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Assessing the integration of planning instruments for urban land use and water service

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ABSTRACT

Land-use planning instruments guide development, significantly affecting future water demands. Hence, land-use and water-service planning should be integrated. However, water availability issues in urban areas might indicate that this integration is not happening. To evaluate the integration among planning instruments, we propose a set of indicators to quantify the magnitude of the integration and an appraisal framework for exploring the possible causes of a lack of integration. We apply them to eight settlements in Chile, and we find some inconsistencies between water service and land-use planning instruments. Suggestions are proposed to enable the desired integration.

1. Introduction

In the context of climate change, the rapid increase in urban population has led to many cities are significantly challenged to provide residents with adequate quantity and quality of water and sanitation services. The management of water is crucial for humans and natural ecosystems (Furlong et al., 2016). Accordingly, ensuring the universal access and sustainable management of water and sanitation services is one of the United Nations' Sustainable Development Goals (United Nations, 2015). Cities can be extremely efficient to address this goal as it is easier to provide water and sanitation services when people live more concentrated in space. However, with the rapid growth of urban populations, especially in developing countries in Asia, Africa, and Latin America (Zhang, 2016), the cost of meeting basic needs increases, and the pressure on the environment and natural resources intensifies. Moreover, the phenomenon of rapid urbanization observed in recent decades in many cities around the world has translated into serious water shortages within urban areas (Chen and Wang, 2010; Hylton and Charles, 2018: Lu et al., 2018). This implies that the adequate provision of water is a frequent problem in many cities worldwide, and can translate into major water quantity issues such as ground and surface water depletion, as well as important water quality issues related to various forms of artificial pollution (Furlong et al., 2016).

An estimated third of the global population does not have access to safe drinking water, and only 54% has access to a safely managed sanitation service (WHO, 2022). For example, in Africa and Asia, about 50% of the urban population has deficient access to drinking water (Nganyanyuka et al., 2014), and between 30% and 40% of the urban population suffers similar deficiencies in Latin America and the Caribbean, respectively (Kujumulo, 2003). Alterations in precipitation patterns and droughts associated with climate change are increasing this challenge.

In cities, water security depends on local hydrological conditions and capable management institutions (Krueger et al., 2019). Water management institutions traditionally deliver segregated water service, sewerage, and drainage services through a network of buried pipes and open channels. As urban populations have grown, urban water management institutions have systematically improved and extended the water infrastructure to meet specified targets (Furlong et al., 2016). Accordingly, the territory was usually considered a service for urban

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development, and water was considered an element supporting this growth. A common assumption behind city expansion has been that water service is always available (Li et al., 2015). However, the evidence has shown that this is often not the case. In many countries under rapid population growth and rural-to-urban migration, development occurs in rather chaotic and often informal ways, which implies that previous urban and water planning fails frequently. In these cases, rapid unplanned urbanization may lead to serious shortages of infrastructure, limited access to urban services such as drinking water and sanitation, and environmental problems that affect the quality of urban living (Zhang, 2016; Stanganini and de Lollo, 2018). Some settlement patterns in the urban fridges of many cities internationally, such as growing low-density urban sprawl and rural-residential developments, also put pressure on the ability to plan and provide water services.

The procedural integration of land-use planning and water services planning can contribute to establishing capable management institutions that can adequately deliver universal access and sustainable management of water and sanitation services. Urban growth and the residential zones should be defined by their availability of water (Long and Pijanowski, 2017). Thus, we argue that land-use planning is a crucial management institution that can support water services planning and contribute to facilitating reliable access to water and sanitation services. The objective of land-use planning is to delineate the best spatial pattern of different activities wanted to be promoted in a geographical area, managing potential conflicts and looking for the common good (Healey, 1997). It allows planners to look at different governance, timespans, and spatial scales while taking action at the local level (March and Henry, 2007; Hürlimann & March 2012). Accordingly, land-use planning enables the management of the territory to help coordinate the different aspects of water service from both a general and a local perspective (Angelo, 2001; Li et al., 2015).

Land-use planning can envision the impacts of possible changes on urban development and anticipate future needs rather than responds to problems after they arise (Hopkins, 2001; Hürlimann & March 2012). Thus, the procedural integration of land-use and water-services planning can maximize the current sanitary infrastructure by eliminating or postponing new projects that imply an environmental compromise (Beckwith, 2014). It can also contribute to more inclusive decision-making and a better understanding of impacts and trade-offs between competing objectives (Furlong et al., 2016). Ultimately, this procedural integration can lead the development of cities to more sustainable growth strategies and better and more permanent access to clean water (Gober et al., 2013).

The formal integration of both land use and water service can be obtained through legal and non-regulatory strategies (Stoker et al., 2022). As a first step, laws that require or cause coordination between land use planning and water management at different administrative levels should be implemented. Examples of this are the legal requirement to include a water component within land use plans, the exigency of developers to demonstrate adequate water services to receive a permit to develop, and the mutual requirements of both land use and water management agencies in a stormwater groundwater basin, floodplain and landscaping laws. Among non-regulatory strategies, the existence of guidance and best practices, financial incentives, resources and education, and partnership and stakeholder engagement have been reported to help the coordination between land and water management sectors (Local Governments Commission, 2019).

Despite the importance of integrating urban and water planning, in most countries, land-use and water management planning are, in practice, planned separately (Li et al., 2015; Rugland, 2022). This lack of integration prevails despite the evidence that unsustainable land-use planning practices produce induced dryness and inadequate water services (Gober et al., 2013). There is a range of uncertainties, contingencies, and conflicts involved in integrating urban and water planning, which relate to major categories of obstacles for sustainable development within the context of socio-ecological resilience presented by Gallopín (2002, p. 362): willingness, understanding, and capacity. Politicians, the private sector, and communities may have different reasons for their willingness or the lack thereof to promote urban growth or water services expansion. The lack of understanding about urban and water planning methods for dealing with change that acknowledge the linkages within and between systems and across scales can also be a barrier to integration. Moreover, urban and water planning's structural and agency capacities are essential for effective integration.

This disconnection has motivated a deeper analysis of how water and land-use planning are indeed being accomplished. For instance, in Carter et al. (2005) a normative framework for integrated land and water management is suggested and applied to three processes of community planning in Ontario, Canada. Using evaluative questions and benchmark criteria, they argue that their approach provides a flexible and practical tool to implement and evaluate integrated and sustainable management. Beckwith (2014) notices that the incoordination between land use planners and water services is not the exception, but the norm, and calls for more effective integration. He shows a 27-point survey tool designed to assess the integration of land use and water planning aspects of a community plan in Colorado, USA.

Acknowledging significant water management issues, Young and Sedoura (2019) applied a framework defined in the Water Framework Directives of the European Union to analyze the integration between water and land management in Lisbon (Portugal) and Porto Alegre (Brazil). The authors observed that the water management national guidelines are not fully consistent with the cities' master plans, concluding that additional efforts are needed to integrate water plans with master plans effectively. As the above-mentioned studies illustrate, the deficient integration of water service and land-use planning represents an increasing need for related research.

1.1. The case of Chile

Chile is a geographically diverse, highly urbanized country in the Southwest of South America. Chile has a population of 17.5 million people, and 87.8% of the country's population lives in urban areas, most of whom live in the central regions (INE, 2018). 'Continental' Chile, comprising the territory within the American continent excluding insular and Antarctic land, is 4000 km long between parallels 17°S and 56°S and more than 750,000 square kilometers, mainly delimited by the Andes Mountains and the Pacific Ocean. The country has markedly diverse climates, given its location, length, and topography (Universidad de Chile, 2019). In particular, Chile's central territory has a Mediterranean climate characterized by rainy winters and dry, warm summers. It is also important to point out that climate change is increasing the occurrence of droughts and that projections suggest a small rainfall decrease by 2100 but a large temperature increase (Williams, 2017).

In Chile, many cities are significantly challenged to provide their population with adequate water services. Different areas of rapid urban growth in Chile have had issues reaching the amounts of water they require due to a lack of availability of water stock all over the year, lack of infrastructure, or financial or technical difficulties in providing the service (Aguirre, 2013). Although Central Chile has various freshwater reservoirs and receives considerable rainfall throughout the year, it is common to find places without systems for drinking water distribution or wastewater disposal. This fact evidences that the government and communities have not adequately planned their property developments.

For example, in certain areas of Florida and Cobquecura, two urban areas in Central Chile with a Mediterranean climate and rainy winters, water is distributed by tank trucks. In Florida, fifty trucks service drinking water to more than 3500 people every day (Bascur, 2013). Governmental efforts to deal with the drinking water shortage issues in Central Chile have meant a significant monetary cost. For instance, in 2014, the regional government had to pay out approximately US$4.5 million for the water service plan (AMRBB, 2014). This shows that management institutions and instruments in Chile are not guiding the cities' growth to ensure universal and secure water access, and that the presence of a safe water service cannot be assumed even if local hydrological conditions suggest water availability.

Despite agreement about the need to integrate urban and water planning, the fact that many cities in central Chile are challenged to provide their population with adequate water sevices suggests that Chilean systems often struggle to achieve this integration. Thus, this research aims to examine the integration of urban and water planning systems in Chile, focusing on contrasting the projected growth established in land-use planning instruments versus water planning instruments. To do so, in the methods section, we describe the approach we used to assess the integration between urban and water planning considering four key instruments: (1) operational territories; (2) expansion plans; (3) land-use plans; and (4) sanitary feasibility studies. The water companies prepare operational territories and expansion plans. The municipalities prepare land-use plans and sanitary feasibility studies. We propose using three numerical indicators to quantify the level of coordination of planning instruments. In addition, to determine the possible causes of inconsistencies between the instruments, a 9-points appraisal framework was developed. As shown in the results section, we applied the indicators and the appraisal points to eight settlements in central Chile and verified a deficient integration between the water service and the land use planning instruments. The possible causes of the lack of integration are presented. Finally, we discuss the implications of these results and provide some concluding remarks.

2. Methods

This research uses a mixed-method approach of multiple cases (eight urban settlements in Central Chile). Using quantitative and qualitative analysis techniques, we examine the level of integration of urban and water planning systems in Chile. This mixed approach has been suggested to be crucial for public policy research and useful to provide an understanding that is difficult to attain with only one method (London et al., 2007; Brannen and Moss, 2012).

Eight urban areas within the Biobio region in Central Chile were selected as cases (Fig. 1). The Biobio region was chosen as a study region because of its Mediterranean climate; it has various freshwater reservoirs and receives considerable rainfall throughout the year, especially (but not exclusively) during winter. The following two criteria were considered to select the urban areas: (1) areas with valid land-use plans, that is, approved within the last 15 years that corresponds to the legal duration of these instruments in Chile; and (2) areas that cover a wide range of population sizes, according to government classifications, to obtain a representative study case. The main attributes of the selected zones are shown in Table 1. Socioeconomic characteristics of each area are included in The Communal Index Development, which combines welfare, education, and income levels, characterizing areas from low to middle development levels. In these cases, issues associated with rapid unplanned urbanization, informal development, growing low-density urban sprawl, and rural residential developments can be found.

2.1. Data sources

Four key instruments for planning water services when guiding urban growth are selected as data sources, because they are the main parallel instruments for this purpose. The water companies prepare operational territories and expansion plans. The municipalities prepare land-use plans and sanitary feasibility studies. These instruments provide information conceptually comparable about water services and their expansion associated with expected population growth from the parallel perspectives of water companies and local governments.

The first key instrument corresponds to the operational territory defined by the water companies. This instrument is a geographical area defined within urban boundaries where water companies are legally mandated to provide water services (see Fig. 1). Chile's main water management institutions are private companies providing water and sanitation services. According to the current regulations, water companies are free to choose the area they serve as long as they do it inside the urban boundary defined by the land-use planning instrument. Private water companies may be able to extend their services outside the urban area as long as it does not affect the quality and continuity of urban service. In addition, the state has mechanisms to require the extension of sanitary coverage to certain areas inside the urban boundary for social housing purposes. Companies are not allowed to provide water services to informal settlements.

The second key instrument considered in this analysis is the expansion plans. The future expansion of the operational territory, including the planned expansions of the areas serviced, should be reported in an expansion plan. This expansion plan is mandatory, designed by the water companies, and should be updated every five years.

The third key instrument is the land-use plan. Urban planning in Chile is mainly implemented locally by local land-use plans, *Plan Regulador Comunal*[1] (PRC), that regulate the use and development of land, focusing on urban areas. Land-use plans are usually managed and implemented by local governments. Various reports, including the sanitary feasibility stud,y inform the development and update of local land-use plans.

The fourth key instrument is the sanitary feasibility study. The sanitary feasibility study assesses and guarantees that water and sanitation services will be provided to all the urban areas at the local scale. Urban areas are those within the urban boundary defined by the land-use plan. Accordingly, the sanitary feasibility study is a key input in developing and updating land-use plans.

2.2. Data analysis

The quantitative analysis was selected to determine the level of integration between the instruments for water and land-use planning that plan for future growth, while the qualitative analysis helps us understand the possible causes of the lack of integration observed in the quantitative results.

2.3. Quantitative analysis

We designed three numerical indicators to examine the geographical coverage of water companies. These indicators allowed us to investigate the consistency among the current operational capacity of the water companies, the number of customers to be served in the future based on the companies' planned expansion, and the projected population growth defined by the land-use plans.

The Spatial Coverage Index compares the extent of the operational territory defined by the expansion plan of the water companies with the geographical scope of the urban area defined by the land-use plan. The Spatial Coverage Index measures the geographical extension covered by water companies relative to the ideal coverage envisioned by the land-use plan.

$$\text{Spatial Coverage Index} = \frac{\textbf{Size of the operational territory}}{\textbf{Size of the urban area}}$$

The Potential Expansion Index compares the population served by the water companies within the operational territories versus the potential population that the land-use plan allows inside the urban boundaries. The Potential Expansion Index shows the proportion of the maximum potential requirement for water within the covered urban boundary.

[5] Communal Regulatory Plan.

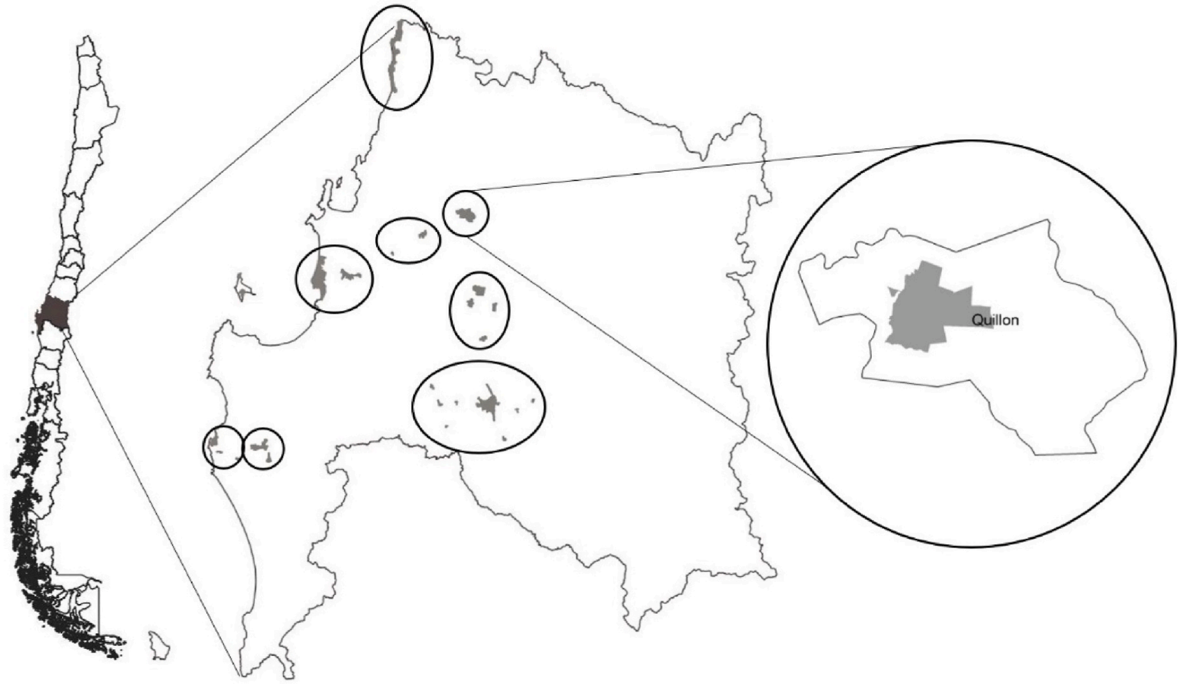

Fig. 1. The eight study areas (encircled) were located in the Biobio region, Central Chile. As an example, the case of Quillón is further detailed, showing the operational territory (grey area) in which the water provider is legally mandated to provide the service and the Urban Boundary (grey line) established in the land-use plan (Source: Authors).

Table 1
Main attributes of the urban zones considered in our study (Source: Authors).

Name of Urban área	Year land-use plans enforcement	Population (2002 census)	Operational territory size (ha)	Urban area size (ha)	Comunal Index Development[b]
Cabrero	2009	28,573	411	2456	0.407
Cobquecura[a]	2006	5012	88	5682	0.197
Coronel	2013	116,262	5715	7071	0.504
Florida	2007	10,624	138	505	0.251
Lebu	2009	25,522	359	771	0.424
Los Álamos	2008	21,035	472	1419	0.392
Los Ángeles	2007	202,331	2480	4694	0.470
Quillón[a]	2007	17,485	286	2350	0.299

[a] Cobquecura and Quillón were part of the Biobío Region when this study was conducted. Since 2018, they have been part of the new Ñuble region.
[b] Hernández et al. (2020).

$$\textbf{Potential Expansion Index} = \frac{\textbf{Population served by water companies}}{\textbf{Potential population within the urban boundary as per land} - \textbf{use plan}}$$

The Potential Demand Index compares the expected number of people that the water companies estimate they will serve in the near future (five years, in accordance with the duration of the expansion plan) with the number of people that the land-use plan allows inside the operational territory during the same period. This indicator represents the proportional difference in the number of people projected by both planning instruments in the same area.

$$\textbf{Potential Demand Index} = \frac{\textbf{Population that water companies expect to serve as per expansion plan}}{\textbf{Potential population in the operational territory as per land} - \textbf{use plan}}$$

For all indicators, the closer the indicators are to one, the greater the level of consistency and, thus, integration between the planning instruments under analysis. GIS datasets of SISS (2015) and MINVU (2016) were used for the numerical calculations.

2.4. Qualitative analysis

We performed a qualitative content analysis of the planning instruments to complement the above-mentioned indicators. This analysis allowed us to identify the reasons for the lack of consistency between urban and water planning instruments. As Beckwith (2014) and Carter et al. (2005) suggested, we supported our analysis with a set of appraisal points formulated for this study. These points examine the level of integration of the instruments analyzed. Three appraisal points (A, B, and C) were designed for each numerical indicator (Table 2): A and B focused on the integration between the land-use plan and expansion plan, and C focused on the integration between the land-use plans and the sanitary feasibility study.

To analyze these appraisal points, we reviewed the corresponding planning instruments and classified the assessment into deficient, improvable, and satisfactory categories. The relevant information in each case depends on the particular indicator under analysis (area, population, or potential population for the Spatial Coverage Index, Potential expansion index, and Potential Demand Index, respectively). We assessed these as follows:

- *Deficient* if the analyzed instrument did not mention the relevant information contained in the other instrument.
- *Improvable* if an instrument only mentioned the relevant information contained in the other instrument and this information did not affect its own definition.
- *Satisfactory* if one of the planning instruments considered the relevant information contained in the other planning instrument for its own definition.

3. Results

This section presents the results of the quantitative analysis used to determine the level of integration between the instruments for water and land-use planning that plan for future growth and for the qualitative analysis undertaken to suggest possible causes of the lack of integration observed in the quantitative results. The quantitative results show clear discrepancies between the potential water demand and current water service capacities. This finding indicates the lack of integration between the water service and land-use planning instruments. The qualitative analysis shows that most of the studied instruments do not refer to the relevant information in the other corresponding instrument, suggesting that these key omissions contribute to explaining the discrepancies between urban and water planning. These qualitative results show that water companies are not considering urban planning instruments (or inadequately doing so) when defining their instruments and vice-versa. This practice generates discrepancies in their definitions of the urban area versus the area with water services, the population currently served by water companies, the maximum potential population projected by the land-use plan, and their projected future population estimates of both instruments.

3.1. Quantitative analysis

The first set of results corresponds to the numerical results of the three indicators – (I1) Spatial Coverage Index; (I2) Potential expansion index; (I3) Potential Demand Index – applied to the eight cases. Fig. 2 shows a graphical representation of the results per indicator per case. For each of the three indicators, the shaded area represents the observed value of the indicator (the exact values are also shown above the circle),

Table 2
–Three appraisal points for each indicator were designed to examine the level of integration among the different planning instruments that were analyzed (Source: Authors).

Point	Indicator		
	Spatial Coverage Index	Potential expansion index	Potential Demand Index
Point A	When the urban boundary is defined, does the land-use plan consider the area defined by the expansion plan?	When defining the urban boundary, does the land-use plan consider the population identified by the expansion plan?	When defining the population density, does the land-use plan consider the potential population identified by the expansion plan?
Point B	When defining the operational territory, does the expansion plan consider the urban areas defined by the land-use plan?	When the operational territory is defined, does the expansion plan consider the population the land-use plan allows in the urban area?	Does the expansion plan consider the population the land-use plan allows within the operational territory?
Point C	Does the sanitary feasibility study consider the urban area defined by the land-use plan?	Does the sanitary feasibility study consider the population the land-use plan allows within the urban boundaries?	Does the sanitary feasibility study consider the population the land-use plan allows within the operational territory?

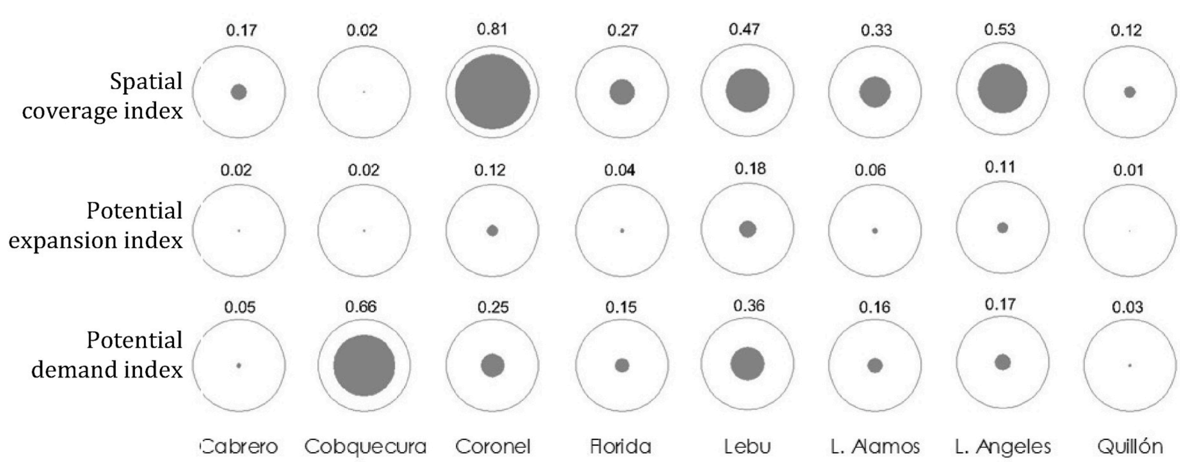

Fig. 2. Graphical representation and the exact numerical value of the results of the three indicators: (I1) Spatial Coverage Index; (I2) Potential expansion index; (I3) Potential Demand Index; per each study case (Source: Authors).

while the outer circle corresponds to the maximum possible value of the indicator. The maximum possible value of the indicator is 1, and it would imply 100% consistency between instruments and, therefore, full integration. Using normalized indicators allows us to visualize the degree of water coverage service companies can provide relative to the growth trends projected by the urban planning instruments. Overall, these results show the lack of consistency between the water companies' current and projected operational capacity (in terms of population and area serviced) versus the potential demand defined by the land-use plans in terms of population growth and urban area expansion. Even though threshold values showing how good an indicator is are not common (Shen et al., 2011), the observed disparity between the potential water demand and the current water service capacities is clear from our results. Since the higher the values of the indicators are, the more integrated the planning instruments are, Fig. 2 shows limited integration between the water-service and land-use planning instruments.

The first indicator, the Spatial Coverage Index, measures how similar the urban area and the operational territory are and shows great discrepancies between the urban area defined by the urban boundary of the land-use plan and the operational territory of water companies. As previously mentioned, water companies must provide the service within their operational territory, an area smaller than the urban boundary, creating an urban area (and therefore population) without water services coverage. The results show that in six of the eight areas under study (Fig. 2), more than 50% of the urban area was not part of the operational territory of the water companies. In those six cities, water companies are not required to provide water service in more than 50% of the urban land.

The most extreme result for this indicator was observed in Cobquecura (OCT = 0.02), where only a fiftieth of the urban territory is covered by a water service company. It has recently been reported that Cobquecura faces serious water shortages (Fuentealba, 2017). A coverage gap between the operational territory and the urban boundary was expected because water companies may require a minimum number of customers in a new area before expanding their operations there. However, the low values observed in all the study areas illustrate the lack of integration among the planning instruments participating in the water and land use planning processes. Because of the high cost for water companies to extend their facilities to new sectors, the spatial nature of this indicator is important as it makes visible the potential difficulty that will exist to service water if the urban development unfolds as allowed by the urban plan.

The following indicators, (I2) and (I3), show the necessity of expansion required from the water companies if urban areas evolve as the land-use plans allow.

The second indicator, the Potential Expansion Index, shows the greatest discrepancy of the three indicators. This indicator is designed to represent the magnitude of the expansion of the current operations required to guarantee water availability within the urban boundary. Accordingly, the results show great discrepancies between the current population served by water companies and the maximum potential population projected by the land-use plan. For example, in Quillón, the water service company may have to expand its current operations by 100 times to guarantee the service of its potential urban users. This situation again illustrates the lack of integration between water services and land-use planning.

The third indicator, the Potential Demand Index, considers the number of potential residents that urban planners and the water companies project in the same area, the operational territory, and shows more directly the lack of integration of the water service and the land-use planning instruments. Excluding Cobquecura (0.66), the low values obtained for this indicator show that both instruments, the land-use plan, and the expansion plans, project the future state of the cities based on different population estimates. This fact certainly affects the odds of fulfilling the future drinking water demand.

3.2. Qualitative analysis

For each indicator, a three-point appraisal framework was applied to each urban area of the study case, obtaining 72 assessment points. Table 3 details the frequency of assessments in each category, showing that the norm is that the planning instruments ignore each other (deficient). Only 14% were found satisfactory in the degree of integration between instruments. Surprisingly, the indicator with the worst results is associated with the Potential Demand Index, which compares the estimates of future residents within the operational territory of the water companies. Despite enforcing the water service within the operational territory, the planning instruments do not seem to be aligned with this goal. Eighteen out of the 24 appraisal points (3 points for each of the eight urban areas) resulted in a deficient level of integration (76%), four were improvable (16%), and only two were satisfactory (8%).

The major disconnect seems to be between the expansion plans of water companies and the land-use plans (point B for the three indicators), where all were assessed as deficient. The water companies are not considering and are probably not informed about the number of potential residents and the size of the urban areas defined by the land-use plans when planning their future operations. In these conditions, the future water demand may likely exceed the planned service capacity of the water companies. Although the less satisfactory integration is between the land-use and expansion plans (point A for the three

Table 3
Frequency of assessment to the three-point appraisal framework (Source: Authors).

Indicator	Point	Frequency of achievement		
		Satisfactory	Improvable	Deficient
Spatial Coverage Index	(A) When the urban boundary is defined, does the land-use plan consider the area defined by the expansion plan?	0	3	5
	(B) When defining the operational territory, does the expansion plan consider the urban areas defined by the land-use plan?	0	0	8
	(C) Does the sanitary feasibility study consider the urban area defined by the land-use plan?	3	4	1
Potential Expansion Index	(A) When defining the urban boundary, does the land-use plan consider the population defined by the expansion plan?	1	7	0
	(B) When the operational territory is defined, does the expansion plan consider the population allowed by the land-use plan in the urban area?	0	0	8
	(C) Does the sanitary feasibility study consider the population the land-use plan allows within the urban boundaries?	4	1	3
Potential Demand Index	(A) When defining the population density, does the land-use plan consider the potential population defined by the expansion plan?	1	4	3
	(B) Does the expansion plan consider the population the land-use plan allows within the operational territory?	0	0	8
	(C) Does the sanitary feasibility study consider the population the land-use plan allows within the operational territory?	1	0	7
Total		10	19	43

indicators), almost 60% of the assessments are improvable. Thus, the land-use plans at least acknowledge the water companies' expansion plans, although this information is not considered when defining the urban growth plan. Overall, these appraisal points complement the results of the indicators presented in the previous sub-section, explaining the lack of consistency between urban and water planning instruments by looking at the concrete reference and acknowledging the definitions established by the other instruments.

For the Spatial Coverage Index, the results show minimal reference to relevant information across instruments when establishing the territory included within the urban and operational territories. In terms of point A, in most cases, the land-use plan does not consider the area defined by the expansion plan when defining the urban boundary, not even mentioning it. For point B, all the cases reveal that the expansion plans do not consider (nor mention) the urban areas defined by the land-use plan when defining the operational territory. Lastly, for point C, in half of the cases, the sanitary feasibility study only mentions the urban area defined by the land-use plan, yet this information does not affect its definition. Overall, assessing these appraisal points contributes to explaining the considerable discrepancies between the urban area and the operational territory that create urban areas (and therefore population) without water services coverage.

For the Potential expansion index, the results indicate minimal mention (with no meaningful impact) of the relevant information contained across instruments when establishing the definitions that will impact the need and actual capacity for expanding the operational territory. For point A, the results show that in most cases, the land-use plan does not consider the population defined by the expansion plan when defining the urban boundary. For point B, the results show that in all cases, the expansion plan does not consider the population allowed by the land-use plan in the urban area when the operational territory is defined. Lastly, for point C, the results indicate that in half of the cases, the sanitary feasibility study considers the population that the land-use plan allows within the urban boundaries for its definition. These results explain the great discrepancies between the current population served by water companies and the maximum potential population projected by the land-use plan.

For the Potential Demand Index, in general terms, the results show almost no reference to relevant information across instruments when establishing the number of potential residents that urban planners and the water companies project within the operational territory. In particular, the results for point A show that, in most cases, the land-use plan does not consider the potential population defined by the expansion plan when defining the projected population density. For point B, the results indicate that in all the cases, the expansion plan does not consider the population allowed by the land-use plan within the operational territory. Lastly, point C shows that in most cases, the sanitary feasibility study does not consider the population that the land-use plan allows within the operational territory. Overall, the assessment of the three appraisal points (A, B, and C) helps explain the low values obtained for this indicator and shows that both instruments, the land-use plan, and the expansion plans, project the future state of the cities based on different population estimates.

4. Discussion

The results of this study support those challenging the common assumption that water service will always be available to support settlement growth (Li et al., 2015; Zhang, 2016; Stanganini and de Lollo, 2018). They advance this knowledge by contributing evidence of the misalignments between city and water planning in the Chilean context. As previously indicated, water security results from local hydrological conditions and capable management institutions (Krueger et al. 2019). Therefore, these results explain why many Chilean cities are significantly challenged to provide their population with adequate water services from the perspective of institutional capacity. When considering these explanations, it is important to acknowledge that urban and water planning – and their integration or the lack of it – are determined by the willingness, understanding, and capacities within these systems and across larger economic, environmental, social, and political systems that intersect with planning, although further examination of these aspects is beyond the scope of this research.

As done in Beckwith (2014), we designed three appraisal points to evaluate possible causes of the lack of integration among the instruments that may lead to a water shortage. Through the application of these appraisal points to the three indicators, we can identify how the land-use plan fails to consider the expansion plan of the water companies (point A), how the expansion plan of the water companies fails to consider the urban growth defined by the land-use plan (point B), and how the sanitary feasibility study, which should guarantee that the urban area will have enough drinking water, fails to consider the expansion of the urban area as defined by the land-use plan (point C).

The three indicators proposed in this study tackle what we consider to be one of the most important aspects of the water service and land-use planning integration, i.e., the spatial coverage and the water service capacity planning, both within the area where companies are required to provide the service and in the complete urban area. Since the set of indicators is normalized, a quick comparison of the criteria fulfillment can be performed, as shown in Fig. 2. The indicator of spatial coverage (Spatial Coverage Index) of drinking water shows the degree of similarity between the urban boundaries and the operational territory of the water companies. In other words, the Spatial Coverage Index represents the proportion of the urban territory where water providers must provide the service. Although this indicator reported the best average result (0.34) in our case studies, the water providers still did not properly cover the urban areas. The lowest value for the Spatial Coverage Index (0.02) was obtained in Cobquecura, where the water provider covered only the fiftieth part of the urban area. Because water providers are private companies, extending their operational territory to the urban boundaries is economically inefficient because new urban areas are gradually populated, so new infrastructure would be underutilized.

On the contrary, private companies will prioritize expanding their services towards areas with high-density and high-income populations and where the cost of expansion is less, such as areas under steep terrain. For example, the scattered geographical delimitation of the Cobquecura urban area's low density does not contribute to an efficient distribution system for drinking water. As it has been reported, Cobquecura faces serious water shortages (Fuentealba, 2017), highlighting that companies are choosing not to cover areas that lack sufficient density, which can be expected in contexts of privatized services if planning does not force companies to cover less profitable areas, as it is only done for social housing purposes in the Chilean context.

In addition to spatial coverage, the current and planned capacities to provide drinking water associated with the population are crucial. The Potential Expansion Index and Potential Demand Index determine the proportion of potential customers water companies can serve in urban areas relative to the operational territory. The Potential Expansion Index is always lower than the Potential Demand Index because it is based on a larger area and considers not the projected but the actual customers. The value of the Potential Expansion Index is significant because it gives an idea of the immediate capacity expansion required to guarantee adequate water service inside the urban boundaries. For instance, the water service company in Quillón currently serves 5131 customers, while the land-use plans allow for more than 400,000 people in the urban area. It would be interesting to know whether land-use planners and water companies have ever thought about what an 8000% increase in people living in urban areas would represent for the water service.

On the other hand, the Potential Demand Index compares the number of customers a water company estimates it will have to serve within its operational territory with the population allowed by the land-use plan within that same operational territory. Since both population estimates are for the same area, this indicator directly shows the coherence between the two planning instruments in terms of population estimates. The low values observed in the Potential Demand Index in our case studies mean that water companies plan their operations based on quite different population estimates than those allowed by land-use plans. For example, in Quillón, the water provider plans to serve 5345 customers, while in the same area, the land-use plans allow for almost 160,000 residents. The lack of coherence between these two numbers is evident and suggests that the permitted population densities are unlikely to be supplied with drinking water. The qualitative analysis showed that only 2 out of the 24 appraisal points (8%) regarding the Potential Demand Index were satisfactory, explaining a major discrepancy in the future number of residents within the operational territory.

Moreover, it seems from point B that water companies never look at the population densities defined by the land-use plans inside their operational territory. Two observations can be made here. First, population densities defined by the land-use plans seem to allow for a broad range of future states of the cities rather than moving the city growth towards a more limited set of possible states that the Community and its authorities consider appropriate, reducing the usefulness of land-use plans. Second, it seems reasonable to oblige water companies to use the population densities defined by the land-use plans (or a pre-defined fraction of them) as a base for their expansion planning rather than using their own estimates.

After discrepancies in the future population within the operational territory, the second most critical factor seems to be the spatial difference between the operational territories and the urban boundaries (Spatial Coverage Index indicator). In this sense, the participation of water service providers in defining the urban boundaries may be necessary, together with a minimum coverage requirement in the operational territories. Requiring equivalent time spans for the planning instruments would also be convenient. As mentioned, the major reason for a deficient integration between water and land-use planning seems to be that water companies do not consider the urban growth guidelines given by the land-use plans, followed by the fact that the land-use plans give scarce consideration to the expansion plans of water companies. The ideal setting would be a parallel planning process with the integrated participation of each institution. Although the proposed indicators are used in this study as state indicators to describe the current urban system according to Pissourios's classification (2015), they could be used as planning indicators and considered during urban planning to ensure more sustainable urban growth.

5. Conclusion and future work

We presented three indicators to quantify the degree of integration between water service and urban land-use planning instruments and a three-point appraisal framework to explore the possible causes of these numerical results. The indicators compare water companies' current and future geographical and demographic coverage with the proposals of land-use plans for urban development, illustrating the coherence between the two planning processes. The proposed indicators and appraisal points were based on broadly used planning instruments for land use and water service planning, so we believe the suggested approach can be tailored to other situations.

Based on the quantitative analysis of our case study, we consider a severe deficiency in the integration of the water service and the land-use planning processes. The observed values of the proposed indicators showed the magnitude of the inconsistencies, both in the number of potential people that might need to be served and in the geographical coverage of the water companies. The qualitative analysis suggested that the major inconsistencies were mainly explained by the fact that the water companies ignore the future urban development defined by the land-use planning instruments and vice-versa. Under this condition, problems with access to drinking water are very likely to happen.

Using the proposed indicators was convenient for quantifying and visualizing the discrepancy in how the different planning instruments estimated the future of the cities. In addition, applying an appraisal framework as a complementary mechanism helped us determine the possible causes, if any, of the deficiencies in integrating the planning instruments. We observed that water service and land-use planning instruments ignore the relevant information available in the other instrument when making their own definitions. This omission may explain the service problems of drinking water in urban areas.

Some recommendations can be suggested to promote a more integrated water and land use planning process. First, the need exists for a technical coordination agency that links the local planning authorities and the water companies. This agency should conduct the overall planning process and its continuous updates, for instance, defining the population estimates on which water companies should base their expansion and monitoring indicators such as the ones presented in this paper. Second, land-use plans should promote a more compact and contiguous urban development to create economic conditions favorable to the companies' expansion. Since land-use plans are set for long periods, typically between 10 and 20 years, land-use plans should be complemented with rate-of-growth control policies such as growth-phasing regulations or development moratoria to avoid scattered urban growth. Finally, a more coherent validity period should be defined for land-use and expansion plans. Because of the longer validity period of land-use plans, water providers should develop their expansion plans simultaneously with formal pre-defined stages of land-use plans update.

Future studies should focus on determining the impact of different numerical values of the indicators so that critical (minimum acceptable) and target (desirable) values can be identified. As noted by Pissourios (2015), to define appropriate values for the indicators, a much larger set of urban areas should be considered to discover statistically valid patterns that allow us to relate indicators and water service fulfillment. Additional indicators that reflect other sustainable issues related to urban development are also of increasing interest. Moreover, further research would explore the impact of integrating the willingness, understanding, and capacities within the urban and water planning systems and in their wider context.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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