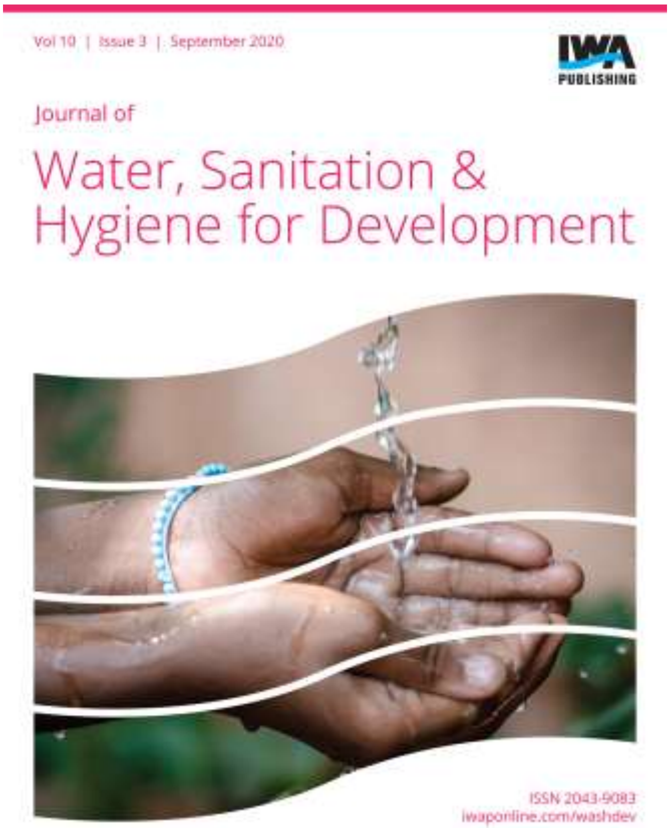

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Research Paper

Closing the cycle? Potential and limitations of Water and Sanitation Safety Plans (WSSPs) for Latin American metropolitan areas

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ABSTRACT

Water and sanitation management faces major challenges due to the rapid urban growth of metropolitan areas and the resulting pressure on water resources. Metropolitan areas often combine formal and informal water and sanitation services and regularly face shortages, leakages, and other situations involving risk to users and the environment. This work presents an integrated approach for the development and implementation of a Water and Sanitation Safety Plan (WSSP) for metropolitan areas, especially in developing countries. The plan allows for the assessment of all the risks associated with the components of the urban water cycle by means of a semi-quantitative approach. In the case study described, the overall risk estimated was 37.2% (44.0 and 30.3% for the drinking water supply and sanitation sub-systems, respectively). Highest risk values were obtained for components of water treatment (53.0%) and wastewater treatment (51.7%). Our assessment took into account both formal and informal sanitation components of the water and wastewater management cycle and included a multi-institutional analysis of the entire system. Results obtained may contribute to establishing new policies and guidelines for the protection of public health and the local environment in our case study and other areas of the region with similar contexts and comparable institutional settings.

Key words | Argentina, decentralized sanitation, risk assessment, Water and Sanitation Safety Plan (WSSP), water governance

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HIGHLIGHTS

- An integrated approach, the WSSP has been developed with a focus on a metropolitan area of Argentina.
- A semi-quantitative approach for health and environmental risk assessment was used. Highest risk value was obtained in the water treatment (53%) and wastewater treatment (52%) process.
- A component with the greatest number of hazardous events was decentralized wastewater treatment systems (DWWTS).
- A multidisciplinary and multi-institutional analysis allowed a more reliable evaluation of the urban water cycle.
- An adequate legal framework is indispensable to manage the entire urban water cycle and improve the governance of water and sanitation service.

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INTRODUCTION

The global water crisis, resulting from insufficient water supply and the growing demand for water to meet human, commercial, and agricultural needs, is one of the greatest challenges facing humanity today. Water management faces major challenges due to increasing pressure on existing water sources (Loucks & Van Beek 2017). These concerns include aging infrastructure, poor water quality, depleting groundwater aquifers, pressures associated with population growth, climate change effects on water availability, and continued public demands for low-cost services. Worsening water quality and increasing water scarcity and lack of access to water supply and sanitation threaten socio-economic development and national security in countries around the world. The recognition of the human rights to water and sanitation (UN 2010) confirms the importance of universal access to safe drinking water and sanitation as essential for the realization of all human rights. In fact, water supply and sanitation issues are a central dimension of the Sustainable Development Goals (SDGs). SDG 6 refers to the need to *ensure availability and sustainable management of water and sanitation for all*, by placing water and sanitation at the core of sustainable development, cutting across sectors and regions. While the proposed sub-goal for improved water quality and wastewater management includes the aim to reduce both the urban population with untreated wastewater and untreated industrial wastewater flows, there are currently no globally comparable data on the percentage of wastewater treatment at the national scale to aid in the assessment of this effort. SDG 6 requires that countries worldwide engage in more robust planning of new water and sanitation systems, and subsequently, put in place effective enforcement mechanisms to ensure these systems consistently protect public health all along the water chain and can also adapt to an ever-changing environment (Winkler *et al.* 2017).

Risk assessment and management in drinking water supply systems have been conceived as a way of safeguarding public health. In 2004, the World Health Organization (WHO) introduced an integrated and preventive risk management approach through Water Safety Plans (WSPs), a methodology that includes risk assessment, management, and monitoring in water supply systems, from catchment to consumer. WSPs have been implemented in many countries, prompting widespread recognition of the importance of proactive risk assessment and risk management practices to keep drinking water supplies safe. In 2008, at the World Water Week in Stockholm, the concept of Sanitation Safety Plan (SSP) was discussed and recommended in a broader context of sanitation, based on a similar approach as those used for WSPs. The Water and Sanitation for Health Facility Improvement Tool (WASH FIT), a practical guide to improving quality of care through water, sanitation, and hygiene in health facilities, was also established (WHO 2017). These are effective methodological guides for systematically ensuring the safety of both a drinking water supply system and a sanitation system, outlining the application of a comprehensive approach to risk assessment and management covering all stages of the system.

However, there are still few global experiences. Almeida *et al.* (2014) developed the Water Cycle Safety Plan (WCSP) providing a common risk management framework for both water and sanitation. It was based on the WSP approach, also incorporating different risk management regulations, with a focus on adapting the urban water cycle to climate change. Assessment of the risks associated with the components of the entire urban water cycle facilitates a more comprehensive diagnosis of the current state of water and sanitation systems, and a better identification of the events that may have environmental impacts or threaten the health of the local population.

In the city of Salta (Argentina), a WSP was carried out in 2011 within the framework of a collaboration agreement between the local water company and the National University of Salta (UNSa) (Seghezzo *et al.* 2013). It was based on a modified version of the methodology proposed by WHO (Bartram *et al.* 2009). In order to complete the integral management of the urban water cycle, an integrated strategic management tool was developed to determine environmental risks and impacts defined for the planning of water and sanitation management as an integral cycle, from catchment to discharge or reuse. This new approach promotes and facilitates the establishment of health priorities and the management of associated risks for the entire urban water cycle.

This paper presents an evaluation of this integrated approach, the WSSP, for its application in metropolitan areas of developing countries and to better comprehend the dynamics of water security in the urban water cycle. We used an adapted version of the methodology proposed by WHO in their WSP and SSP manuals. The risk was assessed using a semi-quantitative approach and a simplified risk assessment matrix. The analysis focused not only on the verification of the system functioning but also on public and environmental health. Therefore, the inclusion of social perspectives regarding the different systems and processes of the urban water cycle were considered a priority for the management plan.

The growth of metropolitan areas in Latin America has been very significant in recent decades. This increase in population has generated the need to expand water supply and wastewater collecting networks, but coverage of all sectors is currently still insufficient. There is no clear environmental legislation in Argentina that includes all the formal and informal water and sanitation systems, and there is a lack of suitable institutional arrangements and legal framework for an integrated urban management with respect to water and sanitation. Thus, there are areas of the city supplied with safe drinking water and with wastewater collecting and transport to wastewater treatment plants (WWTP) and other areas without drinking water (supplied by private wells) and with decentralized wastewater treatment systems (DWWTS). Unplanned settlements of the cities and metropolitan areas are not provided with formal, centralized wastewater services for varying periods of time (ranging from a few months to even years, becoming virtually permanent). The diffuse pollution produced, exacerbated by housing density, is a serious health and environmental risk which is not adequately addressed by local institutions. Despite the long-term use of the DWWTS, there is little information about the performance, institutional control, and social perspectives with respect to its use (Iribarnegaray *et al.* 2018).

One of the main objectives of this work was to highlight the need to assess water safety in an integrated manner and from a multidisciplinary perspective, which ideally should be carried out with the engagement of all actors involved in water and sanitation management. In fact, the inclusion of all relevant stakeholders in water management was a key to effectively incorporating WSSPs into water management decisions. The participation of representatives of institutions related to water management is essential to obtain a reliable and complete analysis of the system. Beyond the fact that the inclusion of components of the sanitation system to complete a WSSP was unprecedented in the region, the main achievement of this work was the coordination of institutional efforts to complete the risk analysis of the entire urban water cycle, including informal components not previously considered. Results obtained in this study may contribute to establishing new policies and guidelines for the protection of public health and the local environment in our area and in other areas of the region with similar contexts and comparable institutional settings.

METHODS

Study area

The study was conducted in northwestern Argentina, focused on the Northern metropolitan area of Salta, which is part of the city of Salta (Figure 1).

The area was selected as representative of metropolitan regions of developing countries, where informal settlements, new public housing developments, and established neighborhoods coexist. The study area is, therefore, a mixed district with internal flows of materials, services, and people, and rapid development along the fringes, where water and wastewater services cannot cope with urban growth. This situation is common in most of the constantly growing metropolitan areas in Latin America. The climate is subtropical, with a concentrated dry season from May to November. The average temperature is 16.5 °C, and the average annual rainfall is approximately 700 mm (Arias & Bianchi 1996).

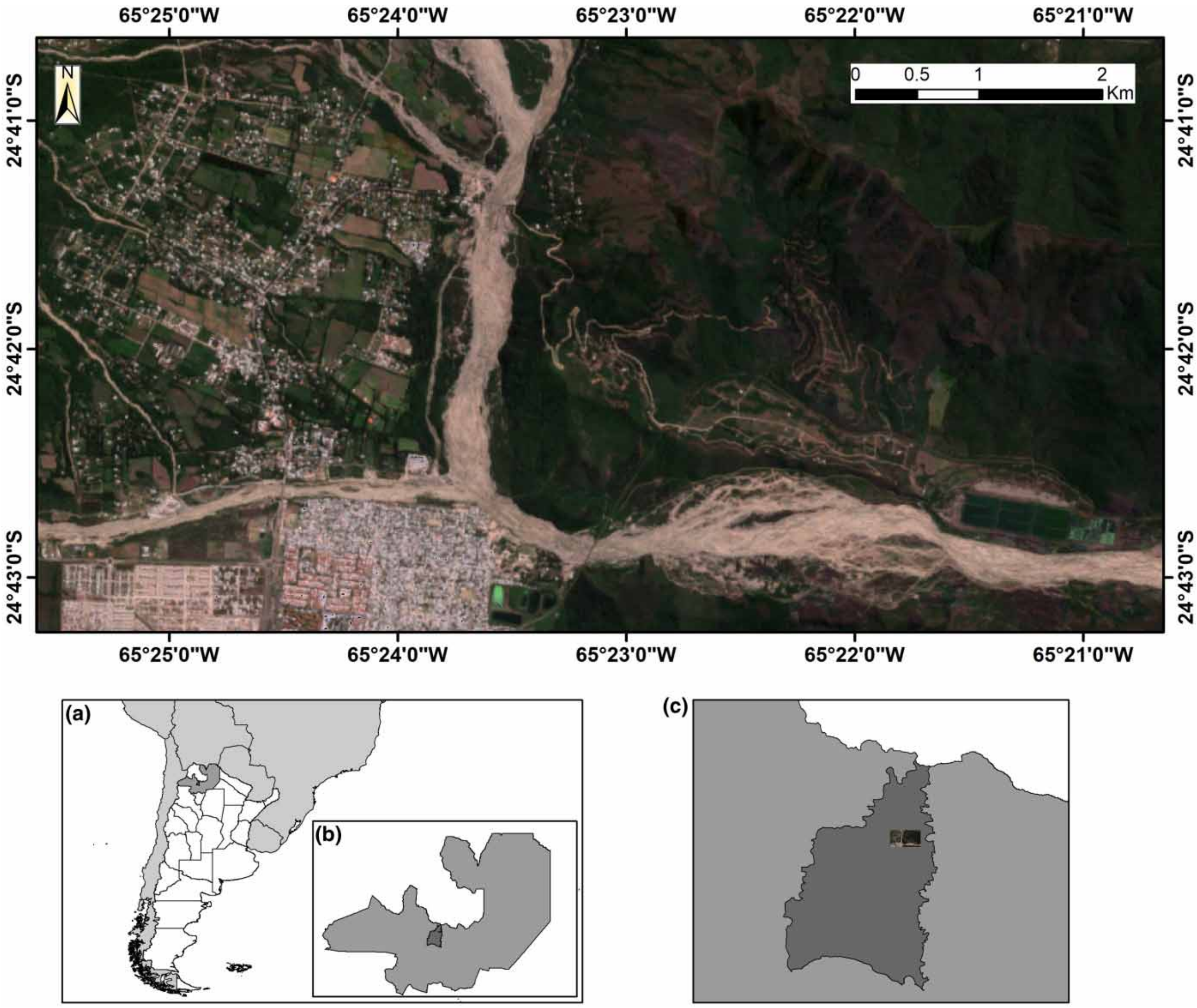

Figure 1 | Study area and location of the Northern metropolitan area of Salta. (a) Salta province in South America, (b) Salta province, and (c) Northern metropolitan area of the city of Salta.

Water supply and sanitation system

Metropolitan areas have coexisting formal and informal water and sanitation systems. According to the latest available official data, in the city of Salta, 91% of households have a public water supply and 62% have a sewerage service (INDEC 2010), which is above the provincial average (Iribarnegaray *et al.* 2018). There are clear deficiencies in the integrated management of the water cycle that create situations of risk for the environment and public health. There are both formal water and sanitation services managed by a local water company (Water Treatment Plants: WTP1, WTP2, and WTP Wierna, sewerage networks, and WWTP, deep wells) and informal services (ditches, shallow wells, and DWWTS) (see the meaning of the acronyms in Figure 2). The latter is usually located on private properties and managed by each owner without a clear legal framework. One of the most important environmental problems is the discharge of raw or partly treated sewage into rivers, water bodies, and soils (Iribarnegaray *et al.* 2018). As shown in Figure 2, formal water systems can be distinguished as the *north system* that includes surface and subsurface water catchments and *deep wells* that represent formal groundwater catchments. Formal water systems include water treatment (potabilization), which usually includes flocculation, sedimentation, filtration, and chlorination (for WTPs) or only chlorination (for deep wells). After the treatment, water is distributed through the

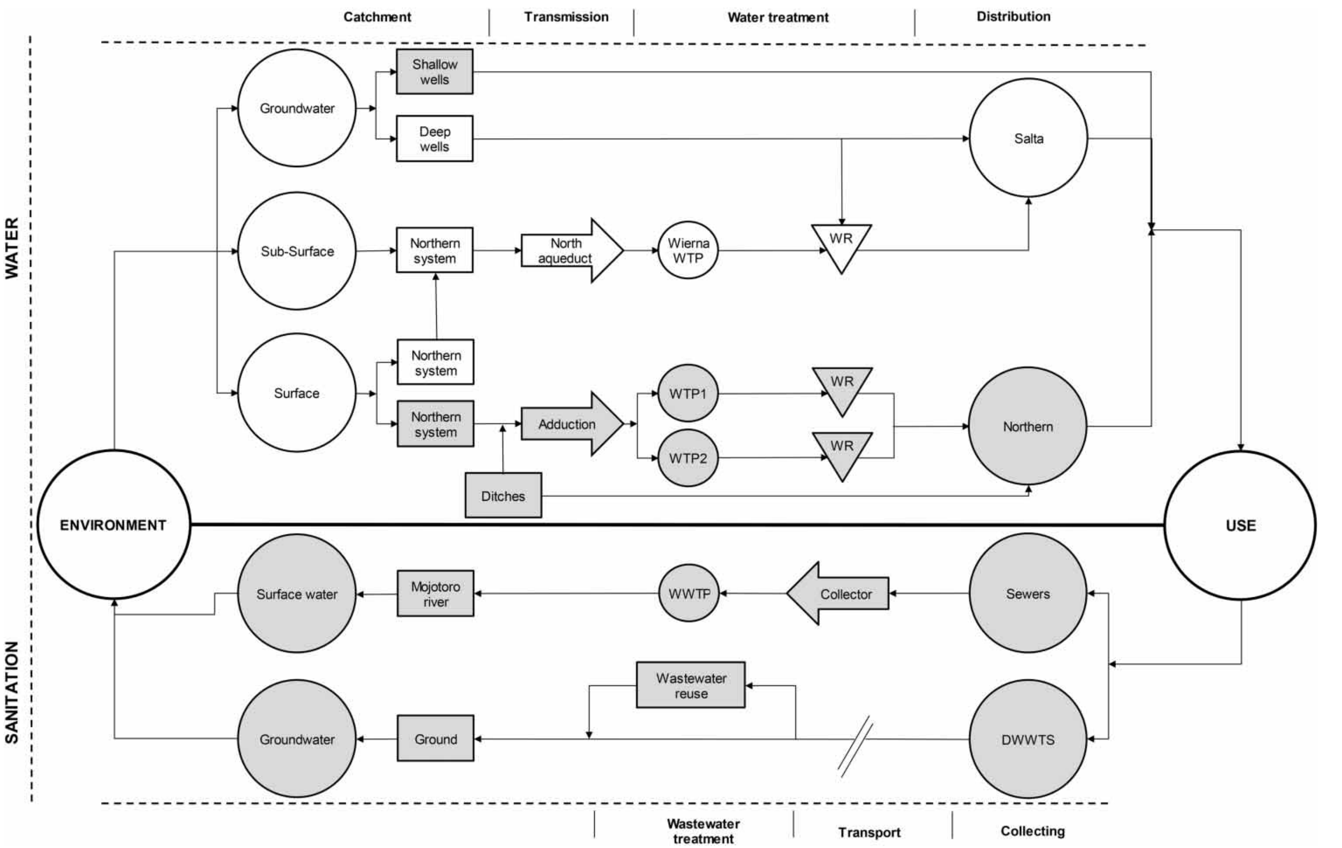

Figure 2 | Flow diagram of the drinking water supply and sanitation system of the Northern metropolitan area of Salta. WTP: Water Treatment Plant, WWTP: Wastewater Treatment Plant, Cl: Chlorination process, WR: Water Reservoir cisterns, DWWTS: Decentralized Wastewater Treatment Systems. Shaded items represent the systems and processes evaluated at the workshop with stakeholder participation.

distribution system. In some cases, the distribution includes water reservoir cisterns, indicated as *WR* in Figure 2. In addition, the informal water system can be seen in Figure 2 as *shallow wells* and irrigation canals (or *ditches*). Both are water sources that the people use as drinking water without treatment. In the same way, raw water from *ditches* is a common water source of WTP1 and WTP2. Regarding sanitation, a centralized formal WWTP serves the northern sector of the city of Salta, and DWWTS plants (mostly *on-site* septic systems) are concentrated in the marginal sectors of the city (Iribarnegaray *et al.* 2018; Figure 2). The growth of the city has been important in the last decades and greatly exceeded the expansion of water supply and sewerage systems. There are still areas of the city with recurrent problems of low water pressure or lack of drinking water supply, and limited or no access to the sewerage system (9 and 38% of households, respectively) (INDEC 2010).

Water and Sanitation Safety Plan

The WSSP approach was based on the WSP (Bartram *et al.* 2009) and SSP (WHO 2015) manuals and modifications introduced by Seghezzo *et al.* (2013) regarding risk assessment, calculation of control measures, establishment of risk hierarchies, and definition of risk thresholds. The methodology used to develop the WSSP consists of 11 modules grouped in four steps: preparation (Module 1), system assessment (Modules 2–7), management and communication (Modules 8–9), and feedback (Modules 10–11) (Bartram *et al.* 2009) (Supplementary material, Figure S1).

The inclusion of appropriate relevant stakeholders who play an important role in the development of the risk assessment and management process is one of the fundamental elements that should be part of the risk management process. Therefore, a multidisciplinary working team was formed including stakeholders of different local institutions with decision-making power in the local management of water and sanitation: the provincial Water Resources Secretariat, the Regulatory Entity of Public Services, the Environment Secretariat of the city of Salta, researchers from the National University of Salta, councilors from the two municipalities of the metropolitan area of Salta, and technicians from both municipalities.

A workshop was undertaken within the framework of the WSSP development activities that included the *Preparation* and *System Assessment* stages (WHO 2015) (Supplementary material, Figure S1). This consortium of different institutions allowed us to evaluate the informal systems that are not managed by the water company. It should be noted that, in the case of the risk evaluation of formal water systems – deep wells and a part of the north system (unshaded items in Figure 2) – data were provided by the water company, which updates risk values annually, ever since the WSP for the city of Salta was implemented in 2013 (Seghezzo *et al.* 2013). To develop that WSP, the risk assessment step was performed during participatory workshops with members of the local water company. The water company contributed with their data to complement the assessment of the other systems that were considered in this study. Thus, the work of the working team was limited to evaluate the water systems WTP1, WTP2, shallow wells, and ditches, as well as the sanitation systems WWTP and DWWTS (shaded items in Figure 2).

All stages of these systems were inspected, described, analyzed, and documented by the research team previously, as input for the workshop. Working groups were provided with photographic documentation and a list of hazardous events based on a preliminary diagnosis (Supplementary material, Table S1). Therefore, this study evaluated the formal and informal components of water and sanitation systems with the aim of assessing the complete water and sanitation cycle. The codes of the evaluated components, processes, and sub-processes of the formal and informal water and sanitation systems are presented in Table 1.

Risk assessment

Risk assessment begins with the identification of hazards at each exposure point for all processes and systems involved

Table 1 | Components, processes, and sub-processes of the drinking water supply and sanitation system of the Northern metropolitan area of Salta

Stage	Process	Sub-process	Component	Code
Water	Catchment	Sub-surface	Northern system	C-SUB-NS
		Surface	Ditches	C-SUP-D
			Northern system	C-SUP-NS
		Groundwater	Deep wells	C-GR-DW
			Shallow wells	C-GR-SW
	Transmission	Transmission	Adduction WTP 1	T-T-AD1
			Adduction WTP 2	T-T-AD2
			North Aqueduct	T-T-NA
	Water Treatment	Water Treatment	WTP 1	WT-WTP1
			WTP 2	WT-WTP2
			Wierna WTP	WT-WiWTP
			Deep wells	WT-DW
	Distribution	Distribution	Salta distribution	D-SD
			Northern distribution	D-ND
Sanitation	Collecting	Collecting	Sewers	Co-S
	Transport	Transport	Collector	T-C
	Wastewater Treatment	Treatment	WWTP	T-WWTP
			DWWTS	T-DWWTS

in the urban water cycle. In this regard, a hazard is defined as a biological, chemical, physical, or radiological agent that has the potential to cause harm (to human health and the environment). Hazards were identified and evaluated for each system, process, and component, assigning probability and severity values on a modified scale from 0 to 100 (Supplementary material, Table S2 and S3, respectively) (Seghezzo *et al.* 2013). All the processes of the metropolitan system were included, complementing the risk assignments of the components already managed by the water company, as stated above. Risk was defined as the probability that hazards will cause harm within a specified time, including the magnitude of the harm and/or its consequences. The risk was calculated for all possible hazardous situations as the product of the probability of occurrence of a hazard and the severity of that occurrence. A percentage scale was considered more intuitive and facilitated the assignment of values during the workshop.

Assessment criteria for likelihood and severity were adapted to local circumstances. Special attention was paid to minimize ambiguities that might introduce biases or confusion to the assessment process. Whenever possible, likelihood and severity were estimated based on objective, statistical, or scientific data. In cases where quantitative criteria could not be applied, values were assigned based on the experience and opinions of the participants. With the data obtained, a semi-quantitative evaluation of the risk was performed using a simplified matrix, classifying the data in different categories. The scale adopted was based on the sustainability scale proposed by Bossel (1999) (Supplementary material, Table S4). A threshold risk value (or acceptable risk) of 24% was established, corresponding to the maximum value within the low-risk range.

Estimation of the theoretical magnitude of control measures

Control measures are those that mitigate or reduce risks to acceptable levels. For each hazardous situation, the numerical magnitude of the control measures was determined as the difference between the risk value obtained and the threshold value. This made it possible to quantitatively estimate the weight that a given control measure must have in order to bring the risk to the acceptability zone. This weight is a quantitative reference value to be taken into account in the technical process of seeking solutions to the problems identified. The magnitude of the measures was calculated in the same risk units, facilitating their identification and evaluation. At a later stage, water company staff and other decision-makers will have to identify exactly what procedures and tangible actions can adequately reflect this magnitude, designing the control measures they consider more appropriate for each case. This process is relatively subjective, and therefore, experience with the operation and maintenance of the system is essential. External audits can also help identify the appropriate type of control measures and avoid over or under-estimations. The scale adopted for the magnitude of these measures is shown in Supplementary material, Table S5. If the magnitude assigned to a particular control measure is severe, actions should be accordingly significant, i.e. the construction of an entirely new WTP. When the risk value for a given hazard in a given component was below the threshold value, no corrective measures were applied.

RESULTS AND DISCUSSION

Risk assessment outcomes

Overall risk estimated in the entire northern metropolitan area of the city of Salta was 37.2% (44.0 and 30.3% for drinking water supply and sanitation, respectively). These figures are pretty high, considering that an acceptability threshold of 24% was adopted. However, it is important to highlight that absolute values are not as important as their relative ranking or their expected variation over time once control measures are implemented.

Figure 3 shows the risk values calculated for each component of the entire system. Values for Catchment, Transmission, Distribution, and Collecting processes were medium magnitude. In contrast, transport obtained a low-risk value, even below the threshold value, while water treatment and wastewater treatment were assigned high-risk values. Workshop participants considered that both the probability of occurrence of a hazard and the severity of occurrence were high for these two processes, meaning that there is high risk involved in the quality and quantity of the water consumed in the city. Specifically, for water treatment, the

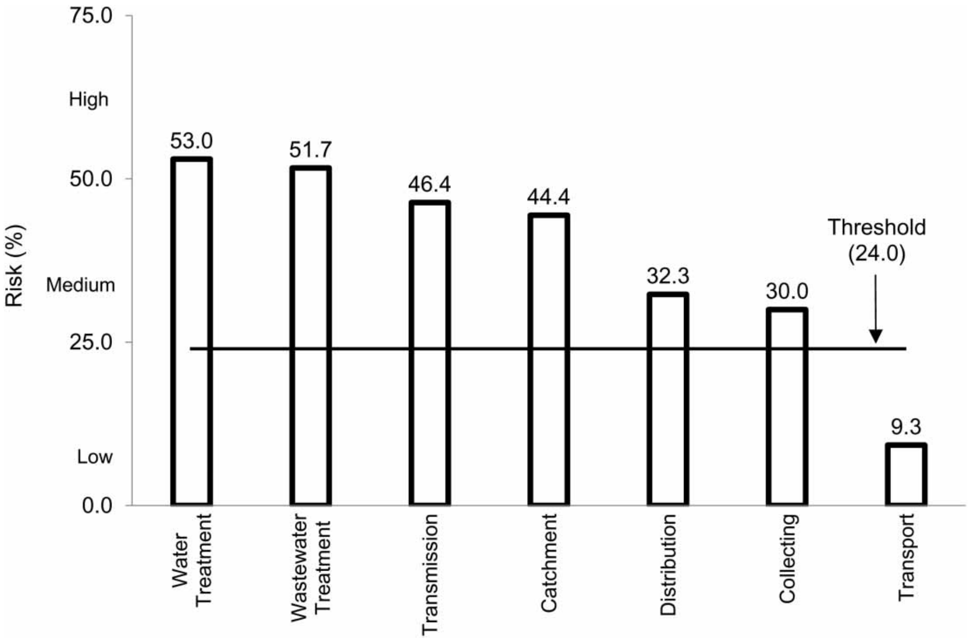

Figure 3 | Risk (%) of the processes evaluated for water and sanitation system of the Northern metropolitan area of Salta.

results were associated mostly with hazards related to insufficient treatment capacity, high turbidity, water outages, and insufficient surveillance (García-Sánchez & Güereca 2019).

On a closer look at the water sub-system, three sub-processes were evaluated within the catchment process, according to the water source: sub-surface, superficial, and groundwater. All of them showed a medium-magnitude risk value; surface uptake exhibited the highest risk with 48.9%, followed by groundwater (45.3%) and sub-surface (39.2%). This may be due to the fact that surface uptake is the catchment type most vulnerable to contamination if the source is not protected. For groundwater, the risk value represents the average for deep wells and shallow wells. The latter is most vulnerable to contamination (of the aquifer water table) (Rodriguez-Alvarez *et al.* 2015). For Wastewater treatment, risks are associated with environmental risks caused by discharging untreated or partly treated sewage into surface water (WWTP or DWWTS). Public concern in this regard is on the health effects of exposure to toxic chemicals and, in particular, the risk of cancer (Diaz-Sosa *et al.* 2020).

On the other hand, a closer look to the sanitation subsystem shows that risk values estimated were very similar for the two basic components of the wastewater treatment process (51.7% for WWTP and 51.6% for DWWTS, respectively). Risks for WWTP may have come from algal blooms, plants, animals, garbage, and other undesirable materials in unitary processes, inappropriate plant design, age of the facilities, and vulnerability to natural disasters (Cheremisinoff 2019). By contrast, hazardous events with the greatest contribution to risk in DWWTS were soils with excessive infiltration, contact with wastewater with insufficient treatment, inadequate maintenance, and insufficient safety.

A detailed analysis of all hazardous events identified for each of the processes is shown in Figure 4 (see also Table 1). More than half of the total number of hazardous events identified (116 out of 213, or 54.5%) exceeded the threshold adopted for this study and would, therefore, require some degree of control or mitigation measures.

As depicted in Figure 4, the component with the greatest number of identified hazardous events was DWWTS. This means that the sources of hazards, in this case, are very diverse, which demands the implementation of different types of control measures to reduce the risk. Failing septic systems are a frequent cause of groundwater contamination. Another system with a great number of hazardous events with high risk was the collection of water through shallow wells (C-GR-SW). Coincidentally, both components were

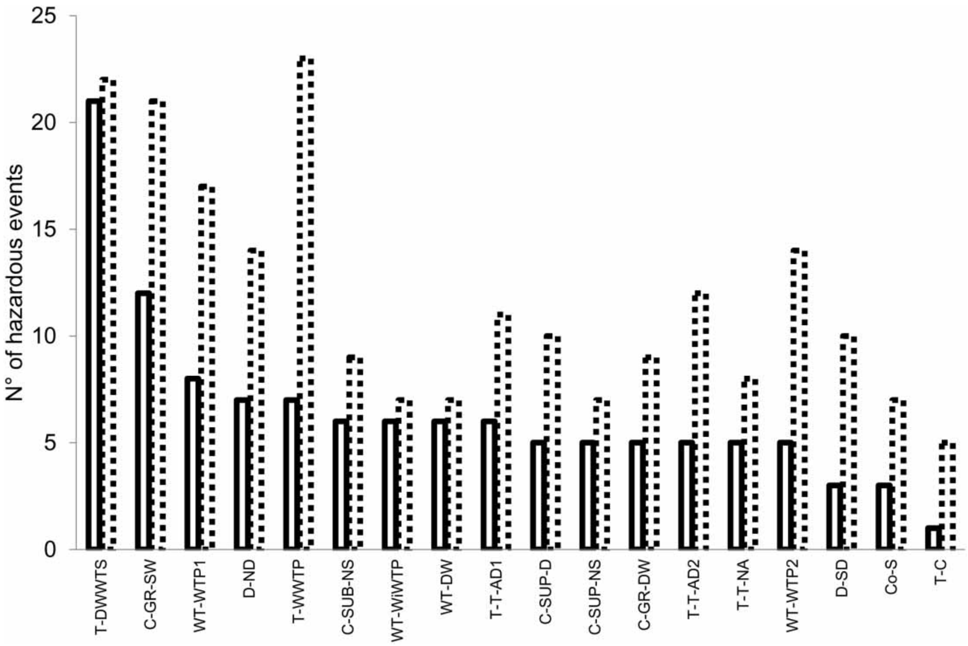

Figure 4 | Number of hazardous events evaluated for each process. Dotted line: the total number of events; full line: the number of events exceeding the threshold of 24%. C-SUB-SN: subsurface catchment Northern system; C-SUP-D: surface catchment by ditches; C-SUP-NS: surface catchment North System; C-GR-SW: shallow well catchment; C-GR-DW: deep well catchment; T-T-AD1: transmission WTP 1; T-T-AD2: transmission WTP 2; T-T-NA: transmission North Aqueduct; WT-WTP1: Water Treatment Plant 1; WT-WTP2: Water Treatment Plant 2; WT-WiWTP: Wierna Water Treatment Plant; WT-DW: Deep Wells Water Treatment; D-SD: Salta distribution; D-ND: Northern distribution; Co-S: collecting Sewers; T-C: transport by collector; T-WWTP: Wastewater North Treatment Plant; T-DWWTS: Decentralized Wastewater Treatment Systems.

characterized as representing current informal services that are presented as accessible solutions in the absence of water and sewage networks. In this area, where formal systems (WWTP) and DWWTS coexist, deficiencies create risk situations for the environment and public health.

Estimation of control measures

Figure 5 shows the magnitude of the control measures that would be required to take the risk below the threshold for each component of the system. The average magnitude of these measures was 20% for the water supply system and 15% for sanitation. This figure was built by subtracting the value of 24% from the risk associated with each one of the components of the system (results not shown). For the sake of clarity, we emphasize here that the estimation of the magnitude of the control measures required is only a theoretical exercise that is not necessarily linked to any specific kind of measure. Technical personnel will have to link this theoretical magnitude with specific actions on the ground, which will have to be equivalent in importance to the magnitude estimated.

Examples of control measures could include the application of restrictive measures such as the definition of minimum distances for agricultural activities, livestock, or transit of people, water quality controls, improvements in potabilization plants, the construction of perimeter fences, and the optimization of security systems. For technical or financial reasons, it could be difficult to implement all required control measures at once (Seghezzo *et al.* 2013). In those cases, it could be wise to establish gradual and responsible risk reduction strategies. These strategies greatly depend on local specificities and some of them could be an input for future regulations. The risk values and magnitude of the control measures calculated for all the components of the water and sanitation system are shown in Supplementary material, Table S6.

Discussion and institutional aspects

In this study, multidisciplinary and multi-institutional participation made the whole assessment more sensitive to local specificities, improving the reliability of the entire WSSP and enhancing the potential effectiveness of

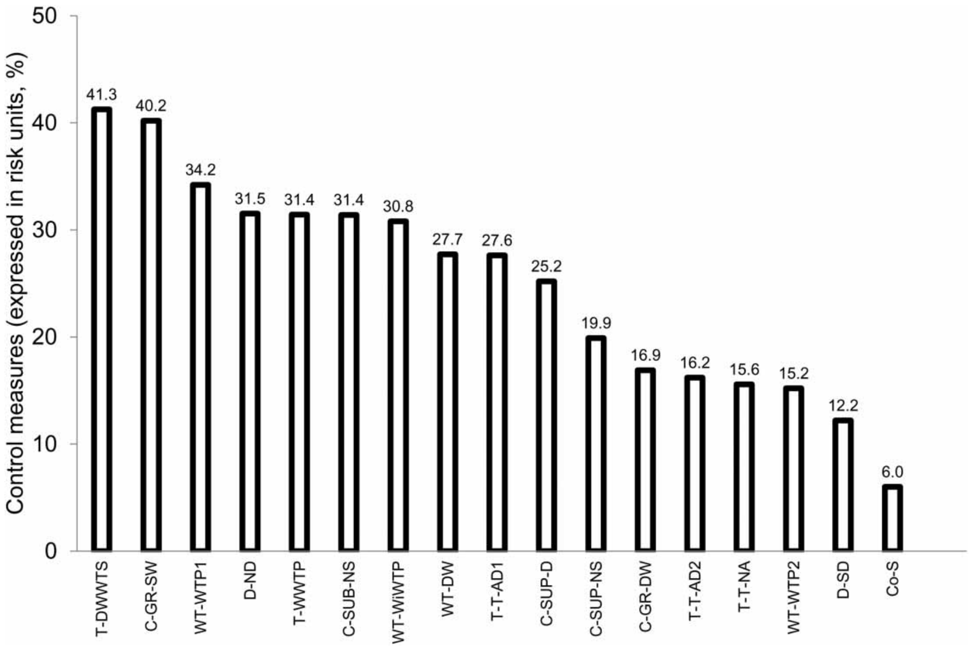

Figure 5 | Control measures for drinking water supply and sanitation system of the Northern metropolitan area of Salta (see acronyms in Figure 4).

control measures. A risk-focused approach is innovative in the region and its application required a considerable amount of institutional adaptation. Current regulatory practices in South America, which are mostly based on the establishment of water quality guidelines, are essentially end-of-pipe approaches and may not always be the most effective method to avoid or prevent problems in complex water and wastewater management systems. In this respect, a WSSP arguably provides a comprehensive roadmap to improve integrated water governance and water management in urban and peri-urban areas. It could also help governments adopt better practices and decision-making processes related to water and sanitation. Moreover, it could be particularly helpful in prioritizing actions and devising efficient and cost-effective risk reduction strategies.

The implementation of a WSSP is also an opportunity for civic engagement as it promotes spaces for interaction and exchange of information between different stakeholders. Integration of water and sanitation in a single safety plan could improve the efficiency of operation and maintenance interventions, boost institutional knowledge and awareness, and ultimately protect water quality. We believe a WSSP can be a powerful tool to achieve SDG Target 6.1, which draws attention to the problems posed by inadequate management of drinking water supplies.

A number of institutional challenges remain. Specific policies and regulatory drivers are needed for the implementation of WSSPs in current institutional frameworks. A holistic management approach is not easy to integrate into established routine system operations, which tend to be dominated by highly specialized protocols. The successful implementation of WSSPs could be limited by a number of factors, including lack of political will in senior management, insufficiently trained human resources, financial constraints, insufficient legislation, aging infrastructure, and even geographical aspects. However, we are convinced that governments and support agencies in the water sector have the opportunity to optimize the effectiveness and sustainability of their investments by promoting and funding risk-based improvement plans developed through a WSSP approach. We believe the WHO's terms WSSP and SSP should be explicitly adopted in Argentina's water management regulations. This is valid for our case study, but it can certainly hold true for many of the metropolitan areas of South America that share similar problems.

The implementation of a WSSP can also present some limitations. Criteria used during the assessment can vary for different actors (company members, local stakeholders, external consultants, etc.). Discussions among participants can help minimize extreme positions and biases, but there will always be a certain degree of subjectivity and contention in the final result. This is not necessarily negative, but disagreements and conflicts need to be appropriately addressed. A WSSP may introduce new elements in an existing management system and some resistance from local managers is to be expected, particularly when innovative components need to be included in the assessment (i.e. DWWTS). This resistance needs to be taken into account in the early stages of the process.

The case of DWWTS deserves special attention since they have become a focus of interest in places lacking sanitation services and have been extensively studied in recent years in the region (Iribarnegaray *et al.* 2018). These types of wastewater treatment plants may be the only option in places lacking a sewer network. Well-designed and operated DWWTS could also reduce construction investments and operation costs while facilitating wastewater reuse and increasing the sustainability of sanitation systems (Capodaglio 2017). The use of risk assessment tools, such as WSSP, could provide a more standardized approach toward the assessment and management of on-site systems. So far, little work has incorporated informal systems into integrated water management. Progress has also been made in studies of aquifer contamination due to DWWTS failure in the metropolitan area of Salta as well as in other areas. Although the knowledge related to the technical characteristics of the different sanitation technologies is relatively advanced, wastewater discharge regulations are not homogeneous and sanitation systems are not sufficiently standardized. In many metropolitan sectors, cases of severe groundwater contamination have been investigated and reported as a consequence of poor management and insufficient treatment of domestic wastewater (Zamora Gómez 2004; Chirisa *et al.* 2017; Selvakumar *et al.* 2017). In our case study, decentralized systems had never been taken into account for urban planning purposes, and yet they are mostly those in place in growing metropolitan areas where they coexist with the formal systems for a time. For a number of reasons, these informal systems may even become permanent and should not be left out when planning an integrated water assessment.

In Salta, but also in the rest of Argentina, as in many other regions of South America, the current water and sanitation management approach is rarely based on a risk perspective. However, based on the lessons learned during this study, we believe that risk reduction strategies can be an important component to enhance current management practices in Salta and beyond.

CONCLUSIONS

In this paper, we present an integrated approach for the implementation of a WSSP in a metropolitan area in Latin America. The implementation of the methodology proposed by WHO in their WSP and SSP manuals was led by a multidisciplinary group made up of members from different institutions involved in water resource management, who discussed system configuration, major components of the systems, hazards, and related risks.

After the risk assignment process, the overall risk estimated for both water and sanitation in the entire northern metropolitan area of the city of Salta was 37.2% (44.0 and 30.3% for drinking water supply and sanitation, respectively). The processes yielding the highest risk values were water treatment (53.0%) and wastewater treatment (51.7%). Absolute values are not as important as their relative ranking or their expected variation over time once control measures are implemented.

The method applied allowed for the quantification of the control measures that would be required to reduce the risks to an acceptable level for each component of the water and sanitation system.

The multidisciplinary, multi-institutional approach followed, allowed for a more reliable evaluation of the entire water cycle, enhancing the knowledge of all participating actors, and offering a potentially powerful tool to improve public health and protect the local environment.

The participatory identification of the most relevant risks and, therefore, the more urgent management priorities was probably the most valuable management outcome of this study.

The experience gained during this study could contribute to the ongoing debate on the ideal institutional framework and management scale for the implementation and operation of a successful WSSP.

ACKNOWLEDGEMENTS

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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