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Unlocking water saving potential in tourism destinations using Smart Water Meters

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ABSTRACT

Smart Water Meters (SWM) hold significant potential to mitigate water scarcity challenges in tourism-intensive destinations, yet their effectiveness in non-residential contexts remains underexplored. This study evaluates the impact of digital metering and feedback mechanisms on water consumption within tourism accommodations, utilising a geolocated panel dataset encompassing 213 high water-consuming establishments in San Bartolomé de Tirajana (Canary Islands). As a leading year-round destination, this region faces operational constraints that complicate conservation initiatives. Our comprehensive dataset integrates water network technical characteristics, tourism demand and supply variables, and climate factors across sub-municipal tourism zones to account for diverse guest profiles and management practices. Employing a random-effects regression model, we identify key determinants of water usage and uncover distinct consumption patterns between hotels and apartment complexes. The results reveal that while SWM installation significantly improves consumption tracking and enables early leak detection—primarily benefiting utilities—access to frequent digital feedback via web platforms correlates with increased water use. These findings challenge the assumption that digitalisation alone ensures efficiency, emphasising the importance of behavioural, organisational, and financial strategies while offering actionable insights for policymakers, utilities, and tourism operators to optimise digital engagement and adapt water governance.

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KEYWORDS
Smart Water Meters; digital feedback; water conservation; tourism sustainability; demand-side management

Statement of novelty

- This study provides the first empirical assessment of Smart Water Meter (SWM) adoption in a large-scale tourism setting, integrating operational, behavioral, and organizational dimensions.
- The research utilizes a novel panel dataset combining geolocated technical records, submunicipal tourism data, and water network characteristics, offering unparalleled granularity in water management analysis for tourism establishments.

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- Findings reveal critical insights into rebound effects in water consumption, providing evidence of how frequent feedback mechanisms can inadvertently increase usage in high-consumption sectors.
- The study introduces tailored policy recommendations that address structural disincentives in utility revenue models, with a focus on aligning conservation goals with financial sustainability in tourism-intensive regions.
- This work highlights the role of organizational complexity and managerial priorities in shaping the effectiveness of digital water management tools, offering actionable insights for improving operational practices.

1. Introduction

The accelerating pace of climate change is intensifying global water scarcity and quality concerns, posing significant risks for tourism-dependent regions (IPCC, 2022). While tourism accounts for a relatively small share of overall water consumption, its heavy concentration in semi-arid regions heightens exposure to climate-induced droughts and water shortages, particularly in the Mediterranean basin (Rodell et al., 2018). Seasonal peaks and spatial clustering further amplify tourism's water intensity, complicating sustainable resource management (Gössling et al., 2012). However, fragmented governance structures and weak coordination mechanisms often undermine conservation efforts, making water management a destination-wide challenge rather than an issue confined to individual firms. Strengthening governance frameworks is essential to ensuring the equitable and efficient allocation of water resources across tourism, residential sectors, agriculture, and ecosystems, thereby reinforcing the long-term resilience of tourism-dependent regions (Becken, 2014; Sandang & Cole, 2022).

Despite growing recognition of governance in water conservation, Demand Side Management (DSM) policies for tourism accommodations remain underdeveloped. While DSM strategies—such as price signals, behavioural nudges, and efficiency standards—have been widely implemented in residential settings to reduce per capita water use (Alias et al., 2017), hotels and apartment complexes operate under distinct economic and operational constraints that limit the effectiveness of conventional household conservation approaches (Gabarda-Mallorquí et al., 2024). Additionally, the absence of high-resolution consumption benchmarks for large tourism establishments complicates the development of enforceable efficiency targets (Becken, 2014; Gössling, 2015). Without detailed, sector-specific data on water use variability across different types of accommodations, policymakers struggle to design targeted interventions that reflect the diverse operational and technical realities of tourism water consumption.

To address this gap, researchers have investigated the determinants of water consumption in hotels and assessed water-saving measures, noting complexities like the overall lack of incentives (Styles et al., 2015; Antonova et al, 2021) and rebound effects that can limit long-term conservation efforts (Gabarda-Mallorquí et al., 2017; Rico et al., 2020; Suárez-Fernández et al., 2024). Yet, the advent of digital technologies in the water sector presents new opportunities for advancing DSM policies through more granular, frequent and transparent data. Smart Water Meters (SWM), for instance, enable real-time monitoring of water usage and more frequent feedback, supporting utilities and consumers in detecting leaks, identifying consumption patterns, and implementing data-driven conservation strategies (Cominola et al., 2015; Daniel et al., 2023; Monks et al., 2021).

Despite these advances, empirical evaluations of water digitalisation are largely confined to residential settings (Beal & Flynn, 2015; Cominola et al., 2021; March et al., 2017), with limited knowledge on the sustained impact of digital water data in tourism. While studies have demonstrated that real-time feedback can positively influence consumer behaviour, leading to reduced water usage (Boyle et al., 2013; Daminato et al., 2021; Fielding et al., 2013; Suresh et al., 2017), long-term sustainability and rebound effects, particularly related to water costs, have raised concerns (Brent & Ward, 2019; Wichman, 2017). Nonetheless, broader implementation of digital water services faces significant challenges related to the absence of compulsory water policies for technology adoption, metres' technical standards, and data privacy that must also be addressed (Koech & Randall, 2019; Msamadya et al., 2022; Stein et al., 2022).

The tourism sector, where water use is closely tied to operational efficiency and guest satisfaction, lacks robust evidence on the potential of digital water management. Organisational barriers, such as high upfront costs, resistance to new technology, and inadequate incentives, mirror those in energy efficiency studies (Andrews & Johnson, 2016; Karlin et al., 2015), which may further complicate SWM adoption in tourism. Digitalisation builds on existing research, which has advanced understanding of water consumption heterogeneity and the effectiveness of water-saving practices, by offering real-time data and benchmarks that empower more precise water management strategies, foster innovation in policy design, and improve sustainability outcomes in destinations.

Water management in tourism-intensive regions faces growing challenges, particularly in year-round destinations like San Bartolomé de Tirajana (hereinafter San Bartolómé), a leading tourism municipality in the Canary Islands. Large water consumers, including hotels and apartment complexes, play a critical role in addressing water resource pressures while balancing operational demands. Recent advancements in SWM offer promising tools for water conservation, enabling real-time monitoring, early leak detection, and options for setting up alarms for continuous, under-, and over-consumption. However, the implementation of these digital solutions requires careful evaluation, as their effectiveness often depends on organisational strategies and incentives.

This study examines the impact of digitalisation on water consumption in the accommodation sector, leveraging a comprehensive panel dataset spanning 48 bi-monthly readings (2011–2018) at a sub-municipal scale. The rich dataset integrates water consumption records, tourism demand and supply, water network characteristics, and climate variables. By analysing the effects of metres digitalisation and access to quasi-real-time data via online platforms, this research advances the understanding of water digitalisation in tourism-intensive destinations. However, emerging evidence suggests that frequent feedback, rather than uniformly promoting conservation, may, in some cases, lead to increased water consumption—a counterintuitive outcome that warrants further exploration in the context of tourism accommodations. These findings indicate both the opportunities and challenges posed by digital water technologies, highlighting the necessity of destination-specific, tailored water management strategies.

Beyond assessing SWM adoption, this study contributes to policy discussions on water governance in tourism-intensive regions. Given that water utilities often rely on volumetric pricing models, conservation initiatives risk creating financial disincentives for providers (Daniel et al., 2023; Mukherjee & Jensen, 2022). The study's findings reinforce the urgency of utility pricing reforms, as SWM feedback alone did not lead to sustained conservation in high-consumption hotels. Aligning volumetric pricing structures with digitalisation incentives—such as integrating digital-driven efficiency benchmarks into tariff models—could help mitigate unintended overuse while maintaining financial stability for utilities.

2. Literature review

Water management in tourism-intensive regions, particularly in year-round destinations like the Canary Islands, presents unique challenges where natural resource constraints intersect with increasing efficiency and sustainability demands. Digital technologies, such as SWM, have emerged as key tools in advancing conservation efforts by enabling real-time monitoring, leak detection, and feedback mechanisms that influence consumer behaviour. However, the effectiveness of water digitalisation in large tourism establishments remains poorly understood, particularly when considering organisational, regulatory, and behavioural barriers that shape digitalisation outcomes. This study addresses this gap by evaluating the impact of digital metres and feedback mechanisms on water use, while controlling for key establishment-specific factors that contribute to consumption variability.

To provide the necessary background for this analysis, we review (1) prior research on water consumption determinants in hospitality, which serve as essential control variables in our study; (2)

known barriers to water-saving measures in tourism, including institutional and organisational challenges; and (3) the role of digitalisation and feedback mechanisms in shaping conservation behaviours and policy interventions.

2.1. Determinants of water consumption in hospitality

Accommodations play a particularly influential role in destinations' water consumption. In hotels and similar establishments, water is an essential resource across services and experiences, with vacationers generally consuming more than residents (Becken, 2014; Bohdanowicz & Martinac, 2007; Eurostat, 2009; García et al., 2023; Gössling, 2015; Hamele & Eckardt, 2006; Kasim et al., 2014). Indeed, the accommodation sector accounts for a significant share of direct water use in tourism destinations (Cazcarro et al., 2014; Gössling, 2001, 2015; Hadjikakou et al., 2013), and consumption patterns exhibit substantial heterogeneity, shaped by the presence of water-intensive facilities such as pools, spas, and landscaped gardens (Gabarda-Mallorquí et al., 2017; Ramazanova et al., 2021; Tortella & Tirado, 2011).

Previous empirical studies on the determinants of hotel water consumption have identified both supply-side and demand-side factors. Structural characteristics—such as the number of rooms, floor area, pool size, and garden plots—are consistently associated with higher consumption levels (Bohdanowicz & Martinac, 2007; Gabarda-Mallorquí et al., 2017; Gopalakrishnan & Cox, 2003; Tortella & Tirado, 2011; Ramazanova et al., 2021). On the demand side, overnight stays and occupancy rates strongly influence usage patterns. Additional factors, such as renovations (Barberán et al., 2013) and leak prevalence (Deng & Burnett, 2002; Bohdanowicz & Martinac, 2007), have also been shown to impact total consumption. However, most prior research has focused on seasonal destinations, where operational cycles allow for structured maintenance periods, influencing conservation strategies. In contrast, year-round destinations like the Canary Islands face additional constraints, particularly in scheduling infrastructure upgrades and leak repairs. To account for these differences, this study integrates the year of construction and partial closure (i.e. periods of time during which certain sections of the establishment are temporarily closed for renovations, while other areas remain operational and accessible to customers) records into the analysis.

While hotel category and service standards have been widely acknowledged as drivers of water use (Becken, 2014; Bohdanowicz & Martinac, 2007; Rico et al., 2020), their precise influence remains less conclusive across different accommodation types. Higher-category hotels typically feature more water-intensive facilities, yet some studies suggest they also invest in efficiency technologies, potentially offsetting higher baseline consumption (Ramazanova et al., 2021; Rico et al., 2020). Similarly, our study explicitly differentiates between standard hotels and apartment complexes, where guests typically stay longer and have access to in-room kitchens, adding an additional layer of complexity to water use patterns.

This study builds on previous research by constructing a comprehensive panel dataset that integrates structural, operational, and behavioural characteristics of 213 large water-consuming establishments. Unlike prior studies relying on either cross-sectional or time-series analysis (Bohdanowicz & Martinac, 2007; Ramazanova et al., 2021; Tortella & Tirado, 2011), our panel-data approach captures both cross-sectional heterogeneity and temporal dynamics. Furthermore, we incorporate sub-municipal tourism zones to reflect distinct market segments and guest profiles, in alignment with the Statistical Framework for Measuring the Sustainability of Tourism (SF-MST) recently introduced by UNWTO (Hernández-Martín et al., 2025).

Beyond visitor demand and facility characteristics, climate factors also influence water use in tourism accommodations. While previous research has explored the effects of temperature fluctuations and rainfall variability on consumption (Mclennan et al., 2017), limited attention has been given to extreme weather events such as dust storms. These factors are particularly relevant in island destinations where water availability is naturally constrained, and climate conditions can intensify demand for pools, irrigation, and cooling systems. Our study explicitly controls for these influences, integrating temperature, precipitation, and dust event data to account for their potential impact on water use.

The accuracy of water consumption assessments depends on the technical complexities of water registration processes, which have been widely studied in residential contexts but remain underexplored for large consumers such as hotels. Centralised water networks, metre age, and pressure variability can introduce distortions in recorded consumption (Arregui et al., 2005; Criminisi et al., 2009; Mukheibir et al., 2012). Additional sources of variability, such as discrepancies in metre calibration, irregular logging intervals, and infrastructure complexity—including multiple metering points and internal water storage systems—create further challenges when linking registered data to actual use (Koech & Randall, 2019). Unlike most prior studies, which do not account for these challenges, our empirical model explicitly integrates variables such as metre age, number of metres per establishment, remote reading installation timing, and frequency and duration of detected leaks. By incorporating these technical variables, our study clarifies the role of water registration processes in shaping recorded consumption, addressing methodological gaps in previous research on water digitalisation for large-scale consumers.

2.2. Barriers to water-saving behavior

As the tourism industry increasingly aligns with sustainability goals, academic research has expanded to explore the drivers, barriers, and impacts of water-saving measures in accommodations (Gabarda-Mallorquí et al., 2024). Water conservation initiatives in tourism are primarily motivated by economic considerations, such as cost reduction, as well as broader environmental and social imperatives, including customer loyalty, environmental certifications, and CSR strategies that enhance brand reputation and meet rising stakeholder expectations (Font et al., 2021; Rico et al., 2020). Regulatory pressures, particularly during water crises, often compel hotels to adopt conservation practices (Alonso, 2008). However, operational constraints and managerial priorities can hinder the long-term success of water-saving measures, as sustainability initiatives may be deprioritized due to perceived inconvenience or upfront costs (Han et al., 2018; Styles et al., 2015). Additionally, rebound effects—where initial reductions in water use are offset by subsequent increases—can undermine the effectiveness of conservation efforts over time (Suárez-Fernández et al., 2024).

Although water costs represent a small fraction of overall hotel expenses (González Pérez et al., 2020; Gopalakrishnan & Cox, 2003), efficient water management is critical in tourism destinations where natural resources are constrained, particularly when water provision depends on energy-intensive processes like desalination. Increasing water scarcity at such destinations can drive investment in alternative water sources and lead to rising water tariffs, directly impacting operational costs. Beyond environmental benefits, efficient water use in hotels minimises energy demand and sustains the quality of guest services, which are central to customer satisfaction. Additionally, effective water management supports the conservation of essential natural resources, ensuring the long-term sustainability of tourism destinations. By reducing operational costs, addressing rising water prices, meeting consumer expectations for environmentally responsible practices, and aligning with CSR strategies (Font et al., 2021; Gössling et al., 2012), hotels can enhance their competitiveness while contributing to sustainable tourism development.

Key barriers such as the lack of local water consumption standards and the absence of tailored incentives—including utility-based rewards or adaptive tariffs—underscore the critical need for sector-specific, real-time data in tourism water management (Becken, 2014; Gössling, 2015). Addressing these limitations requires enhanced local-level data, more refined classifications of tourism activities, and the digitalisation of water data. Despite extensive research on SWM in residential sectors, there is limited knowledge about their application in tourism settings, particularly regarding the long-term stability of water-saving behaviours and the cumulative impact of digital water data on operational decision-making in large establishments. Effectively framing feedback on water consumption to mitigate cognitive biases is crucial for promoting water-saving investments in hotels, where initial costs and perceived risks often hinder technology adoption (Tversky & Kahneman, 1981). Benchmarking consumption against similar establishments further reinforces the business case for investment by providing managers with clear, comparative insights into potential savings (Liu & Mukheibir, 2018).

2.3. Digitalisation and feedback mechanisms

The emergence of digital metres and feedback mechanisms can represent significant advancements in water resource management within the hospitality sector. Digitalisation facilitates real-time monitoring, predictive analytics, and leak detection, offering a proactive framework for optimising water use efficiency (Cominola et al., 2015). Empirical evidence from residential contexts suggests that real-time feedback can yield consumption reductions of approximately 3–8%, particularly when coupled with behavioural interventions and economic incentives (Daminato et al., 2021; Liu & Mukheibir, 2018). However, the applicability of these conservation benefits to tourism accommodations remains uncertain due to distinct operational imperatives and guest satisfaction priorities.

Empirical research in energy and environmental resource management points to digital feedback systems delivering conservation gains but also yielding unexpected increases in consumption when organisational behaviour, operational complexity, and service imperatives mediate outcomes (Andrews & Johnson, 2016). In tourism accommodations, these dynamics are particularly salient: high guest turnover, fragmented departmental structures, and strong cultural norms around guest comfort and satisfaction contribute to a highly competitive environment where digital feedback does not necessarily lead to water conservation (Gössling et al., 2012). While studies have primarily focused on how frequent information shapes guest behaviour (Dolnicar, 2020) or optimises hotel water-intensive infrastructure (Antonova et al., 2021), they largely overlook how feedback mechanisms may influence the daily decision-making of hotel managers and staff—a gap that underscores the importance of integrating behavioural and organisational perspectives.

Understanding these outcomes requires looking beyond the technology itself to consider how perceptions of usefulness, service norms, and adaptive learning processes may influence the impact of real-time data platforms. The Technology Acceptance Model (Davis et al., 1989) suggests that perceptions of usefulness and ease of use determine whether managers and staff view digital platforms as helpful operational tools or as potential disruptions to high service standards and guest experience. Facilities managers may value water data for cost control, while service managers prioritise guest satisfaction, creating inherent tensions in how digital platforms are used. For example, uninterrupted water supply for pools, spas, and guest amenities can take precedence over resource conservation (Antonova et al., 2021). Short-term revenue pressures during peak occupancy periods and the logistical complexities of maintaining continuous service can make managers hesitant to fully engage with data platforms.

Even when digital platforms are integrated, organisational culture, departmental silos, and normative pressures to ensure guest comfort often overshadow purely technological incentives for conservation. The Theory of Planned Behavior (Ajzen, 1991) helps explain why attitudinal, normative, and perceived control factors often trump data-driven environmental goals. Cultural expectations around luxury experiences and departmental silos may reduce staff's perceived behavioural control, even as they recognise the importance of resource conservation (Dawson et al., 2023; Guerra-Lombardi et al., 2024).

Finally, even when there is awareness and an intention to conserve, these efforts can be undermined by the reactive decision-making and short-term operational priorities highlighted by Organizational Learning Theory (Lipshitz, 2000). In hotels, especially in national and international chains, knowledge and feedback frequently dilute in the complexity of operations marked by rapid guest turnover, reliance on seasonal staff, and fear of guest disruption from maintenance interventions (Antonova et al., 2024). Hierarchical decision-making can lead to fragmented responsibilities and delays in implementing conservation measures, such as leak repairs. In this context, the absence of robust, iterative learning structures—such as routine feedback loops, staff training, and adaptive cross-departmental practices—can reinforce reactive rather than proactive behaviour, particularly when water plays a critical role in maintaining the comfort and competitive edge of the establishment.

Despite the technological promise of digitalisation, a persistent gap remains between anticipated and actual conservation outcomes. This gap largely stems from organisational inertia, misaligned incentives, expertise deficits, and decision-making complexities (Suárez-Fernández et al., 2024; Tirado et al., 2019). These challenges are especially acute in large-scale tourism enterprises, where the complexities of high-volume service provision can hinder the effective integration of digital innovations.

This study employs a quasi-experimental research design to assess the impact of metres digitalisation and web-based monitoring platforms across 213 high-consumption tourism establishments in San Bartolomé, Canary Islands. Specifically, it evaluates the extent to which SWM installation, alarm configurations, and access to real-time consumption data contribute to measurable reductions in water usage. By incorporating geospatial technical records and integrating digital monitoring insights with broader tourism market dynamics, this research offers a rigorous evaluation of digitalisation's role in enhancing water efficiency. While SWM and feedback mechanisms hold significant promise, their effectiveness is ultimately contingent upon their alignment with operational structures, regulatory frameworks, and the behavioural drivers underlying water consumption in tourism accommodations. As such, the transition toward digitalised water management must be conceptualised not merely as a technological advancement but as a strategic shift toward data-driven, sustainable resource governance.

3. Methodology

The most relevant aspects of the methodology are described below: the construction of the database, the classification of the variables and the statistical analysis carried out.

3.1. Data and preliminary analysis

The unique database analysed in this paper was constructed by integrating two main records. The first was provided by Canaragua, the concessionary company of the public water supply and sanitation service in San Bartolomé municipality. This database contains information on the bi-monthly water consumption of all the large tourism water consumers, which are those with an annual water consumption of more than 3,000 m^3, for at least one year during the study period (2011−2018). The second database includes information obtained from the Canary Island Statistics Institute (ISTAC) and the Canary Island Government Department of Tourism (TURIDATA) on the individual characteristics of tourism establishments in the municipality, such as type of establishment, category, number of rooms offered, number of overnight stays, revenue per available room, and tourism zone (i.e. tourism zones below the municipal scale). In addition, other databases or web platforms (Cadastre, Google Earth, State Meteorological Agency [AEMET], Weather Underground, and the official websites of the establishments) were used to expand the information available to characterise each establishment and identify other possible determinants of their water consumption.

During the data cleaning process, any missing values or potential inaccuracies were addressed by either completing or correcting the data using information provided directly by Canaragua through direct communication or obtained from the official websites of the establishments analysed. Furthermore, for certain variables, data were available from both ISTAC and TURIDATA, which enabled cross-validation of the information and the imputation of missing values where necessary.

The final sample was made up of the 213 tourist establishments in San Bartolomé considered to be large water consumers, observed at bi-monthly intervals over the period 2011–;2018, with a total of 9,530 observations. Specifically, the sample consisted of 154 apartment complexes and 59 hotels with an annual consumption of more than 3,000 m^3 in the study period. These account for 82% of the beds offered in the municipality, with a representativeness of around 93% for hotels and apartments in 2018.

3.2. Variables

The explained variable of the model is the bi-monthly water consumption (m^3) of each establishment. For those establishments with more than one metre, the bi-monthly consumption of all metres was combined.[1] Total water consumption of accommodation establishments in our sample rose by 10% between 2011 and 2018, from 5.11 hm^3 to 5.61 hm^3. However, the values differ significantly between establishment types: hotel water consumption increased by 18.2%, while apartment consumption decreased by 1.8%. In relative terms, the average water consumption per bed was 65% higher in hotels (92.2 m^3) than in apartments (55.7 m^3) during the study period (Table A1, Appendix).

To ensure a clear presentation and description of this large and heterogeneous set of potential explanatory variables, five categories were established (Table A5, Appendix): (a) Fixed supply characteristics, which describe the establishment's infrastructure, and the tourism services it supplies. In particular, the aim is to explore how the basic infrastructure of the establishment affects water consumption; (b) Variable supply characteristics, which capture changes in the management of the establishment that could affect the services it provides; (c) Demand, which includes variables related to tourist demand, either through the number of overnight stays or guest profiles measured through RevPAR; (d) Climate conditions, such as ambient temperature, precipitation and rainfall levels, as well as the incidence of dust storm episodes, which are common in the Canary Islands; (e) Smart management variables, which include the technical information generated by the water utility, which facilitates, among other processes, the automated monitoring of individual consumption and the detection of anomalies. This category encompasses the installation dates of SWM, the activation of alarms for under- and over-consumption, and the registration of the establishment with the corresponding virtual office to access both electronic bills and, if a SWM has been fitted, quasi-real-time consumption and historical consumption data. This category also includes the number of metres at the establishment, the age of each metre (as a control variable to detect possible anomalies in readings), and leak detection within establishments.

One of the key contributions of this work is the analysis of the impact of smart water management variables. It is important to consider that the digitalisation of metres, through the installation of remote reading antennas, allows automated metre reading records to be obtained remotely at fixed 1-hour intervals, substantially increasing the frequency of the information available.[2] The remote variable provides more frequent information both to the company that manages the water service (which can use this information in its internal water management) and to tourist establishments that, in addition to benefitting from remote reading, have access to customer services via the virtual office.

The digitalisation of metres allows alarms to be set for over- and under-consumption and enables early detection of leaks and metre shut offs. In our case, it is important to note that we only have the records of the alarms automated by the utility. Therefore, although the establishments have the capacity to set alarms for continuous consumption or over-consumption through the virtual office services, we only know whether they are registered users, not the specific use they make of the platform.

In addition to these variables directly related to the smart management of the water supply service, this group of variables includes others related to the technical management of the company providing the service: the number and age of metres installed at the establishment. This information, combined with more frequent water consumption records, can provide valuable knowledge about the accuracy of metre records and about water consumption patterns in tourist accommodation establishments.

The main descriptive statistics for each establishment type are presented in Table 1. From an initial analysis, significant differences can be detected between hotels and apartment complexes, mainly related to infrastructure and tourism demand variables. For example, hotels make more intensive use of the larger plot size, landscaped areas, and swimming pools. Likewise, in the case of demand variables, the occupancy rate as measured through the number of overnight stays is almost five times higher in hotels than in apartments. Accordingly, RevPAR in hotels is between two and three times higher than in apartments.

3.3. Statistical analysis

To evaluate the impact of smart management on the water consumption of the establishments under study, we propose the econometric model expressed below (1). The model also incorporates other explanatory variables for water consumption in the accommodation sector, following previous studies, and adds novel variables to correctly isolate the effect of smart management. The model specification is as follows:

$$ln(m^3_{it}) \ = \beta V_i + \gamma W_{it} + \ \delta X_{it} + \vartheta Y_t + \mu Z_{it} + \rho T_t + \rho T_t \hat{2} + a_i + u_{it} \tag{1}$$

where the dependent variable ln(m^3) is the logarithm of the water consumption of establishment i (i = 1, 2, … , 213) observed in bimester t (t = bimester 1 of 2011, … , bimester 6 of 2018). V_i refers to a set of variables that represent the fixed supply characteristics of establishments that remain constant over time, such as category, number of rooms, plot size, garden and swimming pool areas, the year of construction, the property regime and the tourism zone in which the establishment is located. W_{it} denotes a set of explanatory variables with individual and temporal variability that represent certain characteristics of the infrastructure (variable supply characteristics), such as partial closures and renovations. X_{it} represents a set of variables related to demand, such as overnights and RevPAR, which also have individual and temporal variability. Y_t represents a set of variables that are the same between establishments, but with temporal variability, such as temperature, rainfall, and dust storm episodes. Z_{it} refers to a set of variables related to the smart management variables implemented by the water utility, which have individual and temporal variability. Parameter μ, the most interesting in our analysis, represents the set of estimated coefficients associated with each of the smart management variables, such as remote reading, number of metres, age of metres, virtual office, alerts for over- and under-consumption, and leaks. The variables T_t and T_t^2 represent a time trend (T = 1, 2, … , 48), which aims to capture whether there is a certain pattern of time variation in consumption regardless of the rest of the variables specified in the model.

The use of panel data models provides distinct advantages over alternative approaches, such as cross-sectional or time-series analyses. By incorporating both temporal and cross-sectional variation, panel models allow us to control unobserved heterogeneity factors that are constant over time but vary between establishments—thus mitigating omitted variable bias (Baltagi, 2008).

To our knowledge, this study is the first in the literature to systematically construct and analyse a panel dataset on water consumption in tourism accommodations, providing a unique empirical perspective in high-consumption industries. The dataset's breadth—capturing structural, locational, and organisational features—necessitates a modelling approach that preserves time-invariant regressors of theoretical relevance. While fixed effects models control for unobserved heterogeneity, they do so by eliminating all time-invariant variables, discarding valuable information about other key drivers of water consumption. By contrast, the random effects specification retains these regressors, thereby leveraging their explanatory potential more fully. Given the substantial number of cross-sectional units (N = 213), relying solely on fixed effects would also reduce the efficiency and precision of the estimates.

Additionally, to account for temporal heterogeneity—such as seasonal fluctuations, policy adjustments, or tourism demand shocks—the final specification includes a bimonthly fixed-effects variable

Table 1. Descriptive statistics of the sample.

	Apartments. N = 154						Hotels. N = 59					
Variable	Obs.	%	Mean	Std. Dev.	Min.	Max.	Obs.	%	Mean	Std. Dev.	Min.	Max.
Water consumption (m^3)	6,856		2,417.93	2,697.965	10	25,589	2,674		9,612.70	7,289.76	20	46,353
Category *												
1–2 keys	6,194	90.34										
3–4 keys	662	9.66										
1–3 stars							988	36.95				
4–5 stars							1,686	63.05				
Offered rooms	6,856		83.34	70.22	6	472	2,674		306.20	206.59	16	1136
Plot size (m^2)	6,856		12,452.32	17,819.37	798	155,709	2,674		22,255.19	21,818.58	976	107,626
Garden area (m^2)	6,856		3,360.27	8,520.96	0	77,854.5	2,674		6,584.42	10,680.13	0	53,813
Pool area (m^2)	6,856		249.24	208.01	0	1,092.6	2,674		796.59	1 077.13	0	6,134.09
Year of construction	6,856		1,979.15	8.47	1964	2,008	2,674		1,985.26	11.71	1,969	2012
Tourism zone *												
Bahía Feliz – Playa del Águila	333	4.86					49	1.83				
Campo Internacional	1,235	18.01					118	4.41				
El Veril – Las Burras	144	2.1					96	3.59				
Meloneras	0	0					476	17.8				
Playa del Inglés	4,290	62.57					1,467	54.86				
San Agustín	96	1.4					269	10.06				
Sonnenland	758	11.06					103	3.85				
Rest	0	0					96	3.59				
Property *												
Independent	6,100	88.97					716	26.78				
National chain	528	7.7					595	22.25				
International chain	228	3.33					1 363	50.97				
Partial closures	54	0.79					45	1.68				
Renovations	489	7.13					431	16.12				
Overnight stays	6,856		6,659.57	6,237.72	0	48,096.85	2,674		30,099.12	20,327.83	0	12,5065.4
RevPAR	6,856		31.38	11.58	10.485	62.02	2,674		82.75	29.49	34	134.08
Temperature	9,528		21.11	2.24	17.25	25.15	9,528		21.11	2.24	17.25	25.15
Rainfall	6,856		18.61	25.73	0	121.95	2,674		18.61	25.73	0	121.95
Dust storm *	718	10.47					288	10.77				
Remote *	2,807	40.94					776	29.02				
Virtual office *	2,187	31.9					1,680	62.83				
Default alarm *	84	1.23					18	0.67				
Excess alarm *	82	1.2					18	0.67				
Number of metres	6,856		1.27	0.85	1	9	2,674		1.49	0.68	1	4
Age of metres	6,856		49.52	80.12	0	279	2,674		36.65	67.97	0	284
Leaks *	158	2.3					56	2.09				

Max: maximum; Min: minimum; Obs.: observations; Std. Dev: standard deviation.
*The observations and the percentage refer to the observations in which the variables take the value 1.
Source: Author prepared.

to control for intra-annual seasonality, alongside a quadratic time trend to capture medium-term nonlinear dynamics in water consumption. This approach was adopted after preliminary estimations with annual fixed effects yielded statistically insignificant results. The combination of these components provides a flexible and parsimonious model structure that adjusts for unobserved temporal variation without risking overfitting.

For all these reasons, the random effects model was adopted. This specification allows the inclusion of time-invariant observed characteristics and addresses unobserved individual heterogeneity through a random variable a_i, which captures unobserved, time-invariant factors specific to each establishment. Finally, a random term u_{it} is included, assumed to follow a normal distribution with zero mean and constant variance.

It is important to note that all continuous explanatory variables in model (1) are introduced in logarithmic terms. For the dummy variables, we have chosen to omit one category in each case to avoid perfect multicollinearity. The reference categories of the dummy variables are the following: high category (3–4 keys for apartments and 4–5 stars for hotels), *Campo International* (from the variable tourism zone), national chain (from the variable property) and fourth two-month period (July and August, from the variable two-month period).

In our model, rainfall is considered to affect water consumption in two ways. First, it has a direct effect on water consumption across all the services of the establishment. Second, we hypothesise that rainfall could condition irrigation decisions in gardens and thus, indirectly, the overall water consumption of the establishment. A Taylor polynomial of order two is introduced, combining the variables rainfall and garden surface area.

Since one of the novel aspects of this paper is the distinction between hotels and apartment complexes, we tested whether there is sufficient empirical evidence to justify a differential analysis according to establishment type. To do this, and for each of the explanatory variables specified in the model, the hypothesis of equality between the parameter corresponding to hotels and apartments was tested using an *F-Snedecor* test with 60 degrees of freedom.

4. Results and discussion

Table 2 presents the estimated coefficients for the explanatory variables in model (1) and their statistical significance. The model explains 99% of the variance in total water consumption for the hotel sector. Notably, 83.6% (46 out of 55) of the explanatory variables are individually significant, suggesting that multicollinearity is unlikely to compromise the reliability of the estimates. A joint Wald test also supports the model's validity, with a *p*-value of 0. Finally, the test of parameter equality between hotels and apartment complexes reveals statistically significant differences for 70.8% of the variables, with exceptions primarily related to climate or smart water management factors.

The initial hypothesis of absence of autocorrelation and homoscedasticity in the model's random term was tested and rejected, prompting the application of the Prais-Winsten estimator, which offers unbiased and efficient estimates under these conditions. Furthermore, the presence of serial correlation discourages relying on the Hausman test for choosing between fixed and random effects, as its reliability is compromised in this context.

The results are presented and discussed considering both the parameters of the regressors, and to facilitate comparison with previous studies, their marginal effects in annual terms are provided in Table 3. Overall, the results show an inelastic effect on bi-monthly water consumption for all the variables analysed. The main results are discussed first in relation to existing evidence from previous studies, followed by a discussion of their novel contributions.

4.1. Results in the context of existing literature

The impact of tourism supply features on water consumption are in line with previous findings in the literature, although some clarification is needed with respect to different signs encountered by

Table 2. Regression model (1) estimates.

Variables	Establishment type	Coefficients		Variables	Establishment type	Coefficients	
(a) Fixed supply characteristics				***(c) Demand***			
Category (1–2 keys)	All	−0.2516	***	Ln (overnights)	Apartments	0.1112	***
Category (1–3 stars)	All	0.1881	***		Hotels	0.0697	***
Ln (Rooms)	Apartments	0.4596	***	Ln (RevPAR)	Apartments	0.1187	***
	Hotels	0.7138	***		Hotels	0.3062	***
Ln (Plot)	Apartments	0.2053	***	***(d) Climate factors***			
	Hotels	0.0883	***	Ln (Temperature)	All	0.5723	***
Ln (Gardens)	Apartments	0.0015		Ln (Rainfall)	Apartments	−0.0067	*
	Hotels	−0.0124	***		Hotels	0.0017	
Ln (Swimming pool)	Apartments	0.0144	**	Ln (Gardens) * Ln (Rainfall)	Apartments	− 0.0016	***
	Hotels	0.0776	***		Hotels	−0.0005	
Property				Dust storm	All	0.0238	**
Independent	Apartments	0.2324	***	***(e) Smart management***			
	Hotels	−0.0505		Remote	All	−0.0451	**
International chain	Apartments	0.2625	***	Online office	All	0.0539	***
	Hotels	0.1629	***	Over-consum. alarm	All	0.021	
Ln (Year of construction)	Apartments	0.1339	***	Under-consum. alarm	All	−0.0476	*
	Hotels	0.0184		Leaks	Apartments	0.2445	***
Tourism zone					Hotels	0.1428	***
Bahía Feliz – Playa Águila	All	−0.4644	***	Ln (Number of metres)	Apartments	0.3025	***
El Veril – Las Burras	All	−0.2559	***		Hotels	0.4063	***
Meloneras	All	−0.3558	***	Ln (Age of metre)	Apartments	−0.0037	
Playa del Inglés	All	−0.3289	***		Hotels	0.0088	**
Rest of San Bartolmé	All	−0.5264	***	Ln (Age of metre)2	Apartments	−0.0095	***
San Agustín	All	−0.1139	***		Hotels	−0.0043	***
Sonnenland	All	−0.2893	***	***Trend and cyclical component***			
(b) Variable supply characteristics				January–February	All	0.0044	
Partial closure	Apartments	−0.2518	***	March–April	All	−0.0007	
	Hotels	−0.4624	***	May–June	All	−0.0334	**
Renovation	All	−0.0765	***	September–October	All	−0.0692	***
				November–December	All	−0.0571	**
				T	All	−0.0138	***
				T^2	All	0.0002	***

Note: Three stars indicate statistical significance at the 1% level, two stars at the 5% level, and one star at the 10%.
Source: Author prepared.

Table 3. Elasticities and marginal effects on annual water consumption.

Variable	Type of establishment	Unit of measurement	Elasticity (% / %)	Marginal effect (m^3 / unit)
Rooms	Apartments	Rooms	0.46	87.59
	Hotels		0.71	132.58
Plot	Apartments	m^2	0.21	0.36
	Hotels		0.09	0.45
Gardens	Apartments	m^2	−0.01	−0.10
	Hotels		−0.01	−0.33
Swimming pool	Apartments	m^2	0.01	0.86
	Hotels		0.08	7.81
Year of construction	Apartments	Year	0.13	0.98
Overnight stays	Apartments	Overnights	0.11	0.28
	Hotels		0.07	0.13
RevPAR	Apartments	Euro	0.12	63.45
	Hotels		0.31	235.42
Rainfall	Apartments	mm or litres/ m^2	−0.02	−244.36
Number of metres	Apartments	Units	0.30	3,535.05
	Hotels		0.41	16,218.64
Age of water metre	Apartments	Two-month periods	−0.05	−50.96
	Hotels		−0.01	−1.13

Note: Bi-monthly marginal effects have been converted to annual effects to harmonise the results with those found in previous studies, which are generally expressed in annual terms.
Source: Author prepared.

establishment type. For hotels and apartments, the number of rooms, plot size, swimming pool area, overnight stays have a direct and positive impact on water consumption, in line with previous studies (Barberán et al., 2013; Bohdanowicz & Martinac, 2007; Charara et al., 2011; Deng & Burnett, 2002; Gopalakrishnan & Cox, 2003; Ramazanova et al., 2021; Tortella & Tirado, 2011). A more detailed comparative analysis by accommodation type reveals that, among the variables that increase water consumption, the number of rooms and swimming pool area have a greater impact in hotels than in apartments. By contrast, increases in plot size and in overnight stays have a greater impact on water consumption in apartments than in hotels.

If we consider that the property variable can be interpreted as an approximation of the type of management (Tortella & Tirado, 2011), establishments managed by an international chain have higher average water consumption than those managed by national chains or independent firms. Even though property types are not precisely comparable, our results for both hotels and apartments clearly resemble those of Gabarda-Mallorquí et al. (2017) and Tortella and Tirado (2011). In line with Barberán et al. (2013), renovations reduce water consumption by 7.6% on average in apartments and hotels. Finally, the impact of garden area on water use in apartments, it's influenced by rainfall, while in hotels, it is directly related to the landscaped area. These findings suggest that establishments in drier regions and with larger garden areas use more efficient irrigation and adapted vegetation, making larger garden plots more water-efficient (Bohdanowicz & Martinac, 2007).

We provide significant estimates for RevPAR having a positive impact on water consumption in hotels and in apartments, but greater for hotels, possibly capturing not only the higher occupancy rates but also the greater variety of high-added-value services in hotels. This result in line with more intuitive evidence that higher room prices often correlate with better environmental practices (Kasim, 2007; Styles et al., 2015), as well as with more expensive services and higher guest expectations (Bohdanowicz & Martinac, 2007; Gössling et al., 2012), which typically have higher room rates.

With respect to year of construction, the literature provides evidence supporting the notion that newer hotels are more likely to adopt water-efficient technologies, leading to lower overall water consumption (Bohdanowicz et al., 2011; El-Nashar & Elyamany, 2023; Mensah, 2006). However, our results indicate no significant impact in the case of hotels and a slight but significant contribution for apartments. On the other hand, the variable 'partial closures' reduces water consumption by 46% in hotels and 25% in apartments. While partial closures in seasonal destinations are systematic, allowing for updates and maintenance, this result is specific to a year-round tourism destination like the Canary Islands. According to the utility, this reduction reflects the prolonged duration of leaks and the greater difficulty of repairing them in hotels, where high occupancy rates throughout the year prevent timely leak repairs.

Although San Bartolomé is characterised by mild and stable temperatures throughout the year, a decrease in rainfall and increasingly frequent episodes of dust storms and heat waves have recently been recorded (Carrillo et al., 2022). Our results provide empirical evidence that, as the temperature rises, or dust storms become more frequent, bi-monthly water consumption in accommodation establishments increases in line with Mclennan et al. (2017).

In the case of metre age, the impact on water consumption reflects a loss of measurement accuracy, due to measurement errors, in line with Mukheibir et al. (2012) for domestic metres. The impact of metre age on water consumption indicates annual reductions in water consumption in apartments by 51 m^3, significantly higher than in hotels.

Regarding establishments' category, for apartments, higher categories demonstrate more efficient water use, likely related to higher occupancy rates, as reflected in the average consumption per overnight by apartment grades (Table A2 and A3, Appendix).

We provide evidence that contradicts previous findings regarding hotel categories and their water consumption. Specifically, lower-category hotels (1–3 stars) consume more water than upgraded ones (4–5 stars). This contradicts existing evidence and intuition, which suggest that higher-category hotels, with their water-intensive facilities and larger sizes, systematically have higher water consumption. Previous studies have measured this through litres per guest (Charara et al., 2011; Hadjikakou et al., 2013; Rico-Amoros et al., 2009; Styles et al., 2015), annual cubic metres (Hamele & Eckardt, 2006), and litres per floor area (Deng & Burnett, 2002). Even when considering energy-water consumption, these studies confirm higher usage in higher-category hotels (Yoon et al., 2022).

By contrast, the reduction in water consumption observed in 3-star hotels in Benidorm (Spain), which differs from the increasing average consumption in higher categories (Rico et al., 2020), suggests that lower-category hotels in San Bartolomé might have delayed the implementation of water-saving measures compared to higher-category hotels. Despite this, average water consumption in total, per room, and per overnight, remains higher in higher-category hotels, as well as by bed number.

These contradictory results may be explained by a combination of infrastructural inefficiencies, limited conservation investments, and pricing structures that do not incentivize efficiency. Unlike premium hotels, which often employ advanced water-saving technologies and strict operational policies, lower-category accommodation may rely on older plumbing systems, less efficient appliances, and a lack of automated monitoring to curb excessive consumption. Additionally, if water pricing structures provide little economic pressure for conservation in budget hotels, there is a reduced incentive to adopt proactive water-saving strategies. Guest behaviour may further reinforce this trend, as budget travelers—often staying for longer durations—may rely more on in-room facilities, leading to higher per-room water consumption compared to higher-category hotels where centralised amenities, such as pools or spas, distribute consumption more evenly across guests (Gössling et al., 2012).

Related to this, our empirical approach provides empirical evidence of the influence of tourism segments captured by the increasing scale to eight tourism zones. Significant differences in water consumption of both hotels and apartment complexes have been found according to the eight tourism zones in which the destination is classified for statistical purposes. Such aggregation of establishments into tourism zones, capturing features of homogeneous and differentiated market segments, extends beyond the variables already included by our model. In this respect, the highest average water consumption is recorded in *Campo Internacional* (the reference area), known for its high degree of urban homogeneity.

Table A4 of the Appendix provides a distribution of overnight stays according to the origin country of guests in each zone. Notably, while Germans prevail in almost all zones, *Bahía Feliz – Playa del Águila* stands out for the significant presence of Nordic tourists. Our results indicate that this zone has the lowest average water consumption (46%), which could be attributed to the high environmental standards upheld by its main tour operator, TUI Nordic. This finding suggests a possible relationship between the origin countries of tourists and water consumption behaviour by tourism segments.

This represents a novel insight in line with Gössling et al. (2019), who found that origin—particularly Nordic visitors in the same location—increases the impact of normative appeal messages for linen reuse. This result, combined with the observation that upgraded standard hotels have a lower long-term impact on water consumption, highlights the influence of market segments captured by tourism zone and category (beyond hotel size, swimming pools, and room rates). Specifically, it points to the environmental profile of tourists and the intermediation standards set by tour operators, which in turn prompt hotels to implement more effective water-saving measures.

4.2. Advancing the understanding of digital water management

Regarding the variables in the smart management category, the number of metres, the presence of leaks, and the use of online platforms are associated with increased water consumption. Conversely, the installation of remote reading systems, the activation of under-consumption alerts, and the age of the metre contribute to reducing water consumption. Notably, the impact of smart management variables on water consumption differs between hotels and apartment complexes specifically only for the variables of leakage, metre age, and the number of metres. For the rest – remote reading installation, access to the online platform, and alarm setting (in all options) – no significant differences based on establishment type were observed. This points to technical operations of the water utility more than to proactive behaviour of water consumers.

The massive implementation of remote metering has contributed to a significant reduction in the water consumption of tourism accommodation establishments. On average, the installation of a remote reading system, which expanded between 2012 and 2018, has reduced water consumption in all types of tourism establishments by 4.5%. It should be noted that remote reading identifies the period in which the SWM was installed and, therefore, for which a near-real-time reading of water consumption is available to both water utility and hotel managers.

According to March (2017) and Monks et al. (2019), the increase in information resulting from the digitalisation of water metres may provide advantages to both the water supplier and users. In the case of the water supplier, more frequent information means that data mining processes can be used to improve operations, increase business knowledge and improving communications, products and services for customers. For users, a digital metre directly provides the opportunity to access an online platform with more frequent consumption data. The reduction in water consumption observed can be attributed to several factors: timely detection and repair of leaks, increased accuracy and reduced estimation errors, operational efficiencies, and immediate feedback leading to prompt actions. These factors suggest behavioural changes due to increased awareness (Beal & Flynn, 2015; Boyle et al., 2013; Daminato et al., 2021).

First, our results indicate that access to the online platform correlates with an average increase in water consumption of 5.4%. Recall that this variable does not distinguish between establishments with and without digital metres and, therefore, some water users are only able to access digital bills, whereas those with SWM can also access more frequent information and set alarms for abnormal use. Nonetheless, 98% of all establishments had the SWM installed by 2018, and, therefore, had the possibility to access to more frequent information through the web platform.

A positive correlation between more frequent information and water consumption, suggesting that establishments with access to the online platform consume more water, was unexpected and not in line with the experimental literature (Beal & Flynn, 2015; Daminato et al., 2021). This surprising finding warrants further explanation. On the one hand, if hotel managers are accessing more frequent information and are proactively reacting, such measures might not lead to immediate water savings and could even result in higher consumption records. Indeed, as reported in several studies, investment in water-saving systems might expand facilities, increase guest capacity, or enhance amenities such as pools and spas (Gössling et al., 2012; Rico et al., 2020; Suárez-Fernández et al., 2024). In the context of residential water users, Wichman (2017) found causal relationship between increasing billing frequency (switching from bimonthly to monthly billing) and a 3.5–5% increase in water consumption. The study suggests that more frequent information can lead to increased water usage due to heightened awareness and confidence in monitoring capabilities.

Indeed, access to detailed water consumption data can lead to unintended behavioural changes. For example, hotel staff might feel less compelled to save water if they trust the platform to notify them of any issues, leading to a more relaxed attitude toward daily water use. Another explanation is that, upon registration, staff can become aware of abnormal registrations and detect water usage issues. In this case, initial identification and fixing might temporarily increase water consumption before any long-term reduction is realised as discussed by Boyle et al. (2013) and Cominola et al. (2015). This effect is likely amplified by the unique operational features of tourism accommodations, such as high guest turnover, fragmented departmental structures, and short-term revenue pressures that prioritise immediate service needs over long-term efficiency.

However, a self-selection bias in the adoption phase of the platform rollout could also explain the positive correlation. Establishments with higher baseline water consumption might be more prone to adopt innovative technologies earlier, such as registering on the online platform, since they face greater incentives to monitor and manage their water use more closely and frequently. Similar patterns have been detected by Faruqui et al. (2010). Moreover, seeking to facilitate communication of detected abnormal water registries with water users, the utility may have registered specific water users, including large water consumers, to be monitored.

Second, since the potential benefit of digitalisation is the possibility of setting alarms to detect abnormal consumption, these variables are included in the model. In fact, we found that the default under-consumption alarms identify reductions in water consumption of 4.7% on average. By contrast, there is no evidence that over-consumption alarms have had any effect on water consumption. Indeed, this is a logical result since setting the thresholds of water flows to identify over-consumption is a complex process that has not yet been refined (Farah & Shahrour, 2018).

Third, the leakage detection variable is systemically derived from the utility's billing records, as the utility lacks an automatic leak detection system. In apartments, nearly 40% of leaks persist for more than two months, with some extending to almost two years, whereas in hotels, 95% of leaks are resolved within four months (Table A6, Appendix). This disparity can be attributed to differences in the operational structure: apartments often cater to longer guest stays and provide in-room services such as kitchens and gardening, making it more difficult to shut down operations for repairs. In contrast, hotels, which typically have shorter guest stays and less complex water networks, face less disruption when addressing leaks. Indeed, the estimator associated with the leakage variable shows a significant and positive relationship with water consumption in both types of establishments, with a larger effect in apartments than in hotels. Specifically, when a leak occurs, water consumption rises bimonthly by an average of 24.4% in apartments and 14.3% in hotels. This is consistent with the results of Barberán et al. (2013), who found that leaks increase annual water consumption by 31.27% in the case study of a single hotel.

The increased prevalence of leaks in apartments, despite longer guest stays, highlights a key difference in operational maintenance between rental accommodations and hotels. Hotels typically implement systematic maintenance checks with scheduled inspections, allowing for early leak detection and repair. In contrast, vacation apartments often rely on periodic property manager oversight or guest complaints to identify water issues. This delay in detection results in a higher volume of water loss per incident. Additionally, guests in vacation rentals do not directly bear the cost of excessive water use and may be less likely to report minor leaks, whereas hotels have incentives to address inefficiencies promptly. The less frequent turnover in apartments further compounds this issue, as longer stays mean maintenance is performed less regularly, allowing unnoticed leaks to persist for extended periods. Addressing these structural challenges requires improved detection systems, such as sub-metering or remote leak alerts, which could mitigate prolonged inefficiencies in apartment accommodations.

Finally, since water metres are also sensitive to the number and age of metres, both features are also captured in the model. Note that the number and age of metres, are related to the design of establishments' private networks in water-scarce destinations as well as to the apparent losses caused by water metre inaccuracy (Criminisi et al., 2009). Our results show a positive relationship between the number of metres and water consumption in both apartments and hotels, with annual marginal effects expanding from 3,535 m^3/metre in the case of apartment complexes to 16,220 m^3/metre in the case of hotels. According to the utility's records, 48 establishments (29% of the total sample) were identified as having additional metres connected directly from the public network, which are used for directly watering gardens and filling swimming pools, besides the main metre connected to mandatory water tanks.[3] A visual exploration of the plots shows that when the establishment expands along the public supply network, there is an increase in the number of direct water connections to that network. While adding direct connections and metres to the public network simplifies the establishment (private) network, the additional water metres, which are not connected to the centralised water tanks, will record larger flows and result in a relatively higher level of water consumption.

Our analysis reveals that the implementation of smart metres, including remote reading capabilities, web platform access, and alarm settings for abnormal use, does not result in significant differences in water consumption patterns between hotels and apartments. This suggests a uniform impact of smart metre technology across different types of tourist accommodations. This could be attributed to standardised management practices and similar rates of technology adoption. Both accommodation types appear to benefit equally from the detailed usage data provided by smart metres, leading to comparable water-saving behaviours.

5. Implications and policy recommendations

The practical and policy implications of these findings extend across both organisational management and municipal-level water governance. These recommendations are informed by insights from behavioural and organisational theories, emphasising the need for interventions that address both attitudinal barriers and structural impediments to learning. Effective water conservation in tourism-intensive regions requires more than simply installing SWM and feedback mechanisms—it demands structural regulatory reforms, shifts in organisational behaviour, and enhanced incentive frameworks that align the interests of water utilities, large consumers, and policymakers. Our findings underscore the heterogeneity of establishment types, operational priorities, and facility designs, reinforcing the importance of tailored interventions that fully harness the potential of digitalisation.

While digital metre installation successfully reduced overall water consumption, access to more frequent consumption data correlated with increased usage, suggesting potential rebound effects in water management (Suárez-Fernández et al., 2024). This aligns with behavioural economics research, where increased awareness and feedback can lead to unintended overuse due to rational inattention (Andor et al., 2020) or perceived control over consumption (Gillingham et al., 2016; Wichman, 2017). Studies on real-time feedback in resource utilisation (Faruqui et al., 2010; Sønderlund et al., 2016) further corroborate this concern, illustrating that digital interventions alone may not generate sustained reductions unless reinforced by systematic efficiency strategies. Beyond cognitive biases, the structural complexities inherent in high-consumption tourism establishments must be considered. These entities often feature multilayered managerial hierarchies, where personnel responsible for water use lack decision-making autonomy, and executives prioritise guest satisfaction over sustainability initiatives. This inertia in operational decision-making constrains the potential impact of digital interventions unless complemented by automated conservation mechanisms. To mitigate rebound effects associated with SWM adoption, policy frameworks should incorporate automated conservation defaults, such as pre-set low-flow thresholds, AI-driven leak detection, and predictive efficiency alerts to ensure proactive rather than reactive water management.

Existing utility revenue models, heavily reliant on volumetric water sales, create a systemic disincentive for conservation (Daniel et al., 2023), particularly in destinations such as San Bartolomé, where tourism accounts for a substantial share of year-long municipal water demand. To rectify this misalignment, regulatory frameworks must integrate performance-based incentives, financially rewarding utilities for conservation efforts rather than for consumption increases. Similar models have been successfully implemented in urban water markets, where utilities derive revenue not only from water sales but also from conservation-oriented services (Mukherjee & Jensen, 2022). Furthermore, pricing structures should be reconfigured to reinforce incentives for large-scale consumers. Tiered Increasing Block Tariffs (IBTs), calibrated to efficiency benchmarks, could encourage conservation while maintaining utility revenue stability. Likewise, Pay-As-You-Throw (PAYT) models, which have demonstrated efficacy in hotel waste management (Diaz-Farina et al., 2023), could be adapted for water tariff structures, penalising excessive consumption while incentivizing efficiency.

Our findings also suggest evidence of the influence of external pressures from tour operators and corporate sustainability policies in shaping hotel water efficiency priorities. While large international chains often adhere to overarching environmental strategies, these frameworks may not always align with localised conservation goals. Tour operators in premium segments are increasingly integrating sustainability criteria into contractual agreements, incentivizing hotel compliance. Given that real-time feedback may inadvertently increase water use, tour operators should refine sustainability certification processes by incorporating water efficiency benchmarks derived from digital monitoring data.

Establishments demonstrating advancements in adaptive conservation strategies—such as automated leak response systems and limitations on high-consumption amenities—could receive preferential market positioning, reinforcing sustainability as a competitive advantage. Additionally, the ownership structure of accommodations significantly influences conservation adoption. Independent hotels, lacking centralised sustainability governance, often exhibit reduced investment in digital water management systems (Pereira-Doel et al., 2019; Tortella & Tirado, 2011). The integration of digital benchmarking platforms, allowing hotels to compare consumption patterns with peer establishments, could foster greater participation in conservation initiatives (Gabarda-Mallorquí et al., 2022).

Beyond regulatory and market-driven mechanisms, public-private partnerships (PPPs) play a transformative role in facilitating water efficiency investments. Performance-based rebate systems could incentivize hotels to document and achieve measurable consumption reductions. Likewise, subsidised digitalisation programmes could expedite the adoption of AI-driven leak detection, remote metering, and predictive analytics in high-consumption accommodations, minimising operational barriers to conservation. These strategies would decentralise conservation responsibilities and cultivate a marketplace for independent water audit and digitalisation service providers, thereby enhancing efficiency beyond traditional utility-led initiatives.

Leak detection remains a persistent challenge, particularly in apartment-style accommodations, where leaks tend to persist longer than in hotels due to infrastructural limitations and extended guest stays. Unlike hotels, where centralised systems enable expedited leak repairs, apartment complexes encounter operational constraints that delay corrective interventions. Strengthened local government oversight, complemented by penalties for delayed leak repairs and systematic eco-certifications, could mitigate response delays and curb preventable losses. Our findings indicate that in year-round destinations such as the Canary Islands, prolonged leak persistence in apartment accommodations necessitates regulatory interventions mandating digital leak audits and enforceable compliance timelines for repairs, with financial repercussions for excessive delays.

Tourist demographics also shape water conservation behaviours, necessitating segment-specific conservation strategies. Rodriguez–Sanchez et al. (2020) emphasise the intersection of hedonic consumption motives and sustainability behaviours, highlighting that guests in mass tourism destinations frequently prioritise personal comfort over resource efficiency. Tour operators, therefore, can exert significant influence by integrating water efficiency criteria into sustainability certifications, encouraging hotels to adopt conservation-driven operational models (Araña & León, 2021). Additionally, the deployment of customised digital water dashboards for hotels could facilitate real-time consumption benchmarking, fostering competitive efficiency improvements. Research on digital energy metres suggests that comparative feedback mechanisms can induce sustained reductions in resource consumption of up to 15% (Karlin et al., 2015), underscoring the potential efficacy of analogous digitalisation strategies in hotel water management.

Maximising the impact of water digitalisation in tourism accommodations requires further research into the long-term behavioural effects of digitalisation, the role of utility-led interventions in sustaining conservation, and the alignment of regulatory water metering with hotels' digital infrastructure. However, digitalisation policies must also address equity concerns. Hartley and Kuecker (2020) caution against potential moral hazards in SWM, while Loftus et al. (2016) highlight the commodification risks posed by digital water infrastructure, which could exacerbate inequalities. To mitigate these risks, policies should incorporate equity-focused measures, such as subsidies for vulnerable groups and transparent governance frameworks, ensuring that technological advancements do not undermine access to essential resources.

6. Concluding remarks

This study provides a comprehensive assessment of SWM adoption in tourism accommodations, focusing on San Bartolomé, one of the largest tourism destinations in the Canary Islands. By integrating a rich panel dataset that combines geolocated technical records, submunicipal tourism data, and network characteristics, it examines how digital water management influences consumption patterns in hotels and apartment complexes.

Our findings confirm that digital metre installations contribute to overall reductions in water consumption. However, a critical insight emerges: access to frequent consumption data can lead to increased water use rather than sustained conservation. This highlights the need for carefully designed feedback mechanisms that integrate automated conservation defaults and targeted behavioural interventions to avoid rebound effects. Moreover, financial and regulatory structures must be realigned to support conservation efforts, ensuring that digitalisation does not reinforce consumption-focused revenue models. The role of external stakeholders—particularly tour operators and regulatory agencies—will also be crucial in fostering best practices and market-driven adoption of digital efficiency strategies.

From a policy perspective, these results emphasise the importance of adaptive tariff structures, performance-based incentives, and robust public-private partnerships to ensure the long-term viability of digital water management strategies. Utility revenue models, which often rely on volumetric sales, can create structural disincentives for conservation, limiting the broader impact of digitalisation. Additionally, the utility of granular, submunicipal-level data is underscored for benchmarking, demand forecasting, and sustainability reporting, providing stakeholders with tools for evidence-based decision-making in tourism-intensive regions.

Finally, while our research advances understanding of digital water management, certain limitations point to directions for future inquiry. Notably, there is a lack of detailed data on user engagement with digital platforms, as well as on the operational and cultural barriers that may limit behavioural adaptation. Future studies—potentially employing randomised controlled trials (RCTs) as well as qualitative research methods such as interviews or focus groups—can provide deeper insights into how these technologies interact with managerial practices and organisational cultures. Such efforts are vital for ensuring that digital water management strategies are not just technological advancements but also adaptive governance measures, aligned with the structural and cultural complexities of the tourism sector.

By integrating rigorous empirical analysis with practical policy insights, this study contributes to the growing field of digital water governance, reinforcing the interplay between technology, organisational behaviour, and regulatory frameworks in advancing sustainable tourism water management. These findings may also hold relevance for destinations facing water scarcity challenges and for broader global efforts to enhance resource efficiency and climate resilience in high-consumption industries.

Notes

1. Thirty-six establishments with two water metres were identified, ten with three metres, one with four metres, and one with nine metres.
2. Remote reading provides 1,440 consumption readings in a two-month period compared to a single reading recorded manually.
3. Private water tanks are used to reduce vulnerabilities to shortages and service restrictions, particularly in dry regions. However, they are also mandatory for establishments in the Canary Islands since they are required to carry out on-site and frequent water quality controls. According to Criminisi et al. (2009), there are several reasons why volumetric water meters may lose efficiency and provide inaccurate measures. The presence of private water tanks changes the water demand profile with respect to direct water use and, therefore, the flow rate of water from the public network.

Author contributions

CRediT: **Noemi Padrón-Fumero:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing; **Alba Bauluz:** Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Writing – original draft; **Juan José Díaz-Hernández:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Validation, Writing – review & editing; **Eugenio Diaz-Farina:** Conceptualization, Formal analysis, Investigation, Methodology, Writing – review & editing; **Aránzazu Hernández-Yumar:** Data curation, Formal analysis, Software, Writing – original draft.

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Appendix

Table A1. Total (hm^3) and mean water consumption per bed (m^3) by type of accommodation establishments in San Bartolomé (2011–2018).

	Total water consumption (hm^3)			Mean water consumption per bed (m^3)			Weight of the sample on municipal consumption (%)
Year	Apartment	Hotel	Total	Apartment	Hotel	Total	Total
2011	2.12	2.98	5.11	57.25	95.06	74.59	38.70
2012	2.07	2.94	5.01	55.63	91.21	72.15	38.90
2013	2.04	2.85	4.89	54.19	88.44	70.00	39.20
2014	1.94	2.99	4.93	51.83	89.60	69.56	39.70
2015	1.98	3.32	5.29	53.63	93.12	72.98	41.50
2016	2.12	3.51	5.63	57.29	94.52	75.81	43.30
2017	2.23	3.59	5.82	59.62	95.11	77.38	43.90
2018	2.08	3.53	5.61	56.41	90.84	74.05	43.70

Source: Author prepared.

Table A2. Average total water consumption, per room and per guest (2011–2018).

	Total consumption (m^3)		Consumption/room (m^3)		Litres/guest/day	
Year	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Apartments (1–2 Keys)						
2011	14,675.4	15,415.6	193.6	130.8	439	287
2012	14,075.2	15,5525.3	180.2	122.4	462	300
2013	13,581.3	15,687.7	175.9	115.3	438	258
2014	12,580.3	14,118.1	174.1	118.5	439	266
2015	12,727.3	14,725.7	178.6	117.5	404	243
2016	13,498.7	14,888.6	194.2	131.5	363	233
2017	14,130.2	15,689.3	201.7	130.5	381	243
2018	13,177.7	13,682.8	193.5	131.3	375	225
Apartments (3-–4 Keys)						
2011	22,698.4	19,089.9	206.1	75.6	303	92
2012	26,602.9	18,377.1	212.9	87.1	323	122
2013	20,880.1	19,258.7	193.7	100.6	301	118
2014	18,809.6	19,520.6	180.1	106.6	291	112
2015	21,125.6	21,609.1	209.4	108.9	308	125
2016	24,601.7	22,468.9	243.6	110.2	335	340
2017	25,084.5	21,689.5	244.6	104.2	337	133
2018	23,820.2	23,000.6	229.7	97.6	349	146
Hotels (1–3 Stars)						
2011	53,701.3	38,861.1	190.8	66.7	313	105
2012	47,437.4	33,182.3	165.6	47.8	293	104
2013	45,015.7	31,180.3	157.1	36.9	281	79
2014	44,399.1	29,153.8	157.6	36.8	276	78
2015	45,003.6	27,699.5	156.4	37.7	269	69
2016	47,395.6	30,704.1	162.8	38.6	266	71
2017	47,956.1	31,026.9	165.1	37.1	276	92
2018	43,804.5	28,143.1	153.5	35.9	271	64
Hotels (4–5 Stars)						
2011	63.686.1	51.241.4	191.4	98.9	358	168
2012	64.206.6	48.444.5	193.6	91.1	349	157
2013	62.894.9	47.888.4	186.6	79.9	332	153
2014	63.380.5	48.799.1	186.6	77.9	354	144
2015	65.673.1	47.852.4	202.5	77.8	345	140
2016	63.941.1	46.922.5	200.9	83.1	327	136
2017	62.806	49.566.4	201.6	83.1	323	138
2018	61.024.7	45.566.3	201.6	77.6	351	171

Std. Dev: standard deviation
Source: Author prepared.

Table A3. Apartment and hotel size and water consumption (in liters/guest/day) (2011 and 2018).

Apartments				
Apartment size (Number of beds)	Number of Apartments	Total number of beds	Average water consumption (litres/guest/day) 2011	Average water consumption (litres/guest/day) 2018
(1–2 Keys)				
< 250	87	11.805	468	389
250–500	35	12.711	429	383
500–1000	14	9.572	300	255
>1000	1	1.416	225	196
(3–5 Keys)				
<250	8	911	271	301
250–500	6	2119	343	425
500–1000	3	2.007	304	335
> 1000	–	–	-	–
Hotels				
Hotel size (Number of beds)	**Number of hotels**	**Total number of beds**	**Average water consumption (liters/guest/day) 2011**	**Average water consumption (liters/guest/day) 2018**
(1–3 Stars)				
< 250	2	363	253	251
250–500	8	3.043	314	244
500–1000	9	6.074	316	290
>1000	3	3.515	359	302
(4–5 Stars)				
<250	7	985	423	395
250–500	9	3.628	405	353
500–1000	15	10.479	319	343
> 1000	6	8.576	321	315

Source: Author prepared.

Table A4. Distribution of overnight stays (%) in San Bartolomé by tourism zone and tourist's country of residence (2011–2018).

Country of residence	Bahía Feliz – Playa del Águila	Campo Internacional	El Veril – Las Burras	Meloneras	Playa del Inglés	San Agustín	Sonnenland
Germany	18%	24%	32%	39%	34%	31%	20%
Scandinavia	42%	23%	32%	8%	18%	19%	14%
The UK	19%	18%	8%	13%	12%	14%	26%
Spain	6%	11%	11%	10%	10%	13%	18%
Rest of Europe	13%	21%	15%	28%	24%	19%	17%
Other countries	3%	3%	1%	2%	2%	3%	5%
Total	100%	100%	100%	100%	100%	100%	100%

Source: Author prepared

Table A5. Potential explanatory variables for water consumption in accommodation establishments.

Variable	Definition	Type of variable (and values for categorical variables)	Source
(a) Fixed-supply characteristics			
Category	Category of the establishment, in keys for apartments and stars for hotels	Categorical variable: 1 = category j (j = 1 or 2 keys; 3 or 4 keys; 1 or 3 stars and 4 or 5 stars); 0 = otherwise	ISTAC
Rooms	Number of rooms offered by the establishment	Continuous variable	ISTAC
Plot	Plot size of the establishment in m^2	Continuous variable	Land Registry
Gardens	Surface area of the plot occupied by green areas in m^2	Continuous variable	Google Earth
Pool	Total area of swimming pools in m^2	Continuous variable	Google Earth
Property	Type of property managing the establishment	Categorical variable: 1 = property j (j = independent, national chain or international chain); 0 = otherwise	Official website of the establishment

(*Continued*)

Table A5. Continued.

Variable	Definition	Type of variable (and values for categorical variables)	Source
Year of construction	Year of construction of the establishment's building		Land Registry
Tourism zone (*)	Geographical area in which the establishment is located	Categorical variable: 1 = tourism zone j (j = Meloneras, Sonnenland, Campo Internacional, Playa del Inglés, El Veril – Las Burras, San Agustín, Bahía Feliz – Playa del Águila and Rest of San Bartolomé); 0 = otherwise	ISTAC
(b) Variable supply characteristics			
Partial closure	Periods of time during which certain sections of the establishment are temporarily closed for renovations, while other areas remain operational and accessible to customers	Categorical variable: 1 = two-month periods in which partial closure occurs; 0 = otherwise	Canaragua and external sources
Renovations	Periods of time when the renovation process has been completed and the establishment is considered renovated	Categorical variable: 1 = from the two-month period in which the renovation process has been completed and the establishment is considered renovated; 0 = otherwise	Canaragua and external sources
(c) Demand features			
Overnight stays	Number of bi-monthly overnight stays in the establishment	Continuous variable	ISTAC and Canaragua
RevPAR	Bi-monthly revenue per available room	Continuous variable	ISTAC
(d) Climate factors			
Temperature	Bi-monthly average temperature (°C) in the municipality of San Bartolomé	Continuous variable	AEMET and Weather Underground
Rainfall	Total bi-monthly rainfall measured in litres per square metre (l/m^2) in the municipality of San Bartolomé	Continuous variable	AEMET
Dust storms	Periods of time when episodes of haze/dust occur	Categorical variable: 1 = two-month period in which at least one episode of haze/dust has occurred; 0 = otherwise	AEMET
(e) Smart management variables			
Remote (remote reading)	Periods of time in which the establishment has the remote reading system installed	Categorical variable: 1 = from the two-month period of installation; 0 = otherwise	Canaragua
Number of water metres	Number of metres in operation in the establishment	Continuous variable	Canaragua
Online platform	Periods of time in which the establishment is registered in the online platform	Categorical variable: 1 = from the two-month period of registration; 0 = otherwise	Canaragua
Under-consumption alarm	Periods of time in which the under-consumption alert set by the supply company was triggered	Categorical variable: 1 = two-month periods in which the alarm was triggered; 0 = otherwise	Canaragua
Over-consumption alarm	Periods of time in which the over-consumption alert set by the supply company was triggered	Categorical variable: 1 = two-month period in which the alarm was triggered; 0 = otherwise	Canaragua
Metre age	Metre age in each two-month period	Continuous variable that takes a value of 0 in the two-month period in which the metre is replaced.	Canaragua
Leakage	Periods of time in which a water leak occurs	Categorical variable: 1 = two-month period in which a water leak occurs; 0 = otherwise	Canaragua

AEMET: State Meteorological Agency; ISTAC: Canary Islands Statistics Institute.
(*) Reference to a geographical unit of statistical analysis, characterised by high dependence on tourism with a differentiated supply (homogeneous statistical information on tourism) and spatial continuity.
Source: Author prepared.

Table A6. Number of establishment and total leaks by duration of the leak (2011–2018).

	Apartments		Hotels	
Duration (bi-monthly)	Total leaks	Number of establishments	Total leaks	Number of establishments
1	42	34	29	20
2	11	11	9	7
3	6	6	1	1
4	2	2	–	–
5	2	2	1	1
8	1	1	–	–
9	2	2	–	–
10	1	1	–	–
11	2	2	–	–

Source: Author prepared.