Rural Sanitation in Chile: Diagnosis, Investment and Challenges Towards Sustainability

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Abstract

Chile faces an important challenge in rural sanitation, made evident by the low coverage of wastewater treatment plants (around 13% of communities have sewage or treatment). The rest of the population discharges their wastewater into septic tanks or technologies that meet Decree N°236/26 and, to a lesser degree, utilizes cesspools. This gap, compared to urban areas (coverage close to 99.98%), has negative social, environmental and public health impacts. In the context of implementing Law N° 20.998 of Rural Sanitation Services (SSR), which has been in force since November 2020, the State must guarantee access to sanitation and provide infrastructure in rural areas. This investigation assesses the current situation in said areas and estimates the necessary investment to close the gap, serving as an input to formulate public policy. We applied a methodology based on the analysis of the updated SSR database, with the objective of identifying deficits in the countries three macrozones (North, Center and South) and evaluating the investment in diverse technologies – both conventional and unconventional. The results show a significant issue: only 27% function without significant problems and close to 73% of rural wastewater treatment plants show operational and infrastructure failures; 30% of this latter segment is in a critical state and requires urgent interventions. Among the most common deficiencies, the standouts include lack of maintenance, lack of essential equipment,, rainwater infiltration, unforeseen population growth, deficient engineering design, difficulties operating complex systems and economic problems the rural sanitation services experience while sustaining operations. These gaps include coverage, quality and sustainability of solutions, requiring a comprehensive approach that takes into account local reality and the selection of adequate technology. The impact of these gaps is shown in environmental pollution, sanitary risks, and limitations on communities to administer their services and market their products. Faced with this problem, we present several strategies for a solution. First, it is recommended to increase investment in infrastructure, assigning priority to the replacement or rehabilitation of critical infrastructure following an evaluation of geographic, climatic and [population] density characteristics. It is also recommended to strengthen the operation of SSRs with the training and professionalization of operators, technical assistance, and continuous monitoring, in addition to updating regulations to favor the adoption of adequate technologies. Lastly, it is emphasized that there is a need to promote innovative and sustainable solutions, such as nature-based and renewable systems, which reduce costs and improve performance. Meeting these measures, in harmony with Chile's climatic commitments and the ODS 6, will make it possible to sustainably close the gap in rural sanitation, improving the quality of life of the communities and protecting the environment.

Keywords: *Rural sanitation, Wastewater treatment technologies, Public policy, Infrastructure sustainability, Environmental regulation.*

1. Introduction

In Chile, access to rural sanitation is regulated by Law No. 20.998 regarding Rural Sanitation Services (SSR), in force since November 2020. This regulation recognizes social organizations - non-profit committees and cooperatives - as the operators of rural sanitation services, authorized to manage drinking water and sanitation within a defined service area, usually associated with a locality. The State, through the Rural Sanitation Services Sub-directorate (SSSR) under the Hydraulic Works Directorate (DOH) of the Ministry of Public Works, is in charge of granting licenses, executing infrastructure works, maintaining a public registry of operators and formalizing and strengthening the work of these organizations. The Superintendent of Sanitary Services (SISS), on the other hand, is responsible for overseeing and regulating tariffs [1].

In contrast to the urban sector, which reaches levels close to 100% coverage in terms of wastewater collection and treatment, the rural world presents highly heterogeneous conditions and a structural lag in terms of sanitation [2]. Despite the existence of the legal framework and international commitments such as Sustainable Development Goal 6 (clean water and sanitation) [3], there is no systematized public information in Chile on the situation of rural sanitation. This lack of information significantly limits the planning, prioritization and design of evidence-based public policies, and hinders the understanding of the current state of the infrastructure and its operation.

Although there have been institutional efforts and various public investments in rural sanitation, these have tended to be ineffective due to the implementation of homogeneous technological solutions, without adequately considering the territorial, climatic and cultural particularities of each community. In many cases, these initiatives have been implemented by different government agencies without inter-institutional coordination or systematic medium and long-term evaluation mechanisms. This has resulted in the installation of technologies that are neither understood nor appropriated by the communities, with little or no technical training for their operation and maintenance, which ultimately leads to the abandonment or premature deterioration of the systems. As a result, the rural population faces adverse scenarios such as contamination of surface and/or subway [subterranean] water bodies and biota, increased tariffs to support oversized or inadequate infrastructure, among others.

Given this scenario, it is necessary for public policies to incorporate differentiated technical criteria that respond to local conditions and to strengthen training and permanent support mechanisms for the social organizations that operate the services. This

approach would make it possible to move towards technically viable and sustainable solutions [4] over time.

This study arises from a specific question: what is the rural sanitation infrastructure in Chile and what are its implications for public policy decision-making? This concern arises in the context of the implementation of Law No. 20.998, which establishes the State's duty to provide sanitation infrastructure in rural areas. However, the absence of systematized information has made it difficult to clearly assess the state of existing facilities and their operation, which prevents guiding investment in a manner consistent with the reality of the territory.

Based on internal information from the Sub-directorate of Rural Sanitation Services, the author constructed a database with information on rural sanitation infrastructure and carried out an analysis that made it possible to identify the main challenges in terms of coverage, technologies used and the operational status of the systems. This situation has direct implications for public health, environmental protection and sustainability [4] of community-managed services.

This article seeks to provide technical criteria to guide public policy decisions for investment in rural sanitation in Chile. The analysis is structured around two specific questions:

What is the current diagnosis of rural sanitation infrastructure in Chile in terms of coverage, existing technologies and operational status, considering that there are still information gaps?

What are the technical and regulatory factors affecting sanitation solutions implemented in rural areas and what are the implications?

2. How does rural sanitation operate in Chile? Institutional, regulatory and information diagnosis.

2.1 Institutional and Regulatory Evolution of Rural Sanitation in Chile

The regulation of rural sanitation in Chile has evolved from a fragmented approach to a more structured legal framework, but significant gaps persist in the territorial adequacy of the norms and the operational viability of the systems [5]. Currently, only about 13% of rural communities have sewerage or wastewater treatment, in contrast to almost 100% coverage in urban areas [2], which is evidence of a structural lag. Law No. 19,300 on the General Bases of the Environment (1994) introduced environmental management instruments such as the Environmental Impact Assessment System (SEIA) and emission standards for water protection [6]. Although these tools established unified environmental standards supervised by the Superintendent of the Environment (SMA) and other agencies, the resulting institutional framework continues to be fragmented: multiple sectoral entities (Health, Agriculture, Public Works, Defense, among others) have complementary and sometimes overlapping powers in the supervision of discharges, making integrated management difficult.

As shown in Table 1, different public institutions exercise complementary and overlapping functions in the control of surface and groundwater in Chile, depending on the type of activity, applicable regulations and territorial scope.

Table 1. Public institutions and their relationship with the regulation of contamination of receiving bodies in Chile.

Institution	Main Role	Applicable Regulations	Interaction with Regulations
Regional Ministerial Secretariat of Health (SEREMI de Salud)	Controls sanitary aspects of water discharges	Sanitary Code, sectorial regulations D.S. 90/2000, DS236, DS46/2002 and sludge.	Grant sanitary authorizations and supervise discharges at national level, especially in rural areas, in river, lake and estuary water bodies.
Agriculture and Livestock Service (SAG)	Control of agricultural and agro-industrial wastes	Agricultural sectorial norms, specific S.D. [a].	Control agrochemical use and residues with impact on surface and groundwater.
Directorate General of Maritime Territory and Merchant Marine (DIRECTEMAR)	Controls activities in coastal areas and maritime waters.	Navigation Law, D.S. 90/2000	Grant maritime permits for discharges into marine and lake water bodies.
National Fisheries and Aquaculture Service (SERNAPESCA)	Supervises discharges into bodies of water that affect hydrobiological resources	Fisheries Law, S.D. 90/2000	Verify impacts on aquatic species
General Directorate of Water (DGA)	Manages water rights and protects water resources	Water Code, S.D. 90/2000	Declare depletion and reserve of water sources
Superintendence of Sanitary Services (SISS)	Oversees compliance with sanitary and environmental regulations in companies holding sanitation service concessions and with Law 20.998 in rural areas.	General Law of Sanitary Services, D.S. 90/2000, DS46/2002 and sludge.	Require compliance with treatment and disposal standards for drinking water and sewage in urban and rural areas, in river, lake, marine and estuarine water bodies.
SEREMI of the Environment	Implements environmental policies at the regional level	Law 19,300 and derived regulations	Coordinate local policies with national guidelines
Ministry of the Environment (MMA)	Designs policies, standards and instruments for environmental management.	Law 19,300, S.D. 90/2000, emission and quality standards.	Develop regulations, declare saturated zones and plans
Superintendency of the Environment (SMA)	Oversees compliance with environmental regulations	Organic Law of the SMA (Law 20.417), D.S. 90/2000.	Supervise compliance, applies sanctions
SEA (Environmental Evaluation Service)	Manages the Environmental Impact Assessment System (SEIA).	Law 19,300, SEIA Regulations	Evaluate projects according to environmental impact

[a] Include regulations D.S. 129/2005, D.S. 133/2005, D.S. 148/2003, D.S. 594/1999, on control of pesticides, fertilizers, hazardous waste and sanitary conditions affecting surface and groundwater.

The specific regulatory framework imposes uniform requirements that represent challenges for Rural Sanitation Services (RSS). For example, Supreme Decree No. 90/2000 (DS90) regulates liquid waste discharges to surface waters and classifies as an "emitting establishment" any facility with a pollutant load greater than 100 equivalent inhabitants, requiring monthly monitoring of the effluent with a broad set of analyses (up to 35 different parameters) [7]. Similarly, DS46/2002 establishes strict limits and hydrogeological studies for discharging treated water to the subsoil, with minimum sampling frequencies that often exceed local capacities [8]. In addition, the old Decree No. 236/1926 still exists, which regulates individual systems such as septic tanks and latrines in isolation

without integrating them into the general scheme, generating regulatory overlap and control gaps [9]. Although these regulations are essential to safeguard public health and the environment, in practice they impose high technical requirements and operational costs even on small-scale systems, putting their sustainability under strain.

Law No. 20,998 on Rural Sanitation Services (2017) and its Regulation No. 50 (2020) [10] established for the first time a specific framework for the management of drinking water and sanitation in rural areas, recognizing local committees and cooperatives as operators of these services. This regulation segments the SSRs into categories (major, medium and minor segment) according to the population served and their management capacities, in order to guide investments and adjust requirements to the territorial context [10]. However, the implementation of the law is incipient: only in 2024 did the systematic collection of information on these systems begin at the national level, and there is still no unified registry or permanent monitoring of their operational performance. A critical aspect is that the law requires that the tariffs paid by users cover at least the basic operating costs of the SRHs [1]. Consequently, any increase in regulatory obligations - for example, higher effluent quality control requirements - has a direct impact on their operating costs and must be financed through tariffs, with potential impact on their economic viability.

Regarding wastewater treatment technologies in rural areas, Law No. 20,998 does not establish an explicit technical list. The selection and implementation of these solutions must comply with the requirements established in specific regulations, such as Supreme Decree No. 90/2000 (surface water discharges) and Supreme Decree No. 46/2002 (groundwater). Only Chilean Standard NCh 3456/2, regarding the reuse of treated water, provides technical guidance on possible treatments and uses in irrigation activities [11].

In practice, the costs associated with complying with mandatory environmental monitoring have not been fully incorporated into the current tariff structures of the WWTPs. More than 44% of rural treatment systems are managed by municipalities (directly or through neighborhood councils), 41% by committees operating with partial subsidies, and for the remaining 13% the management model is unknown [12]. Monthly fees charged to users for wastewater collection and treatment range from US$3.41 to US$7.76 (benchmark value as of March 2025) [12]. However, most of these utilities do not regularly monitor their discharges: only 3.7% have a quarterly or more frequent analysis frequency; 26.8% carry out measurements only once a year; and the remaining 69.5% do not monitor their effluents at all [12]. In sum, 96.3% of the WWTPs do not monitor the quality of their treated wastewater [12]. This scenario shows that fully implementing the sampling frequencies required by the regulations (e.g., 12 samples per year according to DS90) would imply a significant increase in the operating expenses (OPEX) of the WWTPs, putting upward pressure on tariffs and compromising their financial and operational sustainability.

Law No. 21,455, Climate Change Framework (LMCC, 2022), introduced principles such as territoriality, water security and the use of nature-based solutions to guide public policies in accordance with local realities [14]. However, the current regulation of sanitation still does not incorporate gradual criteria or territorial differentiation. For example, the SEIA regulations require that all treatment plants serving more than 2,500 inhabitants be submitted for environmental assessment, without considering vulnerability or local operational capacity [13]. Similarly, regulations such as the DS90 lack flexibility, imposing uniform standards and high costs even on small-scale rural systems, which contradicts the territoriality principle of the LMCC. Likewise, aspects promoted by the LMCC -such as integrated watershed management and low-impact technologies- are not reflected in current sectoral regulations or in their draft amendments, perpetuating a sanitation model that is not very adaptable, with little climate resilience and far from modern environmental objectives. In addition, the full implementation of the LMCC presents significant delays: by 2025 only four of the country's sixteen regions have Regional Climate Change Action Plans in force (prepared before the law), which are not fully aligned with the Long-Term Climate Strategy or with sectoral adaptation plans [15].

In summary, although the Chilean regulatory framework has incorporated stricter environmental standards, its application in rural contexts continues to face numerous obstacles. Among the main ones are weak institutional articulation, a centrist approach that ignores territorial heterogeneity, poor adaptation of regulations to local conditions, and the absence of truly flexible and viable legal mechanisms for low-income communities. These deficiencies, together with the technical, economic, training and information access limitations that affect many rural communities, hinder their capacity to comply with current requirements and jeopardize the operational and financial continuity of SRHs. Against this backdrop, it is essential to strengthen local capacities to adequately interpret and apply environmental legislation in order to move towards more equitable, participatory and sustainable rural water management.

2.2 Institutional constraints and information gaps for effective management of rural sanitation

The management of rural sanitation in Chile involves a diversity of institutions with regulatory, operational, oversight and financing attributions. However, the absence of integrated governance has generated a fragmented institutional structure, with poorly coordinated and overlapping roles, which hinders the efficiency of public investment and hinders the timely implementation of sustainable sanitation solutions in rural areas [16, 17].

Various state institutions are involved in the management of rural sanitation in Chile, with functions ranging from investment and oversight to project operation and evaluation. This multiplicity of actors, although necessary, presents overlapping roles and little effective articulation, which contributes to fragmented governance. The following table summarizes the main functions of the entities involved [16].

The following table summarizes the institutional functions:

Tab. 2. Main functions of public institutions related to rural sanitation in Chile

Institution	Main functions
SSSR (DOH)	Investment in infrastructure, formalization of SRH operators
SISS	Control and regulation of health services
MIDESO	Project evaluation through the SNI
MUNICIPALITY	Operation, project formulation, technical units, mandate agreements, etc.
SUBDERE and GORE	Financing of SRH initiatives
SERVIU	Sanitation in rural housing expansion areas
DGA, SEREMI Health, INDAP, SERNAMEG	Complementary technical and regulatory roles

The Master Plan for Public Investment in Rural Sanitation, prepared in 2015, attempted to collect relevant information from the institutional actors listed in Table 1. However, the articulation between these entities has been insufficient to build a national cadaster that is comprehensive, updated and verifiable [16]. Along the same lines, the SISS 2021 Study concludes that most of the available information comes exclusively from the Sub-directorate of Rural Sanitation Services (SSSR), with little or no collaboration from other

institutions. Of 346 municipalities contacted, only six responded, and only one region managed to update its cadaster. In addition, a serious lack of information on sewerage and rural sewage treatment plants was identified, which seriously limits the capacity for sectoral oversight and planning [17].

Although Law No. 20.998 requires the formal registration of operators to access licenses, by the end of 2023 most of them were not formalized. In 2024, 2,291 of the 2,241 rural health services currently recognized by the MOP were registered (93.86%). This progress is recent and reflects the acceleration of the process following the entry into force of the Law. However, the following stages of implementation -administrative, such as licensing, and technical, such as oversight and compliance with standards- are more complex and are progressing at a slower pace, so there is still a significant way to go. In addition, the sector lacks a specific budget line item in the National Budget Law, a situation that will remain in force until 2025. The SSSR has initiated an investment to develop a Diagnosis of the Technical Infrastructure of Assets of Rural Sanitation Services, which will include detailed information on the 2,241 formalized committees and cooperatives. However, the results will take at least a year to be obtained, so this article uses the survey of basic information available to address this gap [17].

Studies agree that sector data are fragmented, obsolete and not standardized. The Master Plan identified 733 RPA systems in the Valparaíso, Metropolitan, O'Higgins and Maule regions, of which only 29.1% had collective sanitation systems [16]. This information is complemented by the technical analysis conducted by IFARLE in 2019, which details technological deficiencies, particularly in plants with processes such as activated sludge or SBR, which require capacities not available in rural areas [18].

The study prepared by SUBDERE in 2018 was based on the information contained in the National Cadaster of Rural Wastewater Treatment Plants 2012. This diagnosis identified a total of 550 operational plants, of which 40% were in fair or poor condition, and 220 required urgent interventions, such as replacement, improvement or rehabilitation. The updating methodology was limited, since only five locations were validated in the field, which restricts the statistical representativeness of the analysis and accentuates the gaps in the quality of the available data [19].

The Final Diagnostic Report on Rural Sanitation Services in the Region of Arica and Parinacota (2024) exemplifies these weaknesses. The study indicates as a base source a set of DWG plans provided by the Directorate of Hydraulic Works (DOH), without specifying their origin or date of preparation. Although it is indicated that these data were complemented by GPS field surveys, no official methodology is described at , nor are collection instruments, validations or primary sources used between 2023 and 2024 identified. This lack of methodological clarity and traceability compromises its usefulness as a robust technical input for sectoral planning. Furthermore, as it deals with only one region of the 16 that make up the country, its results are partial and cannot be extrapolated to the national context [20].

The Final Report of the National Water Roundtable suggests strengthening the institutional framework and improving SRH management. However, this report incorporates coverage data from the WASH database (WHO/UNICEF, 2020) without detailing the primary source or the methodology used for its collection, which detracts from its technical soundness and limits its use as a reliable input for sectoral planning [21]. This situation is not isolated. Other sources such as the National Cadaster of Rural Wastewater Treatment Plants 2012, used as the basis for the SUBDERE 2018 study [19], also lack updated methodological traceability. In these cases, neither the field validation activities nor the data collection instruments are made explicit, which generates uncertainty regarding the validity, coverage and representativeness of the information. This recurrent pattern of using old data or data without clear traceability is evidence of a structural weakness of the national rural sanitation information system, affecting the capacity for decision-making and the design of sectoral public policies.

At the national level, the National Institute of Statistics (INE) has not incorporated information on sewage treatment or collection in its censuses prior to 2023, and even less with an explicit differentiation between urban and rural areas. Only the 2024 Census contemplates the incorporation of these variables for the entire population, which represents a significant advance towards the comprehensive characterization of access to sanitation. However, INE has partially addressed this issue in its sectoral publications. The Annual Environment Report 2023 presents statistics on sewage, focused exclusively on urban areas and based on information provided by the Superintendency of Sanitation Services (SISS), without including territorial disaggregation. The document clarifies that the indicators are constructed based on the urban population with sewerage, reporting the percentage that receives sewage treatment with respect to the urban total and the total with sewerage network [22].

Taken together, these structural and informational weaknesses reveal the urgent need for an integrated national rural sanitation information platform, with standardized criteria, continuous updating mechanisms and effective institutional articulation.

Despite these limitations, Chile has an institutional model for the provision of rural sanitation services that dates back to the 1960s, with the creation of the Rural Drinking Water Program (RWP) led by the Ministry of Public Works (MOP). This model was normatively strengthened with the enactment of Law No. 20.998 in 2020, which formally incorporated the sanitation component -sewage collection and treatment- and recognized the committees and cooperatives as legal operators of the system. Currently, the DOH's Rural Sanitation Services Sub-directorate (SSSR) leads not only investment in infrastructure, but also technical and social support through its Community Management Unit. This unit promotes the education and training of operators in administrative, regulatory, financial and technical areas, with the aim of strengthening their local capacities, guaranteeing continuity of service and ensuring compliance with the standards required to obtain and maintain the license. This approach seeks to consolidate participatory governance, with operational autonomy from the communities, but within a national regulatory and technical framework.

3. Technical-operational diagnosis of the rural sanitation systems in Chile.

3.1 Methodology for the diagnosis and technical-operational systematization of SRHs

There is currently no public, consolidated and updated database on SRH in Chile. The information available is partial, fragmented by region and often outdated, making it difficult to make informed decisions.

To address this gap, a critical review was conducted of regional files, internal administrative databases and technical files compiled by territorial teams between 2017 and 2023 of the Sub-Directorate, inputs that had not been previously integrated. Subsequently, between May 2024 and March 2025, a national survey of technical data was carried out to characterize the state of implementation, operation and coverage of existing systems, with their systematization and validation. This process was led by the author in coordination with the Community Management Department of the SSSR.

In October 2024, the first version of a unified database was consolidated with the information collected, which was updated in March 2025. The process included field verifications, cross-checking with administrative records and validation with regional professionals. Although the database has not been published and is not available to the public, it provides the technical basis for subsequent analyses.

In addition, the Official SSSR Cadaster published in June 2024 [23], which identifies the non-profit operating organizations

governed by Law 20.998, was incorporated. This cadaster made it possible to complete relevant variables such as service segment, number of "start-ups", population benefited and type of settlement. Start-up" is defined as the home connection from the public network to a dwelling.

The resulting database is especially valuable for identifying systems that have deteriorated in operational condition, have been abandoned or lack concurrent interventions by other institutions. This is critical given the difficulty of accessing reliable and updated information from other public entities. The temporal coverage of the data collection varied by region.

Tab. 3. Temporal distribution of the information collected

Year of information	Regions [No.]	Name of the Regions
2024	7	Antofagasta, Araucanía, Atacama, Los Lagos, Magallanes, Tarapacá, Arica and Parinacota
2023	2	Los Ríos, Metropolitan Region
2021	1	Valparaiso
2017	5	Biobío, Coquimbo, Maule, Ñuble, O'Higgins, Aysén

Considering the territorial and operational diversity, the country's 16 regions were grouped into three macro-zones (North, Center and South), defined by climatic and geographic criteria other than the usual political-administrative division. This approach incorporates variables such as aridity, rainfall variability and pressure on water resources, factors that directly affect the sustainability of the SRH [24] [25] [26].

Tab. 4. Regional grouping according to macrozones

Macrozone	Regions
North	Arica and Parinacota, Tarapacá, Antofagasta, Atacama, Coquimbo
Center	Valparaíso, Metropolitana, O'Higgins, Maule, Ñuble
South	Biobío, Araucanía, Los Ríos, Los Lagos, Magallanes, Aysén

In addition to this territorial grouping, the SRHs were segmented by size in accordance with Article 106 of the Regulation of Law 20.998 [1]: major service (more than 600 starts), medium (301 to 600) and minor (up to 300). Likewise, the housing density classification of the Rural Drinking Water Projects Manual [27] was adopted, distinguishing concentrated (≥15 dwellings/km of network), semi-concentrated (8-15 dwellings/km) and dispersed (<8 dwellings/km) systems. Finally, methodological criteria were established to guide the technical and economic evaluation in this and the following chapters. These criteria, selected for their regulatory, operational and social relevance, allow prioritizing future investments. The criteria considered include: Macrozone, Type of settlement, Population constraints, Service size segment, Technology used, Operating entity, Household junction coverage, Critical operational deficiencies, Effluent quality analysis (compliance with DS90 and DS46 [7] [8]).

Based on these integrated criteria, an unprecedented national baseline was constructed to support subsequent analyses of coverage, technologies, operational status and public policy recommendations.

3.2 Coverage and territorial-operational characterization of the rural sanitation systems in Chile

Rural sanitation coverage in Chile presents significant territorial and operational gaps. Of the 2,441 Rural Sanitation Services (RSS) officially recognized nationwide [23], only 316 localities have some kind of sewage collection and/or treatment system, which is equivalent to 13% of the total. These localities benefit 620,617 people, that is, 27% of the rural population with access to drinking water.

In these localities, 326 different systems were identified, indicating that some communities have more than one plant. In fact, 15 localities have multiple treatment facilities, the result of fragmented institutional interventions without central coordination, which have led to disjointed technical solutions, greater operational requirements and additional costs for the communities. In contrast, three localities have a single, integrated plant, which allows for more efficient management. Particular cases were also observed: three SRWs discharge their wastewater into concessioned urban networks and one operates under the management of a mining company, which shows the coexistence of different models in the territory.

Of the total number of systems, 306 correspond to treatment plants in operation, while 20 discharge wastewater directly without treatment, i.e., without associated sanitation infrastructure. This situation, present in 5.5% of the systems with a network, represents a relevant sanitary and environmental risk, especially in contexts with scarce water availability or limited operational capacity.

A critical limitation of the survey was the lack of sewerage network maps in 278 localities, which prevented us from accurately estimating the number of homes connected to or facing the network. To fill this gap, we used as a proxy the percentage of households with household sewage connections with respect to the total with potable water, which allowed us to approximate the effective coverage of the service (Fig. 1).

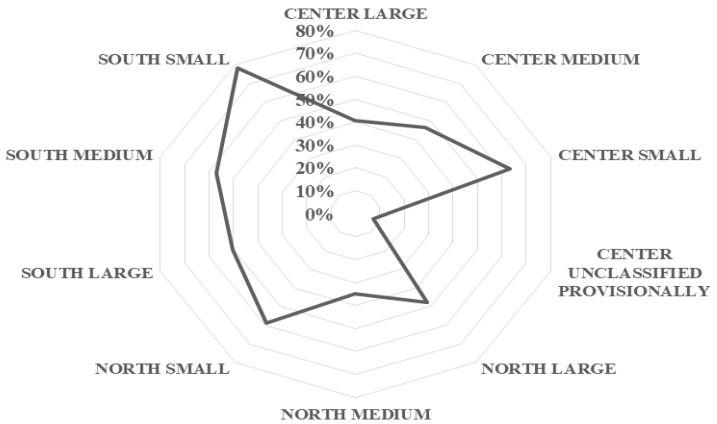

Fig. 1. Rural sanitation coverage by macro zone and SRH segment

National coverage is insufficient, not reaching 100% in any macro zone or segment. The highest coverage is observed in the SRH of the lower segment in the southern macro-zone (78%), followed by the center (64%) and north (59%), which is contradictory considering that the highest concentration of the population is in the higher segments.

Table 5 provides a comparison by macro-zone, considering the number of SRH, systems with network and treatment, and estimated levels of relative coverage.

Tab. 5. Comparison by macro-zone: coverage, number of systems and gaps in rural sanitation

Macrozones	SSR [N°.]	SSR with Networks [N°].	With Network and Sanitation [No.].	Relative health coverage [%].
Center	148	6	142	47%
North	89	1	88	50%
South	89	13	76	61%
Grand total	**326**	**20**	**306**	**53%**

From a territorial perspective, sanitation infrastructure is mainly concentrated in the central macro-zone (45% of localities with systems), followed by the north and south (27%). This pattern reflects a historical prioritization of investments in areas with higher population density. However, it is in the southern macro-zone where the largest number of systems discharging without treatment is registered, followed by the north. These situations are not necessarily due to a lack of resources, but to recurrent difficulties in the execution of projects, such as company bankruptcy, contractual disputes, penalties for non-compliance, and weaknesses in administrative management.

Considering the macro-zones with wastewater treatment, the center concentrates the largest number of localities (44%), also has the lowest relative coverage (47%), followed by the north 27%) and south (23%). The latter has achieved greater effectiveness in the implementation of infrastructure, despite facing climatic and logistical challenges [24] [25]. In contrast, coverage in the northern zone is lower due, in part, to the fact that most of the infrastructure is in the lower segment (58%) and is partially distributed within the same locality, reflecting uncoordinated investments between institutions.

Of the rural sanitation services with access to drinking water, 74% correspond to concentrated localities, which account for 86% of the rural population. This is followed by semi-concentrated systems 22% of the SRHs and 12% of the population), while dispersed systems are underrepresented. This distribution is detailed in Table 6, which segments the SRHs by type of settlement, size of service and population benefiting from drinking water and treatment.

Tab. 6. SRH and population benefiting from drinking water and sanitation, by type of settlement

Type of settlement	Segment	SSR [No.] a	Population with water [No. inhabitants] a	Population with [No. inhabitants] [No. inhabitants
Concentrate	Mayor	272	904.521	123.079
	Medium	384	517.096	50.813
	Menor	1.124	551.478	37.208
	No provisional classification	24	15.881	
Semiconcentrate	Mayor	8	25.845	
	Medium	33	42.349	1.280
	Menor	421	177.580	725
	No provisional classification	69	36.034	74
Dispersed	Medium	2	2.403	
	Menor	22	8.971	
	No provisional classification	8	3.441	
No information	Menor	61	16.545	
	No provisional classification	13	5.927	
Total		**2.441**	**2.308.071**	**213.180**

[a] Official registry of organizations subject to current regulations, non-profit organizations that have received contributions from the State. Information from the Subdirección de Servicios Sanitarios Rurales June 2024 [3].

Although most of the infrastructure is in the lower segment, the largest sanitized population is concentrated in the higher (58%) and medium (24%) segments. This dissociation is evidence of deficiencies in state investment planning. Figures 2 and 3 complement this analysis.

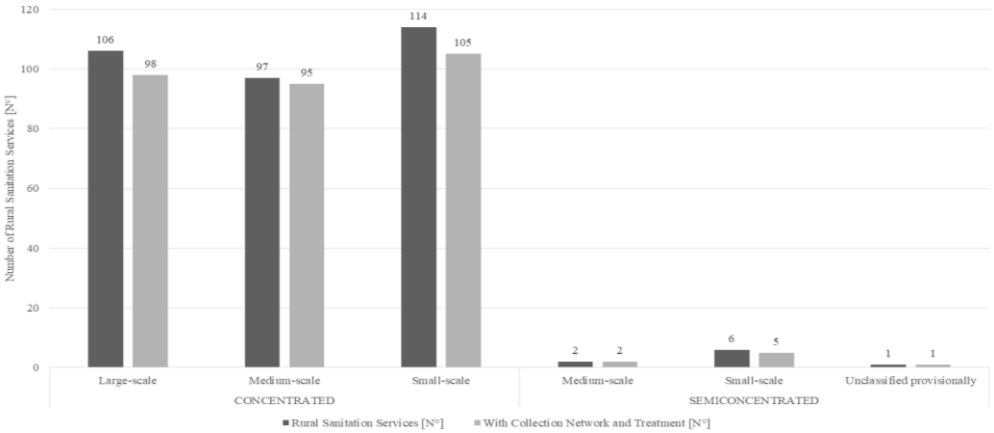

Fig. 2. Distribution of SRH with collection and treatment, according to segment and housing density.

97% of the plants executed are located in concentrated settlements. Within this group, the smallest segment accounts for 34% of the facilities, followed by the largest (32%) and the medium (31%). The same trend is observed in the systems that discharge without treatment. This reveals a structural gap in the operation: SSRs with less than 300 starts lack economy of scale and show weaknesses in local technical capacities.

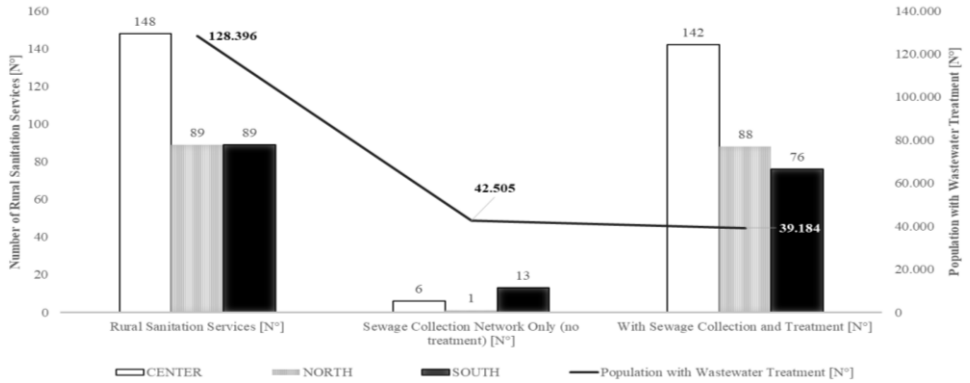

Fig. 3. Distribution of SRH with network and/or treatment, by macro-zone and population served.

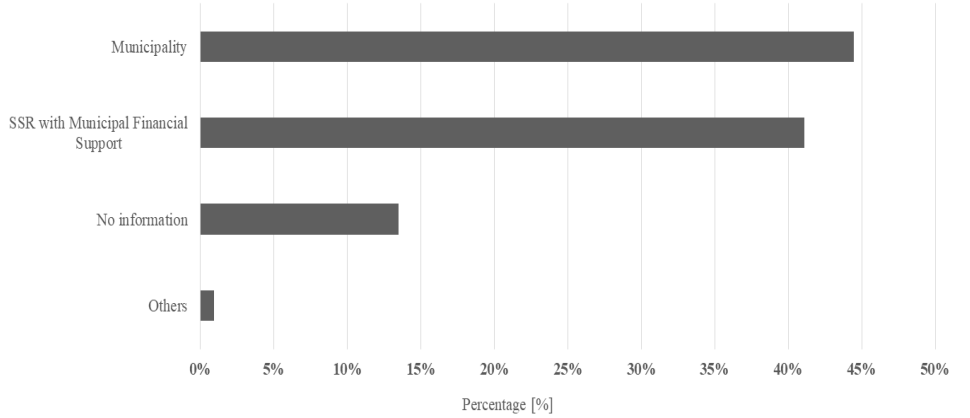

Fig. 4. Distribution of rural plant management models

The central macro-zone has the highest proportion of localities with infrastructure (46%), followed by the north 29%) and the south (25%). However, it is in the south where more untreated systems are concentrated, which highlights the urgency of reviewing the territorial prioritization criteria.

Regarding management models, 44% of the systems are operated by municipalities or community entities under their mandate; 41% are managed by committees that receive partial subsidies from the Municipality or another State entity, and 13% lack clear information on their administration - Figure 4. This last category represents a critical weakness of the system, as it prevents effective oversight and limits long-term planning. It is essential to strengthen local institutions, advance in the professionalization of operators and establish mechanisms for continuous technical assistance.

To complement the previous analysis and visualize inequalities in rural sanitation coverage in an integrated manner, a cross distribution was constructed between the population benefiting from treatment, the SRH segment and the geographic macro-zone. This approach makes it possible to identify not only the concentration of infrastructure in certain types of service, but also how it is distributed territorially, reflecting structural patterns of prioritization and coverage.

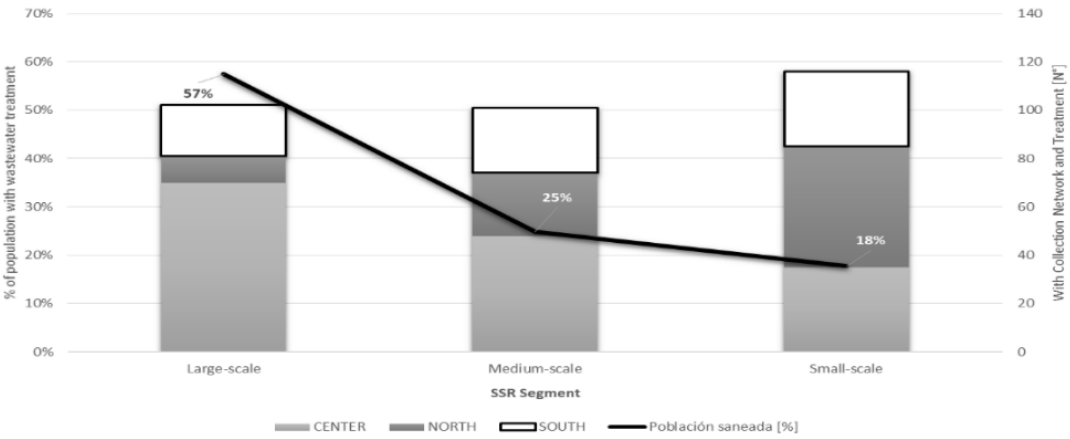

Fig. 5. Distribution of population with treatment by segment and macrozone.

Figure 5 shows a significant concentration of the beneficiary population in the SRH of the elderly segment, especially in the central macro-zone. This segment, despite having less installed infrastructure, manages to provide sanitation services to a much larger population, which reflects a more efficient use of the resources invested. In contrast, the smaller segment of health service providers, despite having the largest amount of installed infrastructure, contribute marginally to healthcare coverage, even in macro-zones such as the north and center, where they have a wider territorial distribution. This unequal distribution reveals a double gap: by scale of service and by geographic location. The intersection of both variables explains more than 80% of the asymmetries observed in this subchapter, and constitutes a key input for the formulation of prioritization criteria in future public policies.

3.3 Technologies used and operational status of the SSRs

The evaluation of the technological and operational status of Rural Sanitation Systems (RSS) in Chile identified relevant patterns in relation to the type of technology used, the size of the system, its technical performance and regulatory compliance. As of March 2025, only 27% of the systems analyzed show adequate performance, while the remaining 73% show structural or operational failures, or lack sufficient information to be evaluated. Of this total, around 30% of the SRHs are in a critical state, requiring urgent intervention. Among the main failures detected in these systems are rainwater infiltration, overloading due to unforeseen population growth, deficient designs, lack of essential equipment, direct discharges of wastewater into receiving bodies without prior treatment and partial abandonment of facilities. This situation reflects not only a gap in terms of coverage, but also a profound deficiency in sustainability and control within the sector.

The analysis revealed that the most commonly used technologies in the SSR correspond to activated sludge (mechanized aeration systems -STAM-, biodiscs and extended aeration), vermifilters, biodiscs, stabilization ponds and artificial wetlands. These technologies have different levels of operational complexity, as well as significant differences in their energy requirements, maintenance facilities and degree of compliance with Supreme Decree No. 90 (discharge regulations). In general, systems using activated sludge, despite being conventional treatment technologies, tend to exhibit higher rates of non-compliance due to their high operational complexity and their sensitivity to failure due to lack of maintenance or qualified supervision. In contrast, simpler technologies such as stabilization ponds, artificial wetlands or worm filters, although offering lower pollutant removal efficiency, tend to be more sustainable in rural contexts due to their low cost, lower energy requirements and ease of operation and maintenance compared to more sophisticated systems.

Additionally, the comparative analysis by system size segment (large, medium, small) shows significant disparities in operating condition. Figure 6 compares the number of SSRs in critical condition and in fair condition for each size segment, showing that systems of smaller scale and larger size present more critical cases. In the small and large segments, the number of systems in critical condition is substantially higher (or at least comparable) to that of systems in fair condition, reflecting greater operational precariousness at these scales. On the contrary, in the medium systems segment, the opposite trend is observed: systems in regular condition predominate, with a relatively smaller number of critical cases. This behavior is directly associated with management capacity, difficulties in the operation of the technology and the resources available according to the size of the service, e.g., Smaller health centers are generally located in rural areas far from urban centers, where institutional capacities are limited and access to specialized technical support is restricted, which increases the likelihood of facing severe failures without a timely response. In contrast, larger systems typically have better technical and human resources, in part because they serve larger populations, but due to lack of training and technological complexity they are not able to sustain the system in the short or long term.

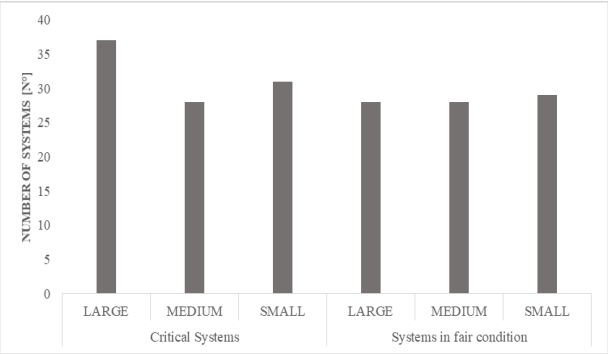

Fig. 6. Comparison of critical and fair condition SSR systems by segment (large, medium, small)

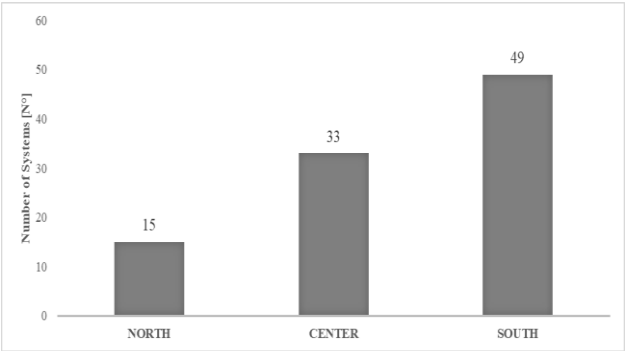

Fig. 7. Critical SSR systems distributed by macrozone (Center, North, South)

There are also important differences at the territorial level. Figure 7 shows the distribution of SRHs in critical condition according to the country's macro-zones (Central, North and South). It is evident that the southern macro-zone concentrates the largest number of systems in critical condition, with a number of cases that far exceeds that of the other regions. In the data analyzed, the south has about 51% of the critical systems, compared to about 34% in the central zone, while the northern macro-zone has significantly fewer systems in a critical situation (15%). It should be noted that the central zone presents a particular condition given its proximity to the capital of Chile (Metropolitan Region of Santiago), which implies a greater availability of support infrastructure and installed operational capacity. This geographical advantage translates into a better relative performance of the SRHs in the central macro-zone compared to more isolated regions, although this macro-zone also has a significant number of critical systems that should not be overlooked. , the territorial differences observed reinforce the need to prioritize differentiated intervention strategies, i.e., to focus resources and efforts on those areas with the highest concentration of critical cases (mainly the south of the country) and adapt solutions to the local realities of each macrozone.

Based on these results, it is recommended that the technological selection of SSRs be strengthened based on criteria of suitability to the territory, local operational capacity and long-term economic sustainability. It is also key to move towards simplified operating models that prioritize stability, incorporating nature-based technologies (e.g., artificial wetlands or worm filters) given their low energy requirements and greater stability in rural contexts. These measures, based on the evidence gathered, would improve the

performance of rural sanitation systems and close the operational and regulatory compliance gaps currently observed.

4. Conclusions

The national diagnosis of rural sanitation in Chile confirms a sustained structural lag, both in terms of coverage and operational sustainability. Of the 2,441 officially recognized Rural Sanitation Services (RSS), only 316 localities -equivalent to 13% of the total- have some type of wastewater collection or treatment infrastructure. These facilities benefit approximately 27% of the rural population with access to drinking water, which shows the low effective coverage of sanitation for a population of more than two million inhabitants. However, this figure not only represents a quantitative gap, but also reflects a profound territorial inequality and high operational fragility, given that 73% of the systems evaluated have technical or structural failures, and 30% are in a critical state, without minimum operating conditions.

The analysis by macro-zone shows that this precariousness is not distributed homogeneously. The southern zone concentrates more than 50% of the country's critical systems, a phenomenon explained in part by the greater geographic dispersion, adverse weather conditions and limited local technical capacity. In contrast, the central macro-zone, although it has a significant number of systems with installed infrastructure, has less relative coverage and faces maintenance and management challenges. The northern zone, despite having a smaller beneficiary population, concentrates a significant proportion of SRH in small segments, with limited operational scale. This unequal distribution of infrastructure and its performance reinforce the urgency of implementing policies differentiated by territory and scale, considering not only geographic, but also socioeconomic and climatic criteria.

In terms of technology, activated sludge systems - such as biodiscs, extended aeration and STAM - are the most widely used, but also those with the highest failure rates, due to their operational complexity and the lack of local capacity for their proper maintenance. On the other hand, simpler technologies adapted to the rural environment, such as stabilization ponds, artificial wetlands and worm filters, offer relative advantages in terms of cost, operational efficiency and resilience in low-technology contexts. The evidence gathered indicates that the homogeneous solutions applied in past decades have not responded adequately to the territorial diversity of the country, resulting in high levels of abandonment, over-dimensioning and scarce community ownership.

On the other hand, the cross evaluation between service size, housing density and benefited population allows us to identify a paradox: although the systems of the larger segment concentrate 58% of the population with treatment, the largest number of installations are located in the smaller segment, with low levels of coverage and high levels of technical precariousness. This disconnection between installed infrastructure and the population effectively benefited reflects failures in the prioritization of investments and in the design criteria of public policies, which have tended to favor replicable models without considering scalability, efficiency or operational sustainability.

In view of this scenario, it is essential to reorient public policy through an integral and adaptive approach. It is recommended, first, to establish territorial prioritization criteria that focus public investment in areas with the highest concentration of critical systems, especially in the southern macrozone, and that incorporate climatic and demographic variables as structuring elements. Secondly, regulatory modernization is required to make the standards of control and monitoring more flexible according to the scale of the service, without compromising environmental objectives, and to incorporate mechanisms of gradualism and territorial relevance. Thirdly, it is urgent to strengthen the operation of the SRHs, through permanent technical training programs, specialized assistance and strengthening of local technical units, ensuring the long-term sustainability of the systems. Finally, it is necessary to promote appropriate technologies, both conventional and nature-based, that ensure energy efficiency, low operational costs and greater adaptability to the rural context.

The articulated implementation of these measures would not only allow closing the coverage gap effectively, but also ensure that the solutions are sustainable, scalable and socially appropriate. In addition, it contributes directly to the fulfillment of Sustainable Development Goal 6 of the United Nations and the climate commitments assumed by Chile, advancing towards a more equitable and resilient rural sanitation management, aligned with the challenges of the 21st century. In short, ensuring the right to sanitation in rural areas is not only a technical goal, but an indispensable condition for community well-being, public health and the protection of ecosystems that sustain life in the territories.

In short, closing the rural sanitation gap in Chile requires prioritizing territories with a higher concentration of critical systems, incorporating climatic and demographic criteria in public investment [21]. The current regulations must be modernized, adopting a gradual approach that adapts the control standards to the scale and local reality. It is also urgent to promote appropriate technologies, including nature-based solutions, for their energy efficiency and operational resilience in rural contexts [28]. All this requires consolidating an intersectoral governance that overcomes the current institutional fragmentation, articulating efforts between the State, communities and technical actors, in line with approaches proposed by recent studies on SRH sustainability in Chile [29].

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