Index insurance as a risk management strategy to hydrological extremes for water utilities

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A prospective analysis of index insurance as a risk management strategy to hedge hydrological extremes for water utilities

Abstract

As the global economy expands, the depletion of natural capital poses a significant challenge, leading to higher costs and inefficiencies in achieving future water security. To address this challenge, risk transfer mechanisms have been employed as part of risk management strategies to safeguard regions that are particularly susceptible to the impact of extreme events affecting water availability. Index insurance has been investigated as a potential solution for dealing with drought-induced water scarcity within the water supply sector. Nonetheless, floods and water quality can affect water supply, resulting in economic losses for the sector. However, these hazards have still been underexploited in the context of multi-risk transfer facilitated by index insurance for water utilities. Here we investigated the need and relevance of implementing index insurance schemes for flood, drought, and water quality risks, by conducting interviews with specialists responsible for strategic decisions in water utilities, inquiring about their Willingness to Pay (WTP) for such schemes, their perceived importance and likelihood of acquiring them for their respective utilities. Our results revealed an average of WTP values of 3.3, 1.3, 2.5, and 1.6% for the insurance schemes related to droughts, and water quality degradation in terms of turbidity, floods, and algal blooms, respectively, signifying a substantial WTP among the water utility to invest in such risk transfer mechanisms, opening new business opportunities in the insurance market for extreme events. Nonetheless, enhancing the design and implementation of the scheme is crucial to bolster the confidence of water utilities in adopting these innovative products.

Keywords: Risk transfer; Risk management; Water supply; Water pollution; Hydrological risks

1. Introduction

Water security is defined as the availability of water in sufficient quantity and quality to meet human and economic needs, as well as the conservation of aquatic ecosystems with an acceptable level of risk from extreme events (ANA, 2022). According to UNEP (2021), water insecurity is the second most vulnerable aspect to the effects of climate change in the eyes of the Paris Agreement signatory countries. Water availability declines can jeopardize the sustainability of other dependent services such as food security, energy supply, and consumer goods (UN-Water, 2021). As a result, such changes affect the risk of capital derived from the use of natural resources, which affect the concern of risk-averse individuals (Kelsall et al., 2022). Natural capital comprises stocks of ecological and economic goods and services derived from renewable ecosystems, like raw materials, food, and environmental services such as climate regulation, nutrient recycling, and biodiversity preservation. Additionally, it includes non-renewable resources like oil, coal, and minerals. Nevertheless, natural capital can be destroyed indirectly through contamination from human productive or consumptive activities, or directly as a result of its exploitation or fragmentation. Sustainable management of these resources is crucial to safeguard the well-being and survival of present and future generations (UN, 2023).

As the global economy expands, increasing losses of natural capital translate into substantially higher costs and inefficiencies in achieving future water security (Vörösmarty et al., 2021). Risk management, according to Kreibich et al. (2022), generally reduces the impacts of extreme weather and climate events. Risk transfer is one of the risk management tools that has been used to protect regions highly vulnerable to the impacts of extreme events, which are exacerbated by climate and land use and cover change (Benso et al., 2022; Navarro et al., 2021), in addition to demand changes caused by population growth (Guzmán et al., 2020). A functional insurance scheme can provide financial relief, which, when combined with adequate risk education and awareness, can reduce variabilities in cash flows caused by the occurrence of extreme events (Mohor & Mendiondo, 2017).

The insurance market has shown significant impacts on improving public infrastructure risk management (Agrawal & Kim, 2022). Insurance products are classified into two broad categories: conventional insurance, in which premiums are calculated based on a series of actual losses suffered by the insured, and index insurance, or climate-indexed insurance, in which premiums are frequently calculated based on a probabilistically estimated climate indicator. Index insurance has the advantage of reducing administrative costs, adverse selection issues, and moral hazard. Different from conventional insurance schemes that rely on loco-verifiable losses, index insurance relies on the observation of an index that is closely related to losses (Miranda & Farrin, 2012). Index insurance stands out as a risk transfer option because it reduces administrative costs by not requiring loss verification, making it more affordable for poorer regions, where insurance availability remains significantly lower than the global average (OECD, 2021). Since the losses are determined by the index value, if policyholders take other measures to mitigate their losses during an extreme event, they will receive the amount agreed upon in the contract. This creates conditions to reduce moral hazards and adverse selection problems (Clement et al., 2018). Nonetheless, the selection of a specific index could face limitations, such as not capturing the total risk, which needs a precise study of the indices aligned to the hazard to set up the payout's arrangement. That can be named basis risk, which refers to the risk that the insurance payout based on an index does not match the actual loss experienced by the policyholder. This can occur due to a mismatch between the index and the actual loss, or due to geographic basis risk, which occurs when the insurance index is based on a location other than the insured location (Benso et al., 2023; Norton et al., 2013). Basis risk is a key challenge in designing and evaluating weather index-based insurance for multi-hazard resilience.

Given the revenue losses associated with multiple droughts over several years or extended multi-year droughts in the water supply sector, index insurance is a recently studied alternative to cover loss and damage (Baum et al., 2018; Baum & Characklis, 2020; Guzmán et al., 2020; Zeff & Characklis, 2013). Index insurance, according to Zeff & Characklis (2013), is an alternative to be taken isolated or combined with temporary conservation measures, such as restrictions on specific types of water use or surcharges and contingency funds.

According to Zeff & Characklis (2013), index insurance is beneficial when the cost of mitigating high-cost and low-frequency drought events would require the maintenance of significant and infrequently used contingency funds. However, one limitation of index insurance implementation during high-cost drought extremes is the need to maintain large reserves by the insurer, which raises the insurer's policy implementation costs. Further, this limitation, according to Baum & Characklis (2020), can be overcome through risk pooling and reinsurance strategies. The literature also brings examples of tailored contracts during drought: Guzmán et al. (2020) estimated the police prices to the utility during drought in the face of climatic, anthropogenic, and economic change drivers and found that insurance contracts that cover only longer droughts offer better financial performance than contracts that cover all types of drought duration.

Water scarcity, on the other hand, can result not only from a lack of water in terms of quantity but also from the degradation of quality. The treatment process's efficiency is highly dependent on the quality of the raw water (Thorne & Fenner, 2011). As a result, deterioration in water quality can cause failures in the treatment process, with consequences for health and supply reliability (Raseman et al., 2017), as well as interruptions and financial losses for the company. In addition to changes in water quality, floods also impact water supply in the process of capturing, adducting, and distributing water, resulting in economic losses for utilities (Milograna et al., 2013).

In the context of the water supply sector, index insurance has been recently primarily studied for drought (Zeff & Characklis, 2013; Baum et al. 2020; Guzmán et al., 2020). However, the existing literature reveals a dearth of suggestions or proposals concerning the implementation of risk transfer mechanisms to address other types of extreme events that can significantly impact water supply companies, such as floods and pollution extremes. Given the multi-hazard nature of threats to water supply services, there is a pressing need to conduct further analysis in this domain, which could potentially pave the way for broadening the application of risk transfer models as a viable strategy to mitigate financial losses faced by water utilities. This work aims therefore to assess the necessity and significance of introducing index insurance schemes covering flood, drought, and water quality risks, aiming to safeguard water utilities from substantial financial losses. Our approach involves two distinct methodologies. Firstly, we establish a theoretical foundation supporting the rationale behind these insurance schemes. Subsequently, we evaluate the actual demand and relevance of these proposed index-insurance products by engaging in interviews with specialists who play crucial roles in making strategic decisions within water utilities.

2. Hazards, damages, and index insurance as mechanisms of response

In this section, we will provide a succinct overview of the various hazards that water utilities encounter and the mechanisms they employ to safeguard themselves from these events. Our primary focus will be on exploring how index insurance can serve as a protective measure for the water utilities' business interests. To illustrate the impact of hazards and the responses of utilities, Table 1 presents a compilation of global case studies. These cases highlight the diverse hazards, the resulting damages, and the corresponding mechanisms utilized by utilities to address them. As shown in Table 1, despite acting through different mechanisms, the three types of hazards, whether they occur independently or in combination, possess the capacity to disrupt the operations of water utilities. Such disruptions may manifest in the form of water service interruptions, amplified costs associated with hydric infrastructure maintenance and water treatment, and adverse impacts on water-related business activities.

Water demand declines during droughts, unbalancing revenue and exposing utilities to financial risk. Coping with this challenge can involve the expansion or retention of substantial supply capacities, which presents an approach to address the issue. However, the high cost of maintenance and the complexities of obtaining regulatory approvals for such measures (Scudder, 2012) force water utilities to frequently rely on conservation strategies to hedge against drought impacts. One conservation strategy observed in drought cases, presented in Table 1, is the implementation of drought surcharges (Zeff & Characklis, 2013). Droughts can last for months or years, putting serious constraints on water utilities' operations and affecting the needs of consumers. Conversely, low-frequency flood events, although shorter in duration (days), have the potential to cause damages to utilities due to equipment loss, additional operational costs, and welfare losses for consumers experiencing service disruptions. Consequently, water utilities often find themselves compelled to invest in new equipment or infrastructure and allocate additional resources to debt service payments or mitigation measures following such events. For instance, the Minnesota case in Table 1 exemplifies the aftermath of flood events where utilities undertake measures like pumping water out of the system to counteract the impact (as in Yorkshire, 2015-2016). Similarly, when there is a drought, the raw water quality can degrade due to reduced dilution in the source or by the need to abstract in low water levels, as is the case of the São Paulo Metropolitan Region (Table 1). These deteriorations increase treatment costs and the frequency of maintenance outages, rendering water utilities financially vulnerable during extreme weather events. Furthermore, during wet periods, runoff and soil erosion can lead to high turbidity of raw water, creating challenges in treatment processes for some plants (Thorne & Fenner, 2011; Maziotis et al., 2020). Resizing treatment processes, diversifying water supply options, increasing plant design redundancy, changing long-term operations, developing effective plans to respond to extreme events, and improving water quality monitoring are some solutions to the raw water quality problem (Raseman et al. 2017). However, implementing some of these measures adds to the high cost and challenges regulatory approval.

Water quality degradation is not always closely associated with weather extremes, as evidenced by the eutrophication events occurring in Rio de Janeiro and Lake Eirie, which are not associated with dilution capacity or runoff, as shown in Table 1. Both events, which occurred more than once, caused water and dependent services business interruption, users' dissatisfaction, and increased treatment costs. The former case is caused by a lack of sewage treatment in the basin (Bacha, 2020), whereas the latter is caused primarily by diffuse agricultural pollution (Scavia et al., 2014), posing a greater challenge to water management. However, as Thornton et al. (2013) point out, the problem of nutrient enrichment was thought to have been solved by municipal wastewater treatment and stormwater management, yet the eutrophication issue not only persists but is worsening in lakes and reservoirs. The climate change factor (Wells et al., 2015) and the unique characteristics of each ecosystem (Thornton et al., 2013) can make the happening of these events uncertain. This requires acting not only to determine the cause of nutrient enrichment (which can be varied or uncertain) but also to financially mitigate the problem when these events happen, giving water utility resources to act when this happens.

During droughts, without enough water reserves to sell in a way that revenue and costs can be balanced, water utilities are often forced to buy water from other sources, such as neighboring regions or drilling into aquifers, which are costly alternatives due to the source of the supply and infrastructure needed to transport it (Polasek, 2014). To address these financial imbalances during droughts, water utilities can take three basic actions, hybrid or individual, to hedge against unbalanced expenses and revenues during droughts: drought surcharges, contingency funds, and index insurance contracts (Zeff & Characklis, 2013). The last one is still little explored in practice and is under study by researchers.

Utilities may raise volumetric water prices to compensate for lost revenue and encourage users to conserve. Surcharges, on the other hand, are unpopular with users and thus politically difficult. The water utility can self-insure against losses by making regular contributions to a contingency fund. However, given the challenges in drought variability, Zeff & Characklis (2013) believe that a high-liquidity fund large enough to hedge against the effects of multiple droughts over several years or an extended multi-year drought would require periodic contributions far over expected revenue losses. Furthermore, for local utilities, local politicians have access to contingency funds that can be used for other purposes.

Index insurance schemes offer an alternative risk management strategy where a financial contract transfers a portion of the financial risk to a third party in exchange for a premium. This third party is a financial institution in charge of taking on risk for one or more utilities.

Alternatively, a group of utilities could pool their resources to self-insure against similar risks (Baum et al. 2018). The premium calculation involves administrative costs, third-party returns, and the opportunity cost of reserves, based on the expected losses simulated during the contract term, utilizing a pre-agreed index value closely related to actual losses (Baum et al. 2018).

While index insurance has been studied as a risk management tool for droughts, existing literature lacks comparable schemes applicable to water quality and flood-related risks faced by water utilities. Hence, further investigation is necessary to develop mitigation mechanisms that can transfer financial losses incurred due to water quality degradation and flood damage. Such mitigation strategies can provide economic compensation to utility companies during extreme events, enhancing their preparedness to cope with these challenges. Importantly, index insurance should complement other mitigation measures, and its proposal does not diminish the importance of sewage and waste disposal measures or the modernization of water infrastructure. Instead, it represents a valuable addition to the risk management toolkit in alignment with national and international sanitation and water security plans.

Table 1 – Extreme events of flood, water pollution, and drought in some locations around the world, damage associated with water supply, and response measures taken.

Location of the incident	Period	Type of hazard	Description of hazard	Damage registered	Response measures taken	Reference
Guandu River Basin, Rio de Janeiro, Brazil	2020, 2021	Water quality degradation	High levels of dissolved total phosphorus, cyanobacteria, and enteric bacteria affecting the plant causing eutrophication. Potable water with high levels of 2-MIB/geosmin.	Series of water supply interruptions. Consumer dissatisfaction was given to the taste and odor of treated water, leading to the search for mineral water. A penalty of 1,06 million to the state water utility in 2020.	Use of activated charcoal in the treatment process. Use of Phoslock in lagoons. Opening the floodgates for flow with greater volume and speed, partially renewing the water in the lagoon.	Bacha et al., (2021); Rodrigues (2021).
São Paulo Metropolitan Region (Brazil)	2013-2015	Hydrological drought and associated water quality degradation	Reduced flow level in the reservoir systems due to reduced precipitation records.	Water utility massive revenue reduction profit of close to 60%. Direct and indirect economic losses in other sectors are dependent on the water supplied by the water utility.	Drought surcharges; advertising campaign; penalty and bonus tariff; pressure reduction; transfer for other reservoirs; reduced consumption; dead volume extraction; water treatment costs increase.	Guzmán et al., (2020); Marengo et al. (2015); Nobre et al. (2016); Souza et al. (2022); Taffarello et al. (2016).
Lake Erie Basin, Ohio, USA	2011, 2012, 2014	Water quality degradation (mainly) and hydrological drought (some years)	Cyanobacterial bloom and hypoxia	Microcystins levels exceed drinking and recreational water guidance values. Water supply interruption for 500,000 users. Lake Erie’s fishing and tourism industries were also affected.	Increase in treatment cost due to chemical acquisitions; water destined for other parts of the state diverted to the affected region; search for alternative water resources.	Dungjen & Patch (2022); Watson et al. (2016).

Cape Town, South Africa	2017-2018	Hydrological drought	Hydrologic drought due to reduced precipitation records	Reduced water revenue, and losses in agricultural jobs and production. Drop in tourism.	Drought surcharges; water use restrictions; search for alternative water resources; communication campaigns.	Muller (2018); Ziervogel (2019).
The metropolitan region of Barcelona, Spain	2007-2008	Hydrological drought	Hydrologic drought due to reduced precipitation records	US$ 511 million in economic costs of emergency measures; Direct and indirect economic losses in other sectors dependent on the water supplied by the water utility.	Water shipping; building pipes to distant rivers; water use restrictions; awareness campaigns; search for alternative water resources.	March et al. (2013); Martin-Ortega et al. (2012).
Minnesota, city of Grand Forks, East Grand Forks, Fargo, and Winnipeg, United States	1997	Flood	Fluvial floods that overcame dykes and reached the city	US$ 3.6 billion in economic costs; more than 50,000 people had to be evacuated, and more than 11,000 houses and businesses were damaged; Water supply was interrupted for five days.	Installation of pumps; protecting the water plant structure to avoid collapsing of walls and infrastructure, opening street valves to reduce the water pressure in the system; Increasing chlorination in the system to avoid contamination.	Bauer (2017); Thornley (1997).
Yorkshire Water, United Kingdom	2015-2016	Flood	Fluvial flooding is caused by a series of storms.	US$109 million for water utilities in capital costs, operational costs, and welfare damages; some business interruptions were reported.	Pumping flood water from the network.	Environment Agency (2018).

3. Methodology

3.1 Proposed insurance schemes for water utilities

Based on the presented issues exposed in section 2, four general insurance schemes are proposed to water supply utilities, and two for raw water quality. The insurance schemes (type of insurance, damage coverage, and condition for triggering claims) are in Table 2. Figure 1 depicts where, in the water supply chain, the proposed insurance schemes protect water utility businesses from financial losses.

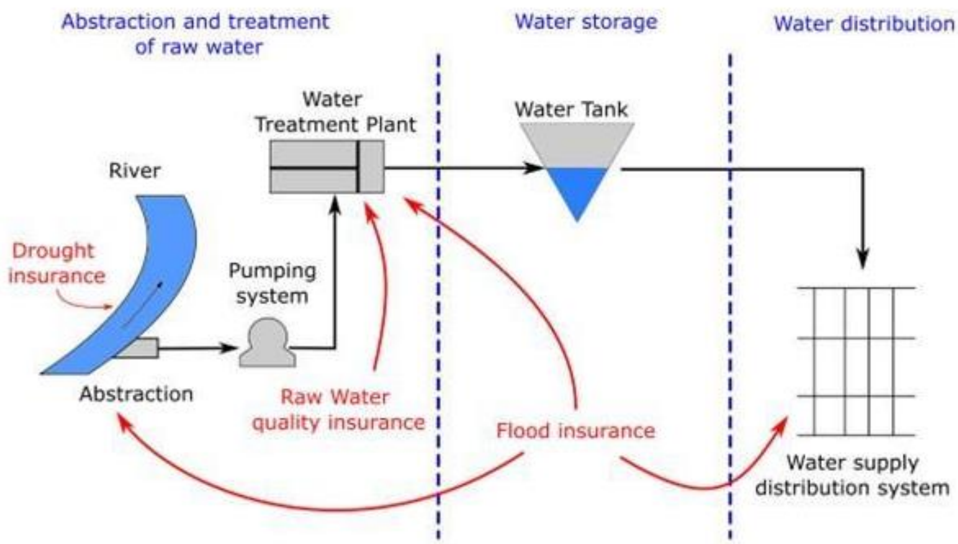

Figure 1 – Types of index insurance schemes based on different hazards and where they can act in the water utility business.

We suggested implementing an index insurance policy to cover pollution caused by algal blooms. The proposed index for this insurance is based on the intensity of taste and odor, as it serves as a reliable parameter indicating the occurrence of algal proliferation. Additionally, user complaints during such events are directly linked to taste and odor intensity. To determine the trigger for the insurance, we propose using a taste and odor intensity threshold of 6. This value aligns with the maximum limit set by the Consolidation Ordinance of the Ministry of Health nº 888/2021, making it a relevant and practical indicator for insurance purposes. Regarding the insurance coverage period, we recommend using a threshold of up to 7 days. This duration is chosen because it is expected that after 7 days, the situation would generally be under control, reducing the potential for prolonged damages. Please note that the specific indices and trigger levels for the index insurance may vary depending on the legislation and utility particularities of each country. Customizing these factors to suit the local context will ensure the effectiveness and relevance of the insurance policy in addressing pollution caused by algal blooms.

Table 2 – Proposed insurance schemes.

Type of hazard	Damage coverage (financial losses covered)	Trigger
Pollution in terms of algae proliferation	All financial losses resulting from expenses due to the water supply by alternative means and the increase in treatment costs	Taste and odor of water distributed above 6 of intensity for a minimum of 3 and a maximum of 7 consecutive days
Pollution in terms of turbidity	All financial losses arising from expenses due to the water supply by alternative means and due to increased expenses with inputs in water treatment	Interruption of supply for a minimum of 6 hours and a maximum of 12 consecutive hours
Droughts	All financial losses arising from reduced income due to drought for a period of up to 4 months	A level below the pumping capacity
Floods	All financial losses due to damage to infrastructure and water supply by alternative means	Overflow of the main source

The second insurance scheme focusing on water quality is related to increased turbidity. During periods of intense precipitation, in the treatment plants, interruptions in the supply for hours may occur due to the increase in the turbidity of the raw water. We used a minimum threshold of 6 hours because we believe that outages of up to 6 hours do not imply significant economic damage to operators or dissatisfaction among users. We add the upper limit of 12 hours in a row because we infer that the situation is unlikely to extend beyond this limit. In this insurance option, we use the occurrence of stoppages as an indicator that is associated with a significant increase in turbidity during rainy periods. However, we did not define a minimum turbidity value to bring more upfront communication with employees, since what matters during such events is the occurrence of stoppages and not the turbidity value, unlike eutrophication occurrences in which the achievement of the recommended levels of taste and odor often incurs user complaints. The relationship between turbidity values and shutdowns can be further studied in future works.

For hydrological insurance, we proposed a drought, in addition to a flood insurance scheme. Given the relationship between income and drought rates explored by Baum et al (2018), we used the reduction in income as a way of covering damage. We used the duration of the drought as an index, also adopted by Guzman et al (2020), and the reservoir level below the pumping capacity as a trigger for insurance. Although this trigger is subject to moral hazard, as it depends on how the company manages water resources (Baum et al 2018), this is easy to understand and communicate with people who are not insurance specialists, which is why we adopted it in this work. For the same reason, the reservoir level was also used as a trigger condition in case of floods.

3.2 Willingness to pay, relevance, and probability of the index-insurance schemes acquisition

The willingness to pay (WTP) denotes the value that the individual gives to a certain good or service delivery, that is, it reflects the trade-off between the consumption of that good or service and the benefit derived from it (Hunter et al 2012). In this work, we investigate WTP as a representative way of perceiving the acceptance and prelaminar economic value of insurance schemes. The acceptability of the scheme was tested in water utilities supplying water to part of the Brazilian Southeastern region, specifically in the part of São Paulo, Rio de Janeiro, and Minas Gerais states. In total, 10 interviews were conducted, with 10 representatives from 8 different water utilities, responsible for the public supply for over 10 million inhabitants, 5.3% of the population of Brazil, in 27 municipalities (IBGE, 2022). Even though for one utility, a state one, there was more than one interviewed, this is a regional company that serves water to municipalities with different vulnerable conditions. The participant water utilities comprehend different kinds in terms of the administrative sphere, varying between public, private, and mixed; at regional (state) and local (municipal) levels. In this way, an overlook of the index insurance schemes acceptance can be inferred between different kinds of administration and geographic domains. During the interviews, the survey was applied to top and middle-level employees involved in the strategic decision-making of the utilities. The complete survey is available in the supplementary material.

During the interview, the employees were exposed to a brief explanation of how index insurance works. Then, they were introduced to the proposal of acquiring the four kinds of index insurance to financially mitigate losses resulting from hydrological and water pollution extremes. Then, they were asked about their willingness to pay (WTP) to the proposed insurance schemes in terms of a percentage of the annual water operating revenue. If the bids were equivalent to zero, they were inquired about the reason. Afterward, a debriefing section is conducted where the interviewees are asked if they have heard about similar insurance schemes, the importance of acquiring insurance for the business of the water utility, and the probability of contracting at least one of the insurance types by the utility.

4. Results and discussion

In total, representatives from four autarchies (public ownership and administration, and local domain), two mixed capital companies (public administration and state level), one private company (private administration and local level), and one direct public administration (local domain) were interviewed. None of the interviewed employees has heard of similar insurance schemes for water utilities, which confirms that the water utilities do not have signed index insurance policies. On a scale from 0 to 5, of which 0 is equal to understanding nothing and 5 to everything, all of them informed at least 4 regarding the comprehension of the explained insurance schemes, validating, in general, the answer provided. In Figure 2, we summarize the WTP for the different scheme types.

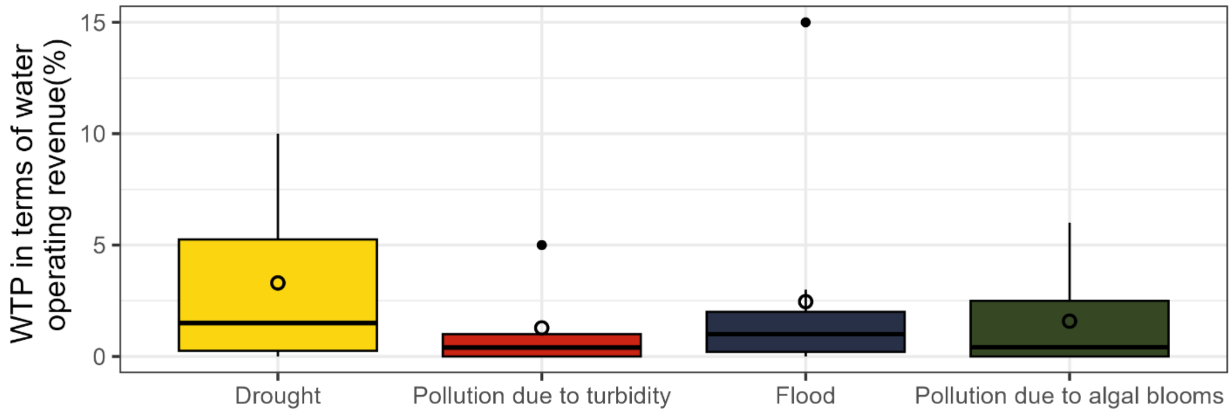

Figure 2 – WTP values for the four different types of schemes.

Average WTP values were equivalent to 3.3, 1.3, 2.5, and 1.6% of direct water revenue for drought, turbidity pollution, flooding, and algal bloom pollution. In this work, we investigated the WTP as an indirect way of perceiving the acceptance of insurance schemes. However, it is emphasized that these are preliminary values and that they serve as a qualitative analysis of the importance of insurance from the point of view of the potentially insured, not serving as a criterion for determining policies.

The interviews offer insight into risk aversion, which plays a critical role in determining the values of WTP (Menezes & Hanson, 1970). It is important to state that risk premiums are often determined by the expected losses and damages, level of coverage, and the cost of risk, yielding values that might be significantly different from what customers are willing to pay for the policies (Young, 2014). Insurance policies that cover revenue have been used for agricultural insurance to protect farmers from both yield and price variation and presented a wide variation of premium rates, e.g, 3% for 90% of coverage of soybean in Brazil (Brisolara & Ozaki, 2021), 12 % for 90% of coverage of jujube in China (Qi et al, 2021). Moreover, Cao & Wei (2004) propose that 12% is a benchmark price for weather risks for a relatively simple contract. When compared with the percentage of water revenue, the WTP results of the present study of up to 3% may be seen as low to cover financial damage. This can be explained by the novelty of these insurance mechanisms, which implies a certain apprehension in giving high values to an unknown product.

Based on the WTP values, we realized that, despite the interviewed subjects giving greater importance to drought, other types of insurance also have significant relevance from the point of view of specialists from participating utilities. It is noteworthy that, to our knowledge, no other work has proposed an indexed insurance scheme involving damages due to water quality degradation. Thus, such results support the opening of new possibilities for a business that has not yet been explored in the insurance market for extreme events.

The percentage of interviews giving a WTP value different from 0 to the schemes corresponded to 70%, 70%, 80%, and 60% for drought, pollution due to turbidity, flood, and pollution due to algal blooms, respectively. The mentioned reasons to give zero to the schemes are no history of incidents of turbidity degradation or flooding (cited 3 times), the possibility of changing the source by 100% of the flow when the main source is inadequate in terms of eutrophication (1 time), availability of technology, capital and sufficient personnel when events of a significant increase in turbidity occur (1 time). Also were mentioned: the possibility of relocating equipment and labor that would immediately meet the demand in case of flooding (1 time), the possibility of the private company with local coverage to receive financial compensation from the granting authority (in this case, city halls) in the event of droughts (1 time), and tariff readjustments (1 time), also there were reasons involving the presented drought trigger (2 times).

Regarding the justifications involving the availability of technology, capital, and personnel and the possibility of relocating equipment and personnel, such reasons came from interviewees from state-owned companies, with mixed capital and wide geographical coverage. These operators serve municipalities with different conditions of vulnerability and rely on the “cross-subsidy” mechanism, which allows differentiated tariffs between rich and poor municipalities so that the excess collected in surplus municipalities can be used to subsidize the service in deficit municipalities (Sousa et al., 2016). These mechanisms thus facilitate the acquisition and reallocation of resources during flood events and degradation of water quality, thus contributing to the absorption of impacts arising from momentary water scarcity. However, during drought events with a wide geographic scope, even such companies' regional reach can suffer relevant financial impacts, as is the case of Basic Sanitation Company of the State of São Paulo (SABESP), a mixed company with a wide geographic scope that in 2014/2015 suffered a massive revenue reduction profit close to 60% (Gúzman et al., 2020). In addition, we also have examples in the Brazilian context of water supply crises due to pollution by algal blooms in municipalities supplied by the State Water and Sewage Company of Rio de Janeiro (CEDAE), a mixed company that supplies water to the metropolitan region of Rio de Janeiro. Both examples are illustrated in Table 1. Thus, such reasons raised to assign a value of zero to WTP by the schemes should not be considered as absolute for utilities with wide geographic coverage. Even more so when considering small geographic coverage utilities, given the tight budget and low availability of resources of local operators compared to regional operators.

As for the possibility of the private company receiving financial compensation from the granting authority (in this case, city halls) in the event of droughts or tariff readjustments, in these cases, the financial damages of these events would only be transferred from the private company to the city hall, not mitigating the situation. In addition, regarding the readjustment of tariffs, in section 2 we discussed the possibility of indexed insurance mechanisms acting concomitantly with contingency measures. As discussed in the work by Zeff et al. (2013), indexed insurance contracts can prevent large price increases or maintenance of expressive contingency funds.

Some respondents reported reasons for not submitting bids for drought insurance due to the trigger presented. One of them states that the insurance is triggered in very extreme cases and a trigger that allows earlier activation of the prolonged drought would be better. Another participant reported a null bid because the existence of an extreme drought prolonged for four months would already result in a break of the contract between the private operator and the granting power (in the Brazilian case, city hall). As we mentioned in section 3.2, we chose triggers referring to reservoir levels to facilitate the communication of the insurance mechanisms proposed to the interviewed, with the level below the pumping capacity being noticeable in the operation. However, we recommend studying less extreme triggers in future work, involving variables that are easy to monitor by third parties, such as accumulated monthly deficits in precipitation or flow.

Figure 3 presented an overview of the degree given to the proposed insurance schemes for the water utility business (on a scale from 0 to 5, where 0 is equivalent to no importance and 5 represents extreme significance), and regarding the probability of the utility taking out at least one of the insurance schemes (with 0 equivalent to no probability and 5 to 100% probability).

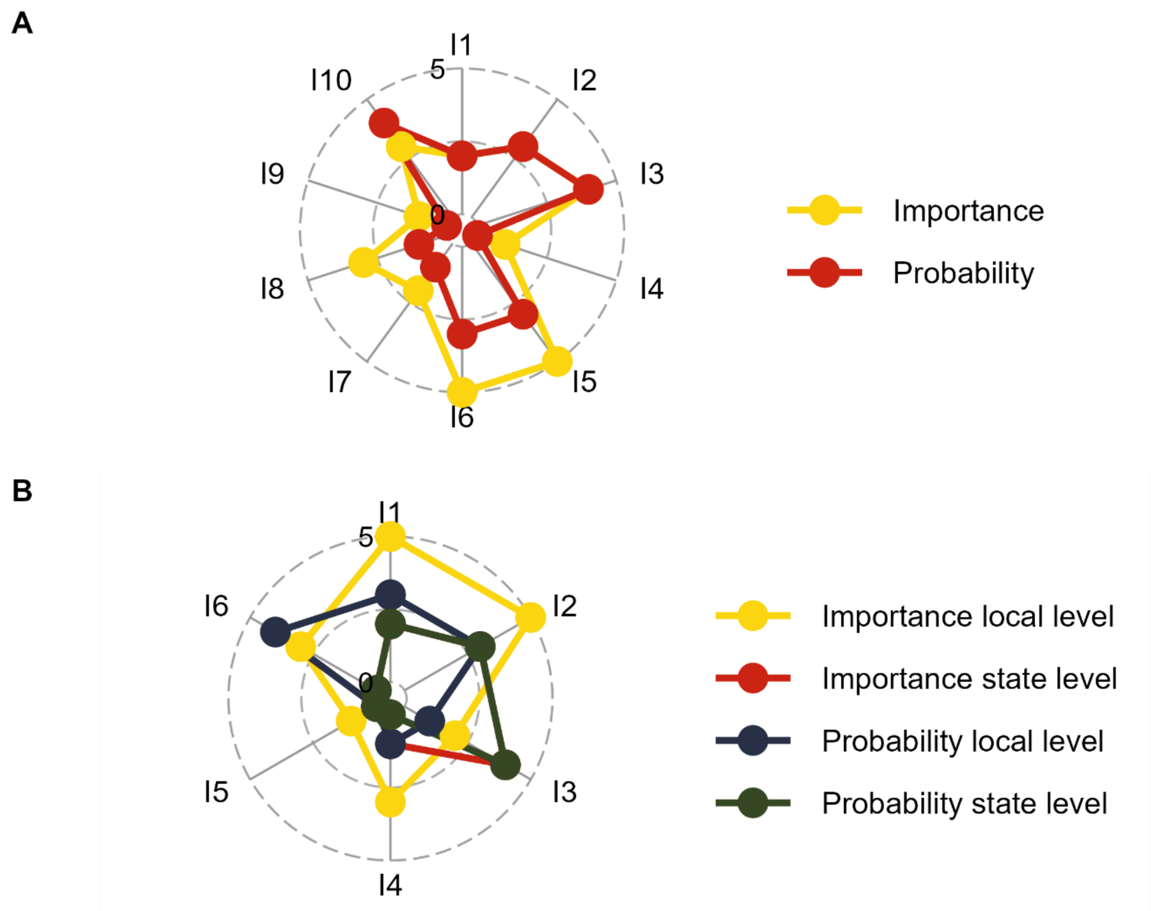

Figure 3 – Importance given by the 10 interviewed (I1-10, 4 for state-level utilities and 6 for local ones) in contracting the proposed insurance for the business of the water utility (with 0 being equivalent to no importance and 5 being extremely important), and probability of the utility taking out at least one of these insurances (with 0 being no probability and 5 equivalent to 100% probability). Results were taken together (A) and splinted by the spatial reach of the water utility (B). In this case, local means autarchies, direct administration, and private companies, all of them serving water at a local level. State means mixed companies with regional reach.

From the analysis of Figure 3A, we can see that the importance given to insurance to the utility business from the interviewed' point of view, which is equivalent to 3 in average, is greater than their probability of contracting, equivalent to 2 in average. Furthermore, in Figure 3B, a smaller value of importance given to companies with regional coverage is notable, which is probably due to the mechanisms explained above. Regarding probability, the main reasons informed by the employees to give low values of acquisition of the insurance schemes are the high capacity to deal with hydrologic extremes and pollution due to easy accessibility of resources and personnel during these events by mixed companies (cited 2 times). Although they still believe that the insurance schemes are important from the point of view of the shareholders of these spatial wide-ranging companies, to contribute to the stability of the businesses (reported by 1 respondent).

Further, one of the interviewees from a local and public utility affirms that, although important for managing the impacts of extreme events, the water utility may not be able to take up the insurance due to current low investment resources (1 time). Also, the insurance take-up probability may be impacted by bureaucratic questions (1 time). This may be critical, especially at the local level and in the case of the public sphere administration. The legal nature of the provider can be one of the main factors in deciding to purchase insurance. Private providers have greater access to the capital needed to carry out investments compared to public providers, where it is more difficult to obtain credit. In addition, they are inserted in a more flexible legal and regulatory environment, without bureaucratic ties (Pinheiro et al 2016).

Another mentioned reason to give low values to the uptake probability is the insecurity about how would be conducted the monitoring of the trigger levels and who would be responsible for it (1 time). As this is a new proposal, we believe that this type of concern is valid from the policyholder's point of view. Thus, given the relevant degree of importance reported by respondents to insurance schemes, we recommend that further work focus on the design and implementation of index insurance for water utilities, and the calculation of optimal premiums.

Within this perspective, it is emphasized that, when estimating policies, the influence of drivers of uncertainty, such as climate and socioeconomic changes in index behavior, must be studied. This means that the contract negotiation without studying the index's stationarity may allow the insurer to transfer an uninsured risk (Zeff & Characklis, 2013), and cause adverse selection problems, which include an absence of information about the disaster's impact (Zhu, 2017). In addition, due to a lack of information about these impacts, insurers may unintentionally assess the risks following a catastrophic event, resulting in reduced insurance availability and affordability (Cremades et al., 2018).

4. Conclusion and recommendations

Given the uncertainties associated with both climate extremes and socioeconomic choices to deal with the problem of water shortages and water security, as well as the definition of how these uncertain factors affect water supply, a residual risk remains in the water supply chain. This risk cannot be eradicated with preventive measures, requiring financial compensation to mitigate the damage. Among various financial tools available, index insurance, a relatively novel risk transfer approach in the supply sector, holds promise in assisting supply companies to reduce risk and uphold financial stability. Such mitigation efforts can provide economic compensation for losses incurred during extreme events, safeguarding the business and ensuring uninterrupted supply services. It is vital to emphasize that the proposal of this management instrument does not intend to replace measures aimed at proper sewage and solid waste disposal or hinder water infrastructure modernization. Rather, the index insurance-based risk transfer model complements other mitigation tools in national and international sanitation and water security plans.

Regarding the insurance schemes studied, the results indicate that in addition to insurance for droughts, schemes involving floods and degradation of water quality in terms of turbidity and algal blooms also have significant relevance from the point of view of experts from participating companies. To our knowledge, no other work has proposed an indexed insurance scheme involving damages due to water quality degradation, and a few have proposed for flood in water utilities. Such results thus support the opening of new possibilities for a business that has not yet been explored in the insurance market for extreme events. However, it should be acknowledged that the acceptance and importance of insurance may vary among companies based on administrative spheres and geographical contexts.

Given the complex vulnerability to different hazards related to the quantity and quality of raw water to which the operation of supply companies is often exposed, improving the application of risk transfer models is still necessary to incorporate multiple risks and uncertainties. Gaps and limitations in the design and implementation of water infrastructure insurance remain, including improved characterization of the relationship between droughts, floods, and pollution extremes and their implications in financial losses for supply; research and development of damage quantification methodologies, primarily related to flood and water quality degradation. Improving the design and implementation of such schemes can enhance water utilities' confidence in adopting these new risk management products.

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Competing Interests

The authors declare no conflict of interest.

Availability statement

The data presented in this study are available in the article itself and references are cited.

Ethical statement

All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted following the Declaration of Helsinki, and the protocol was approved by the School of Arts, Sciences, and Humanities of the University of São Paulo - EACH/USP (CAAE:69024223.1.0000.5390).

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