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ARTICLE

Sustainable Water Management in Eco-Tourism: Addressing Water Scarcity in Morocco's Northern Piedmont of the Western High Atlas

Hamza Ait Zamzami [1*], ***Mohammed Elaanzouli*** [1], ***Ayoub Zahrani*** [1], ***Abdelghani Ezzardi*** [1], ***Jamila Saidi*** [1], ***Jamal Mounaji*** [2], ***Siham Belhaj*** [2,3], ***Abdelmalek Ammari*** [2,4], ***Jumadi Jumadi*** [5], ***Taieb Boumeaza*** [1]

[1] *Laboratory of Dynamics of Spaces and Societies (LADES), Department of Geography, Faculty of Arts and Humanities, HASSAN II University of Casablanca, Mohammedia 21100, Morocco*

[2] *Department of Architecture, National School of Architecture, Marrakesh 40200, Morocco*

[3] *Department of geology, Mohammed V University, Rabat 10000, Morocco*

[4] *Team of Modeling and Simulating in Mechanics and Energetic, Department of Physics, Mohamed V University, Rabat 10000, Morocco*

[5] *Faculty of Geography, Universitas Muhammadiyah Surakarta, Surakarta 57162, Indonesia*

ABSTRACT

The northern piedmont of Morocco's western High Atlas is grappling with significant environmental challenges, particularly regarding the availability of water. The region, characterized by its semi-arid climate, is facing increasing pressure from expanding tourism development, which exacerbates the already strained water resources. While tourism is often seen as a sustainable economic driver, its rapid growth has led to a surge in water demand, further complicating resource management. This study investigates the spatial and temporal tensions between tourism development and water resource preservation in this delicate region. By employing a combination of territorial systems analysis, field surveys, and Geographic Information Systems (GIS), the research evaluates water consumption across a range of tourism accommodations, including hotels, gîtes, and resorts. The findings reveal significant disparities in water use, with large tourist complexes and villas accounting for over 83% of the total water consumption. In response to these challenges, the

*CORRESPONDING AUTHOR:
Hamza Ait Zamzami, Laboratory of Dynamics of Spaces and Societies (LADES), Department of Geography, Faculty of Arts and Humanities, HASSAN II University of Casablanca, Mohammedia 21100, Morocco; Email: hamzaaitzamzami@gmail.com

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stud4 recommends strategies such as the implementation of circular water economies, improving water-use efficiency in tourism facilities, and fostering stronger local governance and regulation. Integrating water conservation measures into tourism planning and management is crucial to balancing economic growth with the environmental limitations of the region. This research provides valuable insights and practical recommendations for managing tourism sustainably in water-scarce areas, offering a framework for balancing development with environmental sustainability.

Keywords: Ecotourism; Water Stress; Semi-Arid Zones; Territorial Resilience; Integrated Resource Management; Sustainability

1. Introduction

The sustainable development of tourism in semi-arid regions is an increasingly pressing issue, particularly as climate change exacerbates existing environmental stresses. In such areas, water scarcity is a critical constraint, posing significant challenges for both local communities and the development of tourism infrastructure. These regions are experiencing greater water shortages due to erratic rainfall patterns and prolonged droughts [1], intensified by rising temperatures and changing weather patterns [2].

Across the globe, several tourism-dependent regions—such as the Mediterranean coast, the Canary Islands, and Southeast Asia—have implemented innovative strategies to address similar water-related challenges. These include the adoption of water-saving technologies, greywater recycling, and regulatory frameworks that enforce water-efficient practices in tourist accommodations. Such global experiences offer a useful comparative lens through which to assess and contextualize Morocco's own water management issues in tourism. The northern piedmont of the western High Atlas in Morocco, characterized by its fragile ecosystems and semi-arid climate, provides a vivid example of these challenges [3]. The area faces a rapidly growing tourism sector driven by the potential for economic benefits to rural communities, as tourism is frequently promoted as a sustainable development strategy. However, this expansion is placing increasing pressure on already limited water resources, as tourism facilities require substantial volumes of water for operations, including accommodations, swimming pools, and recreational areas [4, 5]. While the environmental impacts of tourism on water resources have been widely studied, there remains a gap in research focusing on the specific challenges faced by semi-arid regions like the High Atlas, where water is not only scarce but also highly vulnerable to climatic variability and extreme weather events [6]. This makes such regions especially valuable for understanding the tension between economic development through tourism and the need to preserve vital water resources. Investigating how tourist accommodations consume water and how these practices impact local supplies is therefore essential.

This study addresses this gap by analyzing the water consumption patterns of various tourist accommodations in the northern piedmont of the western High Atlas and assessing their impact on local water supplies. The findings offer practical recommendations for balancing economic development through ecotourism with the imperative of sustainable water resource management.

2. Materials and Methods

2.1. Study Area

The research was conducted in a region situated within the piedmont zone of the western High Atlas, specifically the piedmont area of Marrakech. This geographical area spans an impressive 1500 km², extending from the northern city of Marrakech down to the southern reaches of the Atlas Mountains. It encompasses 12 distinct territorial communes, each contributing to the study's findings. These communes, such as Moulay Brahim, Ourika, and Tameslohte, represent a microcosm of rural tourism development in semi-arid regions as illustrated in **Figure 1**.

Tourism is concentrated in these communes due to their rich cultural heritage and unique natural landscapes, including the renowned Atlas Mountains, which provide an attractive destination for both local and international tourists. This area, rich in natural resources and cultural significance, serves as a key focal point for understanding the dynamics of water consumption and sustainable tourism management in the region.

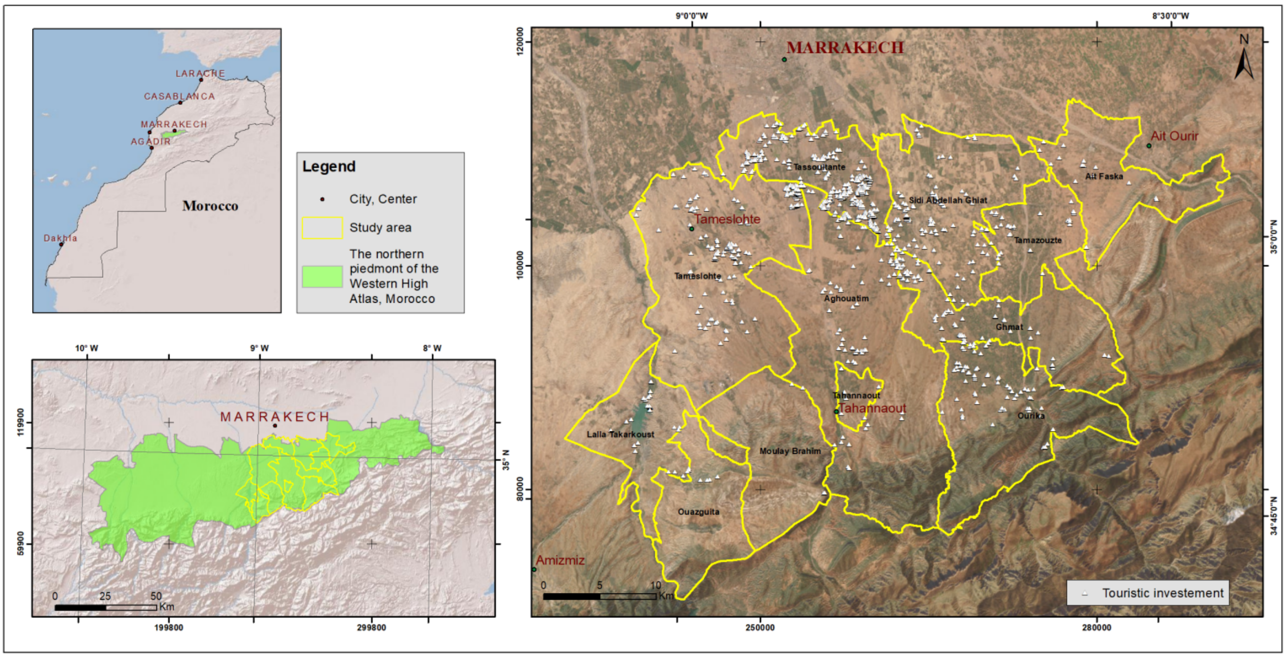

Figure 1. Presentation map of the study area.

2.2. Data

Data for this study was collected through surveys in the 12 target communes, identifying over 1,000 tourist accommodation establishments, ranging from hotels to gîtes, villas, and tourist complexes. The survey collected key data including accommodation capacity, water consumption per person, and volumes of water used for facilities like swimming pools. This field data was crucial for understanding both general and specific consumption patterns, as water use varies greatly depending on the type of accommodation and its amenities.

In addition to field data, secondary data was gathered from local organizations, including the National Office of Drinking Water (ONEP) and the Autonomous Water and Electricity Distribution Authority of Marrakech (RADEEMA). This data was instrumental in estimating water requirements for different types of accommodations and comparing local water consumption practices with national and international standards.

Previous studies on water consumption in semi-arid tourist regions, have provided valuable insights into the environmental impacts of tourism in similar contexts. While these studies often focus on water use in golf clubs and tourist complexes, the actual data on water consumption remains private and confidential, making it inaccessible for public use.

2.2.1. Calculating Pool Water Volumes

We conducted measurements of the swimming pools, and the average depth across all pools was 1.5 meters, which was used for volume calculations. To account for water losses due to evaporation and the usage of swimming pools throughout the year, we have estimated a 20% loss in the volume of water in swimming pools. This estimation is based on interviews with swimming pool technicians in the study area. According to these technicians, most tourist establishments refill their pools only once a year. This practice aligns with recent decisions by water basin agencies and local authorities, which permitted the filling of swimming pools during periods of water scarcity and drought experienced in Morocco in 2023 and 2024 as illustrated in **Figure 2**.

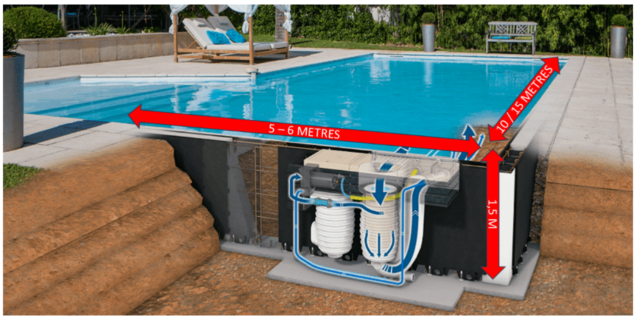

Figure 2. Aerial view and technical diagram of swimming pools: dimensions for calculating volumes.

2.2.2. Water Allocations to Tourism Investments

The volumes of water allocated for each type of accommodation were determined using various sources, including data from RADEEMA (Autonomous Water and Electricity Distribution Authority of Marrakech), ONEP (National Office of Drinking Water), and relevant bibliographical documents, along with international water consumption statistics. The variety of these sources ensured a comprehensive estimate of water consumption across different types of tourism accommodations.

However, to ensure that these estimates accurately reflected the local context of the northern piedmont of the western High Atlas, the ONEP consumption standards were adjusted. These national standards, while useful as a general guide, were found to be exaggerated when applied to this region due to its semi-arid climate and ongoing water scarcity. The area's unique climatic conditions, with periodic droughts and water shortages, lead to significantly different water consumption patterns compared to other regions of Morocco, where water resources are more abundant.

Expert opinions were solicited from local stakeholders—including hotel managers, tourism operators, and representatives from local water authorities—who provided valuable insights into the real water usage patterns in the region. These local experts emphasized that the per capita water consumption in the region is generally lower than what is predicted by ONEP's standards, owing to the widespread use of water-saving technologies and more conservative water usage practices. These adjustments were particularly crucial given the region's vulnerability to drought and the resulting need for water conservation as reflected in **Figure 3**.

To address this, expert opinions from local water management authorities, as well as feedback from stakeholders in the tourism industry, were solicited. These local experts, including hoteliers, gîte owners, and managers of larger tourist complexes, provided crucial insights into how accommodations in the region actually use water. For example, many establishments in the High Atlas region have adopted water-efficient technologies—such as low-flow fixtures, greywater recycling systems, and rainwater harvesting—resulting in lower per-person consumption than the figures provided by ONEP for more water-abundant areas.

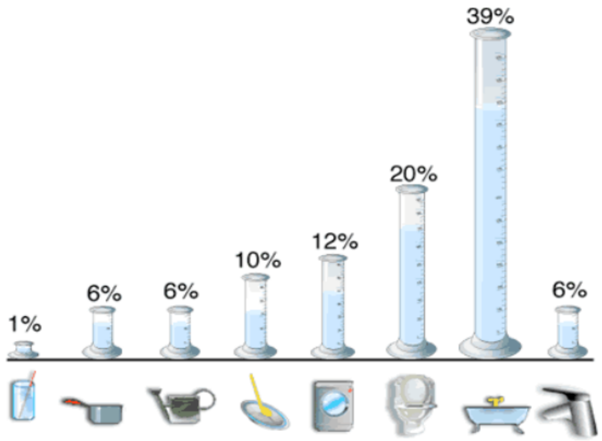

Figure 3. Breakdown of household water consumption by use (Drink–1%, Cooking–6%, Car & Garden–6%, Dishes–10%, Laundry–12%, Sanitary–20%, Baths & Showers–39%, Other–6%).

To account for these factors, the ONEP standards were adjusted by expert recommendation, leading to a more realistic estimate of water consumption for various tourist accommodations in the study area.

The **Table 1** presents the adjusted water consumption estimates for different types of tourism accommodations [7, 8], taking into account the region's unique conditions, such as the use of water-saving technologies and seasonal occupancy changes.

These adjusted estimates provide a more accurate reflection of the water usage patterns in the High Atlas region, considering both the local water-saving measures and the seasonal variations in occupancy. By using this adjusted data, the research can more effectively evaluate the water consumption associated with different tourism investments and identify strategies to optimize water use across various accommodation types.

Table 1. Water consumption standards in Morocco (liter/night).

Tourist Establishment	Water Volume (Liter/Person/Night)
Hôtel 5* Grand Luxe	500
Hôtel	500
Ryad	120
Villa	120
Apartment	120

Source: ONEP.

2.3. Methodology

The methodology employed in this study is tailored to the semi-arid and drought-prone context of the northern piedmont of the western High Atlas, where limited infrastructure and ecological vulnerability present distinct challenges for water management. It builds upon previous research while incorporating site-specific considerations to ensure contextual accuracy.

A mixed-methods approach was adopted, combining quantitative and qualitative data sources to comprehensively assess water consumption in tourism accommodations. Primary data were collected through field surveys targeting a representative sample of tourist establishments (hotels, guesthouses, villas, etc.), while expert interviews with local tourism stakeholders and authorities provided contextual insight. These were supplemented by secondary data from relevant institutions, notably RADEEMA and ONEP, which offer national and regional standards for water usage in tourism.

To estimate annual water consumption, the study applied a 200-day full occupancy assumption, which reflects the seasonal nature of tourism in the region. Local operators and observations indicate that establishments are typically occupied at or near 100% during the high season, resulting in around 200 active operational days per year.

For the quantitative analysis, data were processed using descriptive statistics, followed by Analysis of Variance (ANOVA) to identify significant differences in water consumption across different types and sizes of tourist accommodations. Post-hoc tests were conducted to clarify where these differences were most pronounced. This statistical framework allowed for a robust comparison while accounting for variability in accommodation types and water usage behavior as demonstrated in **Figure 4**.

The study draws on a combination of field observations, expert consultations, and institutional records to strengthen the accuracy and credibility of its results. This integrated approach provides a solid basis for analyzing water use trends and supports the development of informed, context-specific strategies for sustainable water management in the local tourism industry.

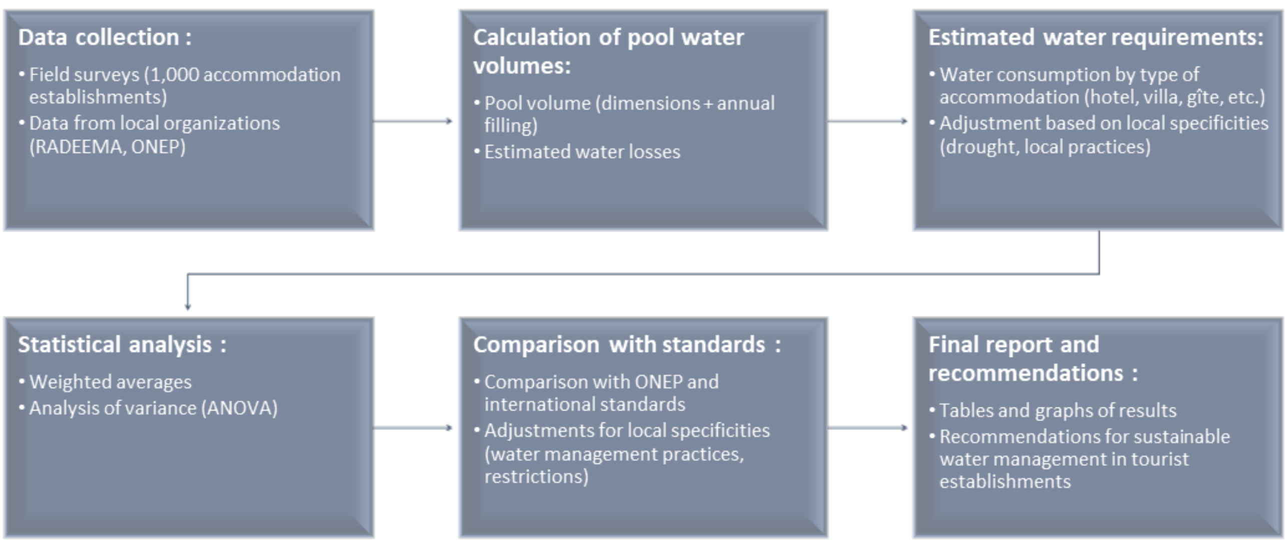

Figure 4. Methodology process of this study.

3. Results

3.1. Statistics of Water Consumption of Survey Tourist Establishment

The census results are presented in the **Table 2**.

The data was analyzed using statistical methods, such as weighted averages and analysis of variance, to ensure the accuracy of the results obtained. The data was also compared with international benchmarks to assess the compliance of local practices with global water consumption standards. For the calculations, we adopted the assumption of an annual occupancy rate for tourism investments of 200 occupied days out of 365 days per year [9], serving as the basis for the average estimate.

Table 2. Estimated water consumption for tourism investments in the study area.

Type of Tourism Investment	Size	Criteria	Number	Total	Capacity - Bed	Unit Consumption per Person in Liters	Swimming Pool (1.5 m Deep)
Apartment				8	6	120 to 150	-
Inn				5	20	120	-
Tourist Complex (Resort)	Grand	> 6 Hectares	13	41	200	500	> 600 m³
	Medium	Between 3 and 6 hectares	12		100		300 m³
	Small	< 3 hectares	16		50		100 m³
Gîte				3	14	120	-
Hotel				23	50	500	300 m³
Guest house				57	16	120	100 m³
Riad				14	16	120	-
Villa	Grand	> 400 m²	162	835	12	200	120 m³
	Medium	200 m² to 400 m²	518		8		100 m³
	Small	< 200 m²	155		6		90 m³

Source: Field/ONEP/bibliography.

3.2. Analysis by Type of Tourism Investment

Apartments: Apartments account for a portion of tourist accommodation, with a total of 8 establishments listed. Each apartment has an average capacity of 4 beds, and unit consumption per person is between 120 and 150 liters per day, corresponding to a minimum annual volume of 27 m[3]/person/year. The apartments in this study are generally not equipped with swimming pools, which may make overall water consumption low compared with other tourist accommodations.

Hostels: Inns are also a notable type of accommodation, with 5 listed in our study area, although there may be more. The average capacity per hostel is 20 beds, and unit consumption per person is 120 liters per day, corresponding to an annual volume of 24 m[3]/person/year. Like apartments, hostels do not have swimming pools, which could make these options more water-efficient than other types of establishments with pools.

Tourist resorts Tourist complexes are classified into three categories according to their size. Unit water consumption per person, including all daily "all-inclusive" services (sports activities, collective meal preparation and laundry service), is estimated at an average of 500 liters per day. In addition to consumption by visitors and tourists, water is also used for cleaning, watering and washing vehicles and materials.

- **Large resorts (> 6 hectares):** 13 resorts with an average capacity of over 200 beds, featuring pools of over 600 m³, requiring increased water consumption and management.
- **Medium-sized complexes (3 to 6 hectares):** 12 complexes with a capacity of 100 beds, equipped with 300 m³ pools.
- **Small complexes (< 3 hectares):** 16 complexes with a capacity of 50 beds, with 100 m³ pools.

Gîtes: although fewer in number with only 3 establishments, offer an average capacity of 14 beds per gîte and a unit consumption per person of 120 liters/day/person. These gîtes are not equipped with swimming pools, which may reduce their water management needs. There may be more gîtes in our study area that are not declared, but generally the gîtes are located in the high and medium mountains.

Hotels: Hotels account for a significant proportion of accommodation, with 23 establishments, each with an average capacity of 50 beds and a unit consumption of 500 l/d. Hotels generally have swimming pools with a capacity of 300 m³, which must be taken into account when analyzing their impact on water consumption.

Guest houses: Guest houses are the most numerous with 57 establishments, offering an average capacity of 16 beds per house and a consumption of 120 l/d. The swimming pools of these houses have a capacity of 100 m³.

Riads: There are 14 riads, with an average capacity of 16 beds and a daily consumption of 120 liters per person. These establishments are not equipped with swimming pools, which may make them more attractive to environmentally conscious tourists.

Villas are classified according to size:

- **Large villas (> 5000 m²):** 162 in number, these villas have an average capacity of 14 beds and a unit consumption of 200 l/d. They have 120 m³ pools.

- **Medium-sized villas (1000 to 5000 m²):** With 518 villas, each has a capacity of 10 beds and a consumption of 200 l/d. The pools in these villas have a capacity of 100 m³.
- **Small villas (< 1000 m²):** 155 small villas with an average capacity of 6 beds and a unit consumption of 200 l/d. The pools in these villas have a capacity of 90 m³.

4. Discussions & Recommendations

An analysis of annual water consumption by different types of tourism investment reveals significant disparities in terms of water resource use. Total water consumption amounts to 8.9 Mm³/year, divided between the different categories of accommodation, ranging from small gites to large tourist complexes. These variations in water consumption are closely linked to the size and type of establishment as shown in **Figure 5**, with large resorts and villas predominating in the total share of consumption [10].

After estimating the average consumption of drinking water per person per day, we calculated the potential annual volume consumed by tourist infrastructures, excluding irrigation of green spaces. The results obtained are presented in the **Table 3** below, enabling us to identify the type of accommodation with the highest consumption of drinking water.

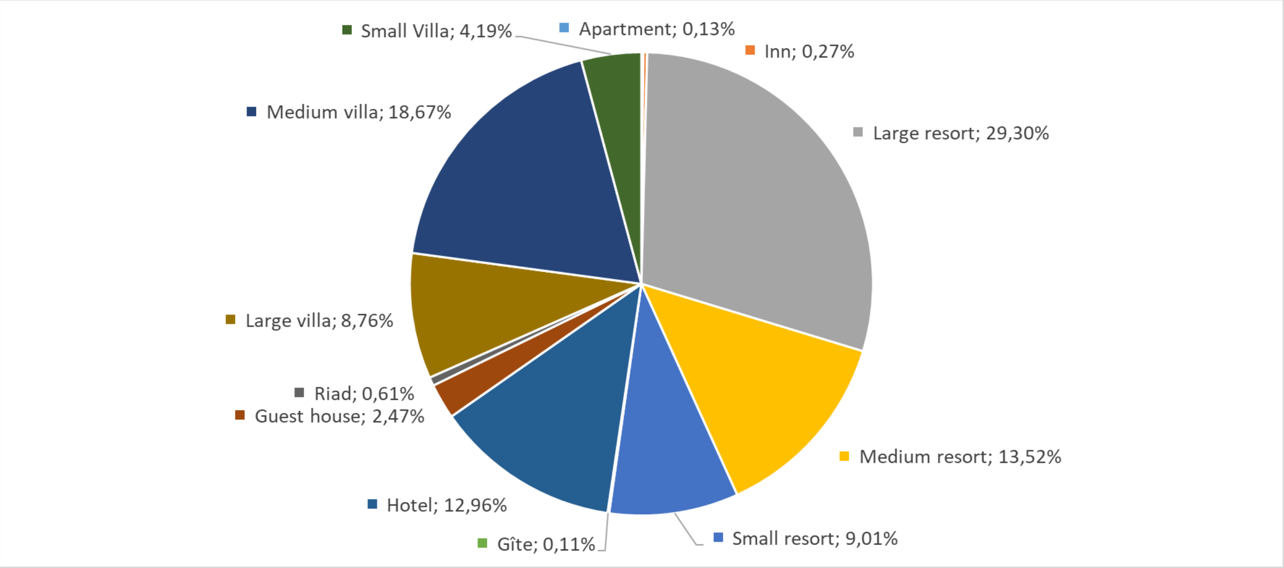

Figure 5. Shares of water consumption by type of tourist establishment.

Table 3. Overall estimate of water consumption by type of existing tourism investment in the piedmont.

Type of Tourism Investment	Size	Water Consumption in m³/Year	Share of Total	
Apartment		11 520	0.13%	
Inn		24 000	0.27%	
Tourist complex	Grand	2 600 720	29.30%	51.83%
	Moyen	1 200 360	13.52%	
	Petit	800 120	9.01%	
Gîte		10 080	0.11%	
Hôtel		1 150 360	12.96%	
Guest house		219 000	2.47%	
Riad		53 760	0.61%	
Villa	Grande	777 744	8.76%	31.63%
	Moyenne	1 657 720	18.67%	
	Petite	372 108	4.19%	
Total		8 877 492	100%	

These findings highlight the significant burden that large-scale tourist complexes and villas place on local water resources, with tourist complexes alone accounting for over 51% of total annual consumption in the piedmont area. Comparable trends have been observed in other semi-arid regions globally. For example, in the United Arab Emirates, particularly in Dubai and Abu Dhabi, large luxury hotels have historically shown high per capita water use, often exceeding 500 liters per tourist per day—largely due to landscape irrigation, pools, and water-intensive amenities [11]. However, policy reforms and infrastructure improvements—including mandatory greywater recycling and high-efficiency fixtures—have led to substantial reductions in water use, often between 20–30% per facility.

Similarly, in Southern California, a region marked by prolonged droughts and intense tourism activity, water conservation policies have been effectively enforced through regulations on turf replacement, incentive programs for xeriscaping, and tiered water pricing targeting high-consumption users. Resorts in Palm Springs and coastal regions have adopted drought-resistant landscaping and intelligent irrigation, achieving reductions of up to 40% in landscaping water use [12].

By comparison, most tourism establishments in the Western High Atlas currently lack structured water-saving strategies, highlighting an urgent need for policy alignment with international best practices [13]. These examples underline the importance of integrating water efficiency measures, not only as technical solutions but also through regulatory frameworks, financial incentives, and public awareness campaigns—elements that remain underdeveloped in Morocco's tourism sector.

Sustainable Management of Water Resources: Adaptation of Tourism Infrastructures to Extreme Climatic Phenomena

Prolonged droughts, for example, threaten the availability of water resources, directly impacting natural ecosystems and agriculture, essential sectors for both local populations and the tourism sector. In addition, a resilient strategy for the sustainable management of water resources is urgently needed to limit their wasteful consumption in the context of tourism investments. The use of recent, innovative and resilient techniques can mitigate the impact of these investments, particularly in periods of extreme drought [14], while maintaining the piedmont's tourist appeal. Among possible solutions, it is recommended to adopt best practices for efficient and sustainable water management in the tourism sector [15].

International case studies, such as those in the UAE and southern California, show that implementing water-saving technologies in tourist accommodations can reduce water consumption by up to 30%. These regions have also introduced tiered water pricing models to incentivize lower water use among businesses and consumers alike.

Optimizing Water Resources: Best Practices for Tourism Investments

Optimizing Water Consumption in Tourist Facilities

Various solutions are available to reduce water consumption and optimize energy efficiency in sanitary installations, as shown in the figure below.

- Installation of faucet aerators (30–40% reduction in water consumption).
- Installation of flow regulators on showers and taps (savings of up to 70%).
- Use of automatic faucets to limit water flow time.
- Adoption of circular showers with immediate water recirculation (water savings of up to 90% and energy savings of up to 80%).
- Installation of double-discharge, flangeless toilets (30–60% reduction in consumption).

Water Recycling: Wastewater Treatment and Reuse Solutions

With water resources becoming increasingly scarce, wastewater treatment and reuse are becoming a priority to ensure sustainable management of this resource [16]. This domestic recycling system involves three successive stages. Firstly, the wastewater (from the sink, washbasin and washing machine) is collected, and then subjected to in-depth filtration to eliminate impurities and odors, before being stored. Finally, the purified water is redirected to the toilet flush, resulting in significant water savings [17]. Simple to install and with proven efficiency, this system represents a concrete solution for optimizing water resource management in accommodation facilities.

Advanced Filtration Technologies: Rainwater Col-

lection and Treatment for Tourism Investments

Water filtration is based on a series of complementary stages, each targeting a specific category of impurities. In the figure below, water treatment takes place in several successive stages, each aimed at removing contaminants of different sizes and natures:

- Screening: The first stage consists of mechanically removing the coarsest elements (debris).
- Sand filtration (10 microns): Water then passes through a sand bed retaining the majority of fine and parasitic particles, helping to significantly reduce turbidity, as detailed in **Figure 6**.
- Microfiltration (0.1 microns): This stage removes bacteria, red blood cells and other smaller micro-organisms.
- Ultrafiltration (0.01 micron): Here comes the decisive phase: thanks to porous membranes with a very small diameter (0.01 microns), ultrafiltration removes not only fine mineral and colloidal particles, but also virtually all pathogens (cryptosporidia, giardia, viruses) and pyrogens.

This approach provides a reliable alternative to conventional filtration methods, since it ensures both clarification and disinfection in a single step, without the addition of chemicals[18]. What's more, treatment efficiency remains high whatever the initial quality of the raw water: turbidity can be reduced to as little as 0.1 NTU.

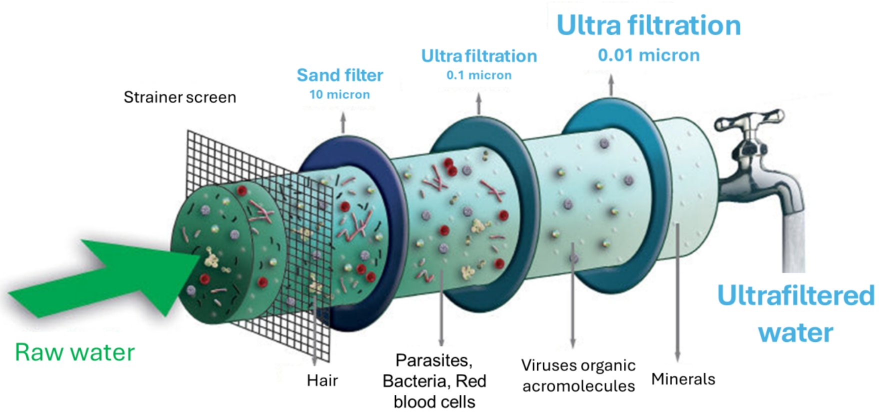

Figure 6. Infiltration system.

Source: https://aquaselection.com/blogs/news/lultrafiltration-alternative-a-la-filtration-conventionnelle.

Ultrafiltration is a cutting-edge technology in water treatment, offering both advanced clarification and effective disinfection in a single step[19]. In the context of tourism investments in hotels, villas and guesthouses, the incorporation of ultrafiltration solutions is of strategic importance. Indeed, the availability of safe, treated water significantly enhances the customer experience, while meeting growing health and environmental imperatives. Ultrafiltration systems can be adapted to a wide range of water resources (fresh, brackish and wastewater), facilitating their integration into various types of tourist facilities, sometimes subject to fluctuating water quality constraints. What's more, this technology can be integrated into recycling and reuse circuits, underscoring the potential for saving water and reducing pressure on water tables.

In addition to its treatment efficiency, ultrafiltration is distinguished by the relative simplicity of its maintenance and the low technical skill requirements for optimal operation. It often replaces more complex processes involving decantation, chlorination or the addition of coagulants such as alum[20]. By reducing the need for these physico-chemical operations, ultrafiltration helps to limit environmental impact and minimize operating costs.

Reverse Osmosis: Advanced Technology for Water Management in Sustainable Tourism

Reverse osmosis is a sophisticated water treatment technology offering high purification and desalination performance[21]. Although this method offers undeniable advantages for tourist establishments, it remains a costly option, mainly accessible to large investors with substantial financial resources. Reverse osmosis is based on the principle of pressure applied to force water through a semi-permeable membrane, thus retaining impurities, dissolved salts and organic and inorganic contaminants. This process produces superior quality water, suitable for a multitude of uses, including human consumption, irrigation, and industrial processes in tourist establishments, as illustrated in **Figure 7**.

- **Pre-treatment:** Before reverse osmosis, the raw water undergoes pretreatment including filtration to remove suspended particles, sediments and large contaminants. This step is mandatory to prevent membrane fouling and ensure process efficiency.
- **Pumping and Pressurization:** Pre-treated water is then pressurized using high-pressure pumps, overcoming the water's natural osmotic pressure and forcing its passage through the semi-permeable membrane.
- **Membrane filtration:** The reverse osmosis membrane retains unwanted ions, molecules and particles, allowing high-quality purified water to pass through. The purified water stream is collected for use, while contaminants are removed as concentrate.
- **Post-treatment:** In some cases, post-treatment may be required to adjust the pH or remineralize the water, ensuring that it meets the quality standards required for specific uses.

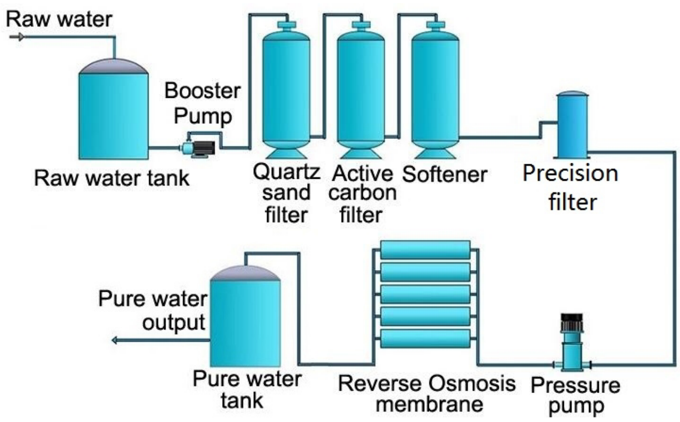

Figure 7. Infiltration Figure.

Source: https://www.roagua.com/fr/drinking-water-reverse-osmosis-water-treatment-plant-china-manufacture/.

Benefits of reverse osmosis for tourism investments:

- **Water quality:** Reverse osmosis ensures thorough purification, effectively removing a wide range of contaminants, which is essential for maintaining high standards of water quality in tourist establishments.
- **Flexibility of use:** This technology can treat various types of water, whether fresh, brackish or marine, offering an adaptable solution for the different water supplies available in tourist areas.
- **Reduced dependence on local resources:** By producing high-quality water on site, establishments can reduce their dependence on public water networks.

Despite its many advantages, reverse osmosis has certain limitations that restrict its widespread adoption within the tourism sector, including:

- **High initial cost:** Installing a reverse osmosis system requires a substantial initial investment, including the cost of equipment, installation and infrastructure required for water pre-treatment and post-treatment.
- **Energy consumption:** The reverse osmosis process is energy-intensive, requiring a constant power supply to maintain the pressure needed to operate the membranes, which can lead to high operating costs.
- **Maintenance and technical expertise:** Maintaining reverse osmosis systems requires specialized technical expertise, as well as regular monitoring to ensure that the membranes are working properly and to avoid fouling problems.
- **Limited adaptability for small investors:** Due to costs and technical requirements, reverse osmosis is mainly viable for large investors with sufficient financial and technical capacity, making it less accessible to small tourist establishments.

Reverse osmosis represents a major technological advance in water treatment, offering high performance in terms of purification and desalination [22]. However, its adoption within tourism investments remains limited by economic and technical considerations, making it mainly accessible to large players in the sector. For resorts with the necessary resources, reverse osmosis is an effective and sustainable solution, capable of meeting high water quality standards while strengthening resilience in the face of water resource management challenges.

Efficient Leisure Water Management: Innovative Solutions for Tourism Investments

Sustainable management of recreational water, such as swimming pools, is essential to prevent prolonged periods of drought. The use of pool covers can reduce water loss through evaporation by up to 90%. When correctly installed, these covers limit direct evaporation caused by exposure to sun and wind, while protecting the water from atmospheric contaminants such as leaves and insects. This reduction in water loss contributes not only to the conservation of water resources [23], but also to the reduction of operational costs associated with water filling and treatment [24]. What's more, by limiting evaporation, tarpaulins reduce the energy consumption required to heat water, thus improving the energy efficiency of installations, as illustrated in **Figure 8.**

Figure 8. Pool cover.

Source: https://www.del-piscine.fr/2023/05/17/del-premium-couverture-alveolaire-la-couverture-isotherme-innovante-pour-piscine/.

In addition, pool treatment with advanced technologies such as electroporation, UV systems and enzymatic products has become an important aspect of recreational water management. Electroporation uses electrical impulses to destroy pathogenic micro-organisms without the use of chemicals, offering an environmentally-friendly and effective alternative to the use of chemical disinfectants [25], as shown in **Figure 9.**

UV disinfection systems neutralize bacteria and viruses, guaranteeing healthy water for users while minimizing environmental impact. Enzymatic products, meanwhile, facilitate the decomposition of organic matter, reducing the build-up of dirt and extending the life of treatment equipment [26]. The integration of these technologies enables tourism establishments to maintain high standards of water quality, while optimizing resources and reducing maintenance and chemical treatment costs.

Resilient Green Spaces and Intelligent Irrigation: Sustainable Strategies in Arid Zones

Efficient irrigation management is a fundamental pillar in maintaining and enhancing the value of green spaces within tourist establishments. The adoption of intelligent irrigation and drip systems enables optimized use of water resources, which is important in a context of water scarcity such as our zone. These systems, incorporating advanced technologies such as soil moisture sensors and automated controlled, adjust the quantity of water distributed in real time to the specific needs of plants and local climatic conditions. Drip irrigation, in particular, targets plant roots directly, reducing evaporation losses and ensuring uniform water distribution. This precision in watering not only reduces water consumption, but also improves plant health and growth, contributing to the sustainability of landscaping [27], as demonstrated in **Figure 10.**

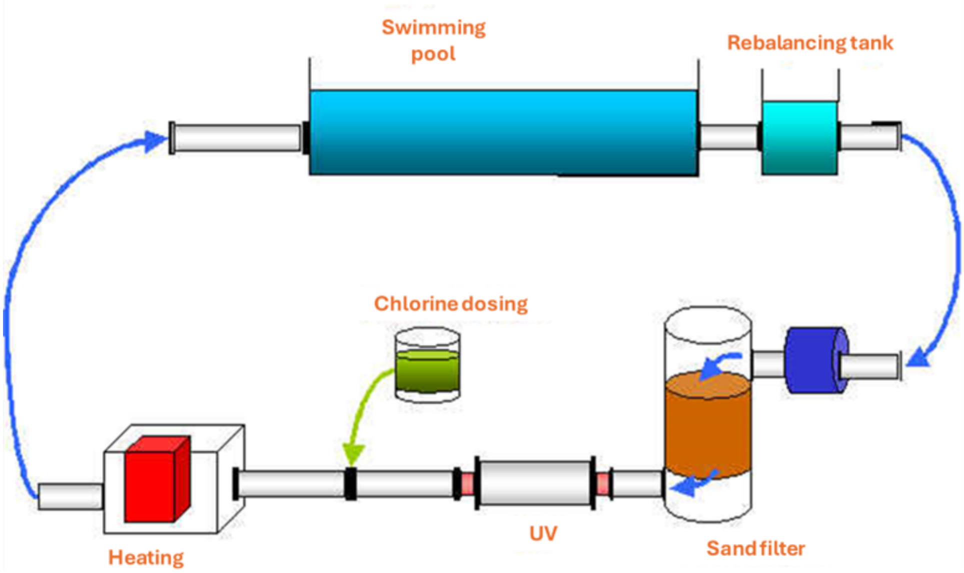

Figure 9. Use of UltraViolet disinfection systems for swimming pools.

Source: https://www.lenntech.fr/piscine-uv.htm.

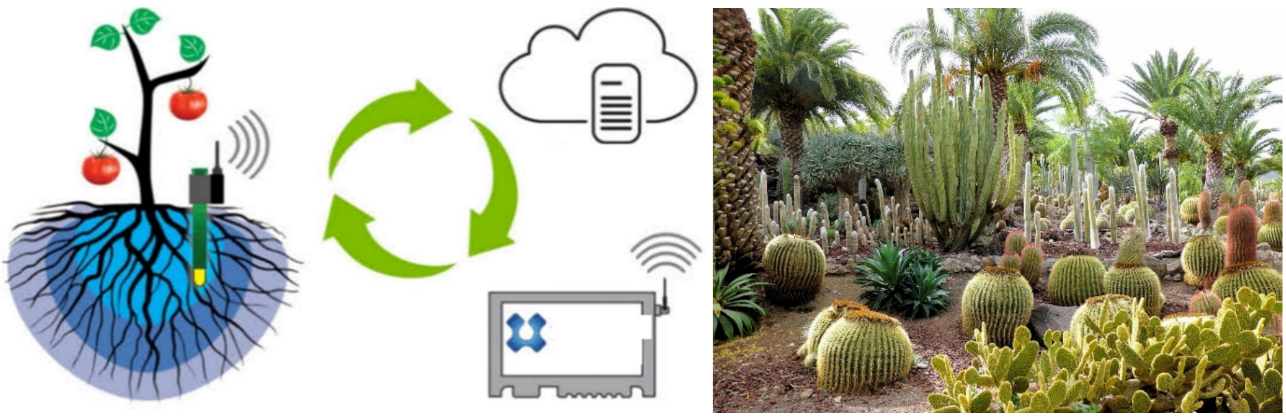

Figure 10. Intelligent watering system[28] (left). Example of a xerophytic garden (drought-resistant plants on right).

Source: https://www.aquaportail.com/dictionnaire/definition/2352/xerophyte.

What's more, these systems enable proactive management of water resources, facilitating early detection of leaks and malfunctions, resulting in reduced maintenance costs and extended plant life. Species such as cacti, succulents and certain native grasses are particularly well suited to these environments, offering visual diversity and increased resistance to water stress. A sustainable garden is designed to respect the environment, promote biodiversity and optimize natural resources.

Alongside the optimization of irrigation systems, the use of plants adapted to arid and semi-arid climates represents an indispensable strategy for tourism investments located in regions prone to prolonged periods of drought[29]. The choice of resilient garden styles (Xerophytic), requiring little water, enables the creation of aesthetic and functional gardens while minimizing the impact on local water resources.

In addition, intelligent garden design, incorporating elements such as organic mulch, shaded structures and rainwater harvesting systems, helps conserve soil moisture and protect plants from extreme temperatures, as illustrated in **Figure 11**.

The need to move away from traditional gardens with turf cover to gravel mulch cover to minimize the impact of tourism investments on water resources, so for golf courses and large tourist complexes we strongly recommend the use of C4 type turf, which is more resilient to drought and compatible with the arid climate in our area, plus it consumes less water than traditional turf.

Figure 11. Illustration to avoiding the use of turf and replacing it with gravel mulch.

This holistic approach not only promotes water conservation, but also enhances the attractiveness of tourism establishments by offering harmonious, sustainable green spaces that meet customers' growing expectations in terms of sustainable development [30]. The integration of intelligent irrigation practices and appropriate plant selection is an effective response to environmental challenges, while optimizing the aesthetics and functionality of tourist green spaces.

5. Conclusions

This study highlights the significant challenges posed by the growing demand for water in the tourism sector, particularly in the northern piedmont of the Western High Atlas. The findings show that tourism infrastructures—especially large establishments such as resorts and villas—are responsible for disproportionately high water consumption, which is especially concerning in a region already vulnerable to water scarcity and climate-change-induced droughts.

To address this, the study advocates for the adoption of water-saving technologies such as wastewater recycling, ultrafiltration, and efficient irrigation systems for green spaces. However, the success of such measures depends heavily on policy and governance. Regulatory frameworks should mandate water efficiency standards for new tourism developments, while financial incentives—such as tax breaks or subsidies—can support retrofitting efforts in existing infrastructures. Local authorities, in coordination with national institutions such as the Ministry of Tourism and the Ministry of Equipment and Water, should establish municipal-level water action plans that operationalize the principles of a circular water economy and promote greywater reuse, drought-tolerant landscaping, and real-time water monitoring systems.

This research further calls attention to gaps in institutional and operational practices. Although some hotel establishments already demonstrate good practices in managing water, energy, and maintenance, several obstacles remain:

A lack of awareness among hotel stakeholders regarding the true cost of water and the implications of Law 36-15, particularly in terms of sanitation fees and taxes.

The absence of clear, sector-specific guidelines for acceptable water consumption levels.

The failure to incorporate water footprint metrics as standard indicators of environmental performance, limiting the ability to assess and compare the impacts of different types of accommodation.

To overcome these challenges, we recommend the development of enforceable water consumption benchmarks by accommodation category, the implementation of mandatory water audits, and the integration of water footprint metrics into sustainability certifications. In parallel, capacity-building programs should be launched to educate tourism operators on water costs, environmental impacts, and compliance requirements.

While this study focuses on the Western High Atlas, the insights are applicable to other semi-arid regions worldwide—such as the UAE or Southern California—where tourism development must be reconciled with resource conservation. Aligning tourism expansion with robust water governance and sustainability policies is essential to ensure the long-term viability of both economic growth and natural ecosystems. These strategies are recommended to stakeholders and tourist investors for broader adoption; however, only a limited number of tourist establishments have implemented such conservation measures so far.

Author Contributions

Conceptualization, H.A.Z. and T.B.; methodology, H.A.Z. and T.B.; software, H.A.Z., M.E., A.Z. and A.E.; validation, J.S. and T.B.; formal analysis, H.A.Z., M.E., J.M., S.B., A.E., J.S. and T.B.; investigation, H.A.Z., M.E., A.Z., J.M. and A.A.; resources, H.A.Z., M.E.; data curation, H.A.Z., J.J. and A.A.; writing—original draft preparation, H.A.Z. and M.E.; writing—review and editing, H.A.Z.; visualization, H.A.Z., M.E.; supervision, T.B. and J.S. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Ethical review and approval were waived for this study due to the use of simulations or model-based research, without any real-world human or animal involvement.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

Data is available upon Request.

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Conflicts of Interest

The authors declare no conflict of interest.

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