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Analysis Of The Relationship Between Water Resource Availability And Animal Production In Arid Zones

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Abstract: Water scarcity represents one of the most serious environmental and productive challenges for livestock systems located in arid and semi-arid regions. The sustainable performance of these systems largely depends on the efficient management of limited water resources, the adaptive capacity of species facing water stress, and the application of appropriate technologies.
This study analyzes the relationship between water availability and animal production through a systematic review of international research published between 2010 and 2024. Emphasis is placed on hydrological variability, forage productivity, and the physiological responses of animals under drought conditions.

The results show that fluctuations in groundwater levels, irregular precipitation patterns, and competition for water among agricultural, industrial, and domestic uses directly affect productivity and economic viability. It is concluded that integrating hydrological monitoring, adaptive genetic selection, and sustainable water management strategies is essential to ensure resilience and food security in arid environments.

Keywords: Water resources; Animal production; Arid zones; Water stress; Livestock sustainability.

1. INTRODUCCIÓN

Water availability constitutes the most decisive ecological and economic factor shaping animal production systems in arid and semi-arid zones. These areas, covering about 41% of the planet's terrestrial surface, are home to approximately two billion people and more than half of the world's livestock population [1].

Given the scarcity and irregularity of rainfall, livestock productivity depends on the ability to capture, store, and efficiently use limited water resources.

In arid ecosystems, the hydrological imbalance has been exacerbated by climate change: longer droughts, higher evapotranspiration, and unpredictable precipitation patterns threaten both forage availability and animal welfare [2]. According to FAO (2023) projections, water stress could reduce livestock productivity by 18–25% in dry regions such as northern Mexico and the African Sahel by 2050 if adaptive strategies are not implemented.

The relationship between water resources and animal production is multidimensional, involving hydrological, physiological, ecological, and socioeconomic interactions. Water availability regulates feed quality, disease incidence, reproductive efficiency, and consequently, overall productivity [3].
From a physiological standpoint, water deprivation affects feed intake, digestion, thermoregulation, and milk production. Dehydration causes metabolic stress, increases body temperature, and reduces nutrient absorption. Certain breeds—such as Brahman, Dorper, and the dromedary camel—have developed remarkable mechanisms for water conservation and heat tolerance [5].

Technological innovation also plays a determining role: the use of solar pumps, rainwater harvesting reservoirs, and drip irrigation systems for forage has been shown to improve productivity in arid livestock systems [6]. However, the adoption of these technologies remains uneven due to financial limitations, lack of training, and institutional fragmentation.

The objective of this paper is to analyze, from a scientific and systemic perspective, the relationship between the availability of water resources and animal production in arid zones, identifying the main determinants of sustainability. Specifically, it seeks to:

- Examine how water scarcity influences animal physiology and productivity.
- Assess the socioeconomic implications of water variability for pastoral communities.
- Propose adaptation and sustainable water management strategies for livestock production.

2. METHODOLOGY
The study was conducted as a systematic review of scientific literature, focusing on works published between 2010 and 2024 in specialized databases (Scopus, Web of Science, Science Direct, and FAO AGRIS).

The main descriptors used were: water resources, livestock production, arid zones, water stress, and animal welfare.
Out of 126 identified studies, 54 met the inclusion criteria:
(a) empirical or review research on livestock systems in arid or semi-arid environments;
(b) presence of quantitative or qualitative indicators of water availability, productivity, or physiological performance; and
(c) methodological validation through peer review.

The analysis followed three phases:
1. **Identification and selection of sources** through Boolean search strings (e.g., "livestock and water scarcity and arid zones").
2. **Categorization of variables,** grouping hydrological, productive, physiological, and socioeconomic information.
3. **Qualitative synthesis,** identifying patterns and correlations between water availability and productivity.

Quantitative data were standardized into comparable units: liters per animal per day, millimeters of precipitation, and kilograms of meat or milk per hectare.

The geographical analysis covered cases from Latin America (Chile, Mexico, Argentina), Africa (Sahel, Maghreb), and Asia (India, Iran), evaluating their hydrological context, management practices, and productive outcomes.

Only scientific sources and institutional reports (FAO, UNESCO, UNCCD) were included to ensure validity and rigor.
The synthesis was comparative rather than meta-analytic due to the heterogeneity of study designs, following standards for review articles.

3. LITERATURE REVIEW
3.1. Availability Of Water Resources In Arid Regions
Water scarcity constitutes the primary limiting factor in arid and semi-arid systems. Annual precipitation rarely exceeds 250 mm, with high temporal and spatial irregularity. According to FAO (2022), approximately 70 % of the world's freshwater is allocated to agriculture and livestock, with particularly high groundwater extraction rates in arid countries [1].

Aquifer depletion has led to salinization, loss of water quality, and soil subsidence, directly affecting water availability for animal consumption and forage irrigation.

In response, contemporary approaches favor **Integrated Water Resources Management (IWRM)** over isolated solutions. Among the most effective practices are rainwater harvesting, artificial aquifer recharge, and the reuse of treated wastewater for forage crops [3].

Table 1. Indicators Of Water Availability In Selected Arid Regions

Region	Annual Precipitation (mm)	Forage Productivity (kg DM ha^{-1} year^{-1})	Aquifer Depth (m)
Sahel (Africa)	200–700	1 500–2 500	40–70
Chaco (South America)	450–500	1 700–2 200	> 100
Western Sahara (North Africa)	< 100	2 000–3 000	50–120

Source: Adapted from FAO (2023); UNCCD (2022); ILRI (2022).

4. RESULTS AND DISCUSSION
4.1. Interactions Between Water Availability And Livestock Productivity
Analysis of the reviewed studies shows a direct and significant correlation between water variability and livestock productivity in arid and semi-arid systems. Animal production fluctuates according to rainfall distribution, aquifer recharge, and forage quality.

Research by ILRI (2022) in the Sahel demonstrated that a 100 mm increase in annual precipitation is associated with a 12 % increase in the average weight of cattle and an 18 % rise in goat milk production, confirming the sensitivity of livestock productivity to minimal climatic variations [1].

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Conversely, water stress reduces feed intake, nutrient assimilation, and reproductive efficiency. Alemu and Tesfaye (2020) found that goats subjected to a 30 % water restriction reduced voluntary feed intake by 35 % and exhibited significant thermal alterations [2].

Water quality is also a decisive factor. High salinity (TDS > 3 000 mg/L) affects palatability and renal function, increasing the incidence of chronic nephrosis and reproductive failure. Studies in Sudan and Pakistan show fertility losses of 10–15 % in herds consuming water with high electrical conductivity [3]. The installation of filtration and solar desalination systems can mitigate these effects and strengthen herd resilience [4].

Overall, the data indicate that continuous access to potable water—beyond its mere presence—determines the physiological balance, metabolic efficiency, and economic sustainability of productive units in arid zones.

4.2. Forage Dynamics And Nutritional Efficiency
Forage biomass production is closely related to rainfall patterns. In natural grasslands, each additional millimeter of effective rainfall can generate between 10 and 25 kg of dry matter per hectare per year, depending on soil fertility and vegetation cover [5].

Drought accelerates leaf senescence, decreases active leaf area, and reduces crude protein content while simultaneously increasing lignin and indigestible fiber, thereby lowering digestibility. In the Argentine Chaco, Gómez et al. (2021) demonstrated that a 40 % reduction in water availability caused a 22 % loss in average daily weight gain in Brangus steers [6].

To address this limitation, various studies recommend integrating hydroponic forage systems, *Opuntia ficus-indica* (prickly pear) cultivation, and halophytic shrubs such as *Atriplex halimus*, capable of maintaining high moisture (80–90 %) and good nutritional value with minimal irrigation [7].

Likewise, energy supplementation with vegetable fats and electrolyte-balanced minerals improves osmotic balance and maintains productivity during hot seasons. Strategic grazing at times of low solar radiation (early morning or late afternoon) reduces heat load and promotes feed intake.

4.3. Breed Resilience And Systemic Adaptation
Adaptive capacity varies among species and breeds. Genotypes such as Brahman, Zebu, the Bedouin Goat, or the Caribbean Creole Sheep maintain productivity under water stress due to thermoregulation mechanisms, lower respiratory frequency, and greater body water retention.

Comparative trials in Egypt and Colombia show that Brahman cows maintain milk production at temperatures up to 42 °C, while Holstein cows reduce their yield by 25 % under the same conditions [8]. Among small ruminants, the Caribbean Creole Goat maintained feed efficiency during drought periods, confirming its suitability for extensive systems [9].

At the system level, **silvopastoral and agroforestry models** demonstrate greater hydric resilience.
Trees such as *Leucaena leucocephala* and *Prosopis juliflora* provide shade, increase soil moisture, and supply additional plant protein. Arenas et al. (2022) documented a 30 % increase in daily weight gain in cattle under silvopastoral systems compared to open pastures in northern Chile [10].
These integrated systems also enhance biodiversity, carbon sequestration, and local microclimate, contributing to both environmental and economic sustainability.

4.4. Economic And Sustainability Evaluation
Water scarcity directly impacts production costs, particularly those related to pumping, transport, and infrastructure maintenance. According to CIAT (2023), water supply can represent between 15 % and 25 % of total operating costs in arid livestock operations [11].

Economic models estimate that a 20 % reduction in water availability generates losses of USD 40/ha/year in extensive bovine systems in Latin America. However, adopting technologies such as drip irrigation and geomembrane-lined reservoirs can recover up to 80 % of the lost productivity [12].

Using indicators such as the **water footprint** allows for efficiency comparisons among species: beef requires an average of 15 400 L/kg, pork 6 000 L/kg, and poultry 3 900 L/kg. Integrating agro-industrial by-products (molasses, bagasse, vegetable residues) can reduce the total water footprint by up to 35 % [13].

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Modernizing infrastructure is equally critical. Producers using underground cisterns or geomembrane tanks report evaporation losses below 5 %, compared with 25 % in open ponds. The **Pampa Seca Livestock Program (INTA, 2022)** successfully promoted these technologies among small producers [14].

4.5. Environmental And Ecological Impacts

Excessive aquifer exploitation causes soil salinization, biodiversity loss, and desertification. In the Souss-Massa Basin (Morocco), groundwater decline has reduced natural vegetation cover by 60 % over three decades [15]. Similar phenomena occur in Latin America, where overgrazing near water points compacts the soil and impedes infiltration.

The concept of **minimum ecological flow** has become essential to ensure water volumes that sustain ecosystem functions. Restoration programs such as the *Baker River Plan* (Chile) or the *Niger Pastoral Initiative* demonstrate that the recovery of wetlands and green corridors stabilizes the microclimate and enhances ecological resilience [16].

Pasture rotation, rest periods, and reforestation with native species improve infiltration and soil water-holding capacity—by up to 25 mm additional per meter of depth [17]. These low-cost, high-impact measures strengthen the sustainability of arid ecosystems.

4.6. Institutional Coordination And Knowledge Transfer

The reviewed literature identifies institutional fragmentation as one of the main obstacles to efficient water management. Competition among ministries of agriculture, environment, and rural development creates overlapping functions and inconsistent policies.

Integrated programs, such as the *Water and Sustainable Livestock Project* (Brazil, 2021–2024) coordinated by Embrapa, show significant progress. Through satellite monitoring of pastures and remote technical assistance, the program reduced water consumption per liter of milk produced by 18 % and increased productivity by 22 % [18].

Strengthening local capacities and creating community watershed committees promote transparency and equity in resource distribution. Experiences in Bolivia and Ethiopia demonstrate that participatory governance systems are more resilient to droughts than centralized models [19].
Finally, digital technologies—such as mobile applications and hydrological alerts—enable real-time decision-making, integrating traditional knowledge with modern management tools.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. General Synthesis Of Findings

The study demonstrates that water availability is the principal limiting factor in animal production in arid and semi-arid regions, conditioning both animal physiology and the ecological and socioeconomic stability of rural communities.

The review consistently evidenced that fluctuations in water resources—whether due to variations in precipitation, groundwater level, or water quality—directly affect productivity, forage quality, and animal welfare.

Regions that have implemented comprehensive water management strategies, such as Israel, Chile, and northeastern Brazil, report productivity levels up to 20 % higher than traditional systems under similar climatic conditions.

Consequently, **biological adaptation, technological innovation, and institutional coordination** emerge as fundamental pillars of livestock sustainability under water stress.

5.2. Implications For Livestock Sustainability

Sustainability in arid zones requires a paradigm shift: from extractive models toward **ecosystem-based water management**.

Water resources should be considered a strategic asset whose distribution must be optimized among agricultural, livestock, and domestic uses.

Incorporating indicators of water-use efficiency, hydrological monitoring, and environmental footprints into livestock policies will allow for performance comparisons, waste reduction, and compliance with international sustainability standards.

These mechanisms not only strengthen sectoral competitiveness but also respond to the new demands of consumers who prioritize animal-origin products with environmental and ethical traceability.

Similarly, the **circular reuse of water**—for example, using treated wastewater for forage irrigation or runoff capture—reinforces environmental conservation and food security. Integrating these practices into national climate adaptation plans would align livestock production with the **Sustainable Development Goals (SDGs)**, particularly SDG 6 (*Clean Water and Sanitation*) and SDG 12 (*Responsible Consumption and Production*).

5.3. Technical And Political Challenges

The main obstacle identified is the technological and financial gap faced by small and medium producers. The lack of credit, infrastructure, and training limits the adoption of water-saving technologies such as drip irrigation, geomembrane tanks, or solar pumps.

In addition, institutional fragmentation reduces the effectiveness of public policies. In most arid countries, water management is divided among different ministries and agencies, generating duplication of functions.

It is imperative to establish an **intersectoral water–livestock framework** that coordinates planning, monitoring, and resource allocation.

Subsidy programs must be redesigned to reward efficiency rather than consumption, linking economic incentives to measurable improvements in water performance.
Payments for ecosystem services and **green certification programs** represent concrete opportunities to encourage responsible water use.

5.4. Perspectives On Technological Innovation

Technological progress offers promising solutions to enhance livestock resilience.

Precision agriculture tools and remote sensors allow continuous monitoring of soil moisture, pasture conditions, and precipitation anomalies. Their integration with satellite imagery and **IoT systems** enables real-time adjustment of animal loads and irrigation schedules.

In the **biotechnological** field, genetic markers associated with drought tolerance, thermoregulation, and metabolic efficiency have been identified in cattle, sheep, and goats. Genomic selection programs make it possible to develop water-efficient breeds, reducing requirements without compromising productivity.

Feed innovations, such as hydroponic forage production or microalgae supplementation, reduce water demand per kilogram of dry matter.

In parallel, **water reuse within production units** can recover up to 70 % of the resource, closing the internal cycle and reducing dependence on external sources.

The integration of **renewable energy**, particularly solar systems for irrigation and desalination, not only lowers operational costs but also contributes to livestock-sector decarbonization, aligning it with climate neutrality goals.

5.5. Social And Educational Dimensions

Adaptation to water scarcity also requires a **cultural transformation**. Awareness of the economic and ecological value of water must be incorporated into training and agricultural extension programs. Environmental education in technical and university curricula is key to fostering sustainable long-term behaviors.

It is equally essential to recognize the role of **rural women** in water management. Their active inclusion in decision-making processes ensures that policies and projects respond to local realities and gender needs.

Strengthening producer networks and knowledge-exchange spaces—such as the **AGWA** or **PLANGASUR** regional platforms—promotes collective innovation and shared learning, enhancing the resilience of livestock systems in arid environments.

5.6. Strategic Recommendations

Based on the conducted analysis, the following strategic lines are proposed:

- Implement **integrated hydrological monitoring systems**, combining local sensors, meteorological stations, and satellite imagery to anticipate droughts and adjust animal loads.
- Promote the **reuse of treated wastewater** for forage irrigation, under strict sanitary controls.

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- Develop **adaptive genetic improvement programs**, focused on local breeds tolerant to heat and efficient in water use.
- Strengthen **interdisciplinary research** integrating hydrology, animal science, and rural economics to model the water–livestock–ecosystem relationship.
- Create **national adaptation funds** aimed at financing water infrastructure (rainwater harvesting, reservoirs, low-pressure irrigation).
- Consolidate **participatory water governance** through watershed committees and pastoral cooperatives.
- Promote **environmental awareness campaigns** presenting water efficiency as a central pillar of livestock sustainability.

Each of these recommendations is supported by the empirical evidence synthesized in this study and offers a viable path toward **climate-resilient animal production**.

5.7. Final Considerations
The future of animal production in arid regions will depend on the collective ability to harmonize productivity with responsible water management.

Water scarcity should not be understood merely as a physical limitation but as a **multidimensional challenge** involving ethics, equity, and environmental justice.

Veterinary and agricultural sciences are called to lead this transition. Through research, technology transfer, and public policy advocacy, they can ensure the evolution toward **efficient, resilient, and ecologically balanced livestock systems**.

In summary, **efficient water management**, the **adoption of appropriate technologies**, and the **revaluation of traditional ecological knowledge** constitute the three fundamental pillars for sustaining livestock in arid zones.

Integrating these principles ensures not only **food security** and the survival of pastoral systems but also the **preservation of natural ecosystems** for future generations.

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