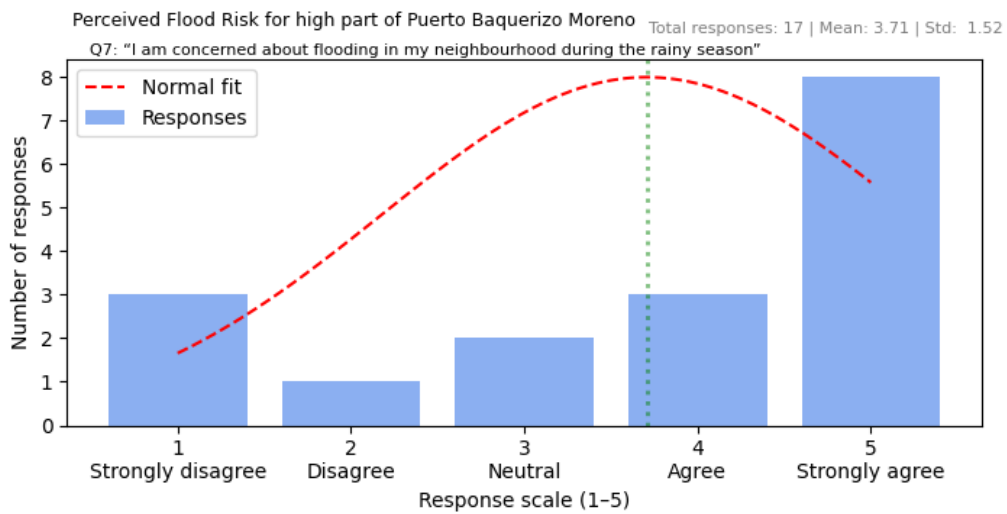
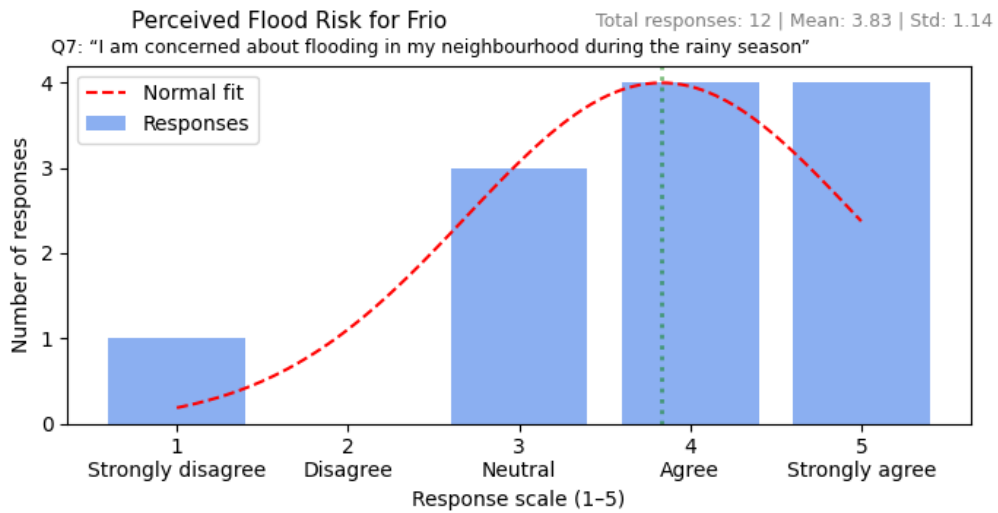
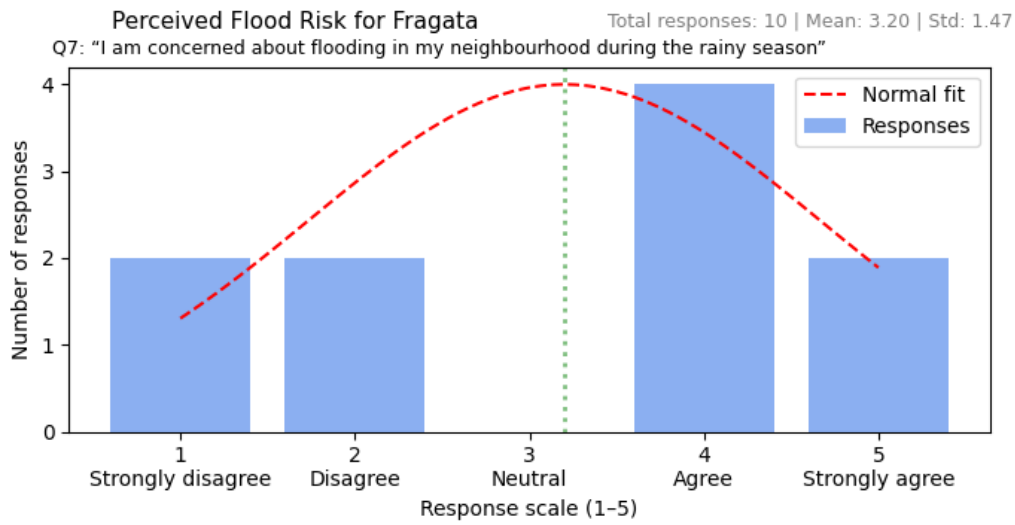
F-4: Perceived Flood risk distribution

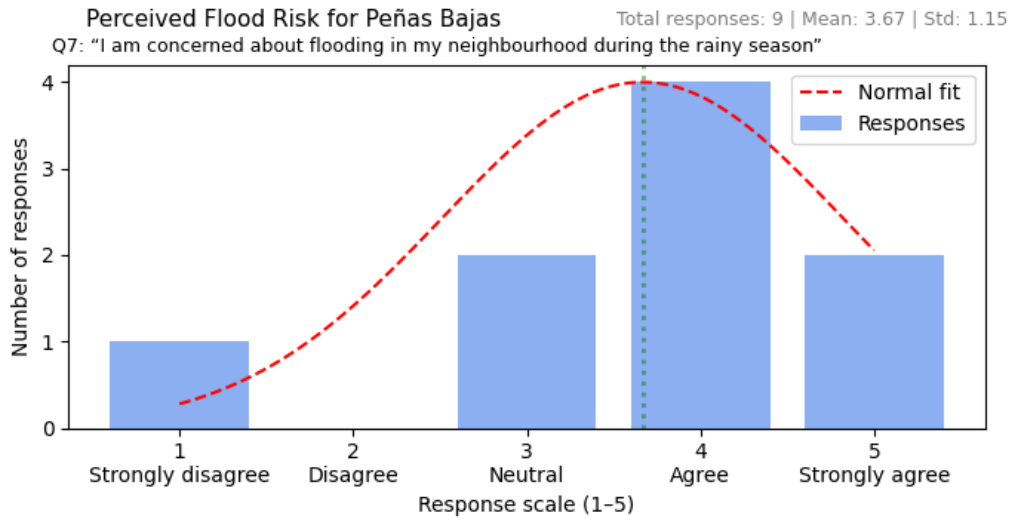
This section of the appendix presents the distribution of responses by neighbourhood to the question on concern about flooding, representing perceived flood risk.

Figure 50: Gallery with distributions of questionnaire responses on concern about flooding by neighbourhood (grouped), with normal fit curves.









*Although 10 questionnaires were collected from Peñas Bajas, one respondent omitted Q7, reducing the effective sample size for that question to 9

