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Assessing water quality in dehesa livestock ponds revealed by complementary indices

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INTRODUCTION

Ponds are the main water resource for livestock and wildlife in the dehesas of the Iberian Peninsula. Water availability varies with rainfall and season, while animal use strongly influences water quality. Frequent droughts have prompted farmers to construct wells and ponds to ensure a continuous water supply for livestock.

Research has largely focused on water storage capacity and consumption, overlooking water quality and its implications for animal health, particularly during summer and droughts. Beyond providing sufficient water, ponds must supply water of adequate quality to reduce disease risks, including potential transmission to humans through pathogens and chemical contaminants.

Water Quality Indices (WQIs) combine multiple parameters to assess overall water quality and suitability for specific uses, including human consumption and livestock watering. The CCME-WQI and NSF-WQI have been widely used across aquatic systems as tools for integrated water quality assessment.

Objectives

- Assess the physicochemical and microbiological quality of water in a network of Mediterranean dehesa livestock ponds using two complementary indices: CCME-WQI and NSF-WQI.
- Adapt and apply both indices to extensive livestock systems by defining parameter-specific sub-index curves and weights based on livestock health and ecological relevance.
- Compare the performance and sensitivity of both indices in capturing seasonal and spatial variability in water quality.

MATERIAL AND METHODS

The study was carried out in 27 ponds of three dehesa pilot farms in Extremadura (Spain; Figure 1).
A total of 16 physical, chemical, and biological parameters were measured, using two methods. The HI9829 Multiparameter from HANNA INSTRUMENTS, and the collection of water samples for subsequent laboratory analysis.
The parameters measured were: Temperature (ºC), pH, REDOX potential (mV), Electrical conductivity [EC](µS cm^{-1}), Resistivity (Ohm-cm), Total dissolved sediments,TDS (ppm), Salinity (mg L^{-1}), Dissolved oxygen (mg L^{-1}), Turbidity (FNU), Fecal coliforms (col $100ml^{-1}$), *Escherichia coli* (col $100ml^{-1}$), Nitrates (mg NO_3-L^{-1}), Nitrites (mg NO_2^- L^{-1}), Ammonium (NH_4^+ L^{-1}), Phosphates (mg PO_4^{3-} L^{-1}), D. B. O_5 (mg O_2 L^{-1}) and Chlorophyll a (mg L^{-1}).

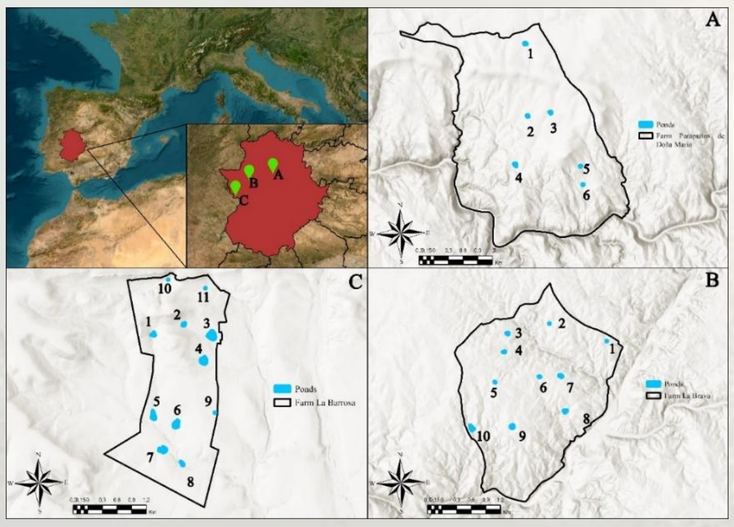


Figure 1. Parapuños de Doña María (A), La Brava (B) and La Barrosa (C).

Calculation of the two livestock-focused water quality indices

CCME-WQI

Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) is based on compliance with predefined water quality guidelines and evaluates water quality through three core dimensions: the scope of guideline exceedances (F1), the frequency of exceedances (F2), and the magnitude of deviations from guideline values or amplitude factor (F3).

$$\text{CCME-WQI} = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}$$

NSF-WQI

The National Sanitation Foundation Water Quality Index (NSF-WQI) is a historically established and widely documented index that integrates normalized sub-indices of individual parameters using a weighted aggregation approach. Weighted 0–100 subindices were adapted to livestock health and shallow-pond ecology. The index was calculated as:

$$NSF\text{-}WQI = \sum_{i=1}^{n} (S\,I_i \times W_i)$$

Each measured parameter was transformed into a sub-index value (SI, 0-100) using continuous response functions specifically adapted to Mediterranean livestock pond conditions. E.g.:

- ***Dissolved Oxygen (DO)***

DO was modeled using a quadratic increasing-response function emphasizing hypoxic stress:

$$SI_{DO} = max(5, min(100, 100 - 3(8 - DO)^2))$$

This formulation assigns high quality to well-oxygenated waters while strongly penalizing hypoxic conditions associated with eutrophication and organic loading.

- ***Escherichia coli***

Microbial contamination was modeled using a logarithmic decay function reflecting the non-linear increase in sanitary risk:

$$SI_{E.coli} = max(5, 100 - 20log_{10}(E.coli + 1))$$

This approach captures the disproportionate impact of increasing fecal contamination on livestock health.

RESULTS

Index scores by season

Both indices scored higher in wet than dry simples (Table 1).
Water quality scores were also higher in 2023 than in 2022.
Boxplot of both indices (CCME and NSF) showed the lower central scores in dry-season samples, consistent with a reduced water quality after summer (Figure 2).

Table 1. Mean, standard deviation and observed range of indices.

INDEX	Mean	SD	Maximum	Minimum
CCME WQI WET	61.20	13.32	84.47	33.19
CCME WQI DRY	42.64	12.29	81.52	29.12
NSF WQI WET	78.00	7.09	89.65	58.34
NSF WQI DRY	67.30	8.69	84.24	50.97

Wet vs dry distributions

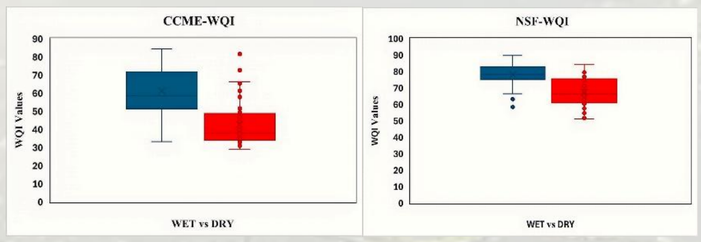


Figure 2. Boxplot of both indices showing differences among seasons.

Dry-season sanitary signal and guidelines

97.73%
of dry-season observations with detectable *E. coli*

Mean ammonium
Wet 1.85 mg/L; guideline met in 81.56%
Dry 4.65 mg/L; guideline met in 47.72%

Mean E. coli count
Wet 4.69 col/100 mL; guideline met in 59.25%
Dry 32.20 col/100 mL: guideline met in 2.27%

Mean Nitrates
Wet 3.29 mg/mL; guideline met in 100%
Dry 4.62 mg/mL; guideline met in 100%

Agreement between indices

The proportion of samples within each water quality class was calculated for both indices.
Classification results differed markedly between indices (Figure 3). While NSF-WQI classify 62.2% of samples as good, CCME-WQI only amounted to 7.1%.
NSF-WQI identified most samples as Good/Fair-Medium classes; while CCME-WQI assigned a larger share to Marginal-Bad and Poor/Very bad classes.
For visualization purposes, in figure 3 equivalent quality classes were grouped (Fair-Medium, Marginal-Bad, Poor-Very bad) to facilitate comparison between indices.

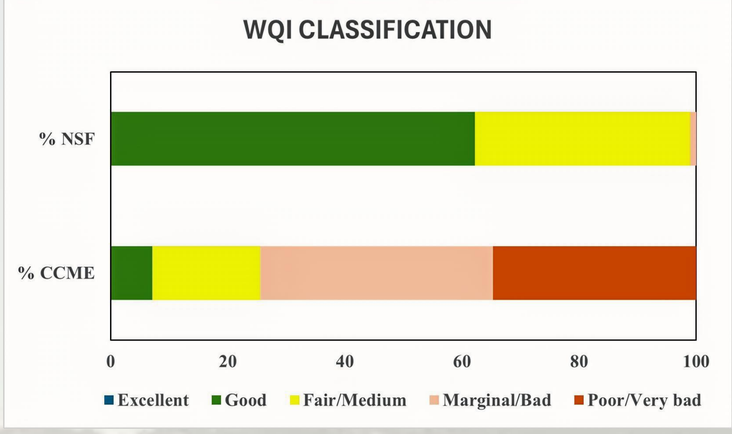


Figure 3. WQI indices classification.

Agreement between CCME-WQI and NSF-WQI was further evaluated using Bland–Altman analysis (Figure 4).
The difference between indices (NSF − CCME) was plotted against their mean value. Mean bias and 95% limits of agreement (±1.96 SD) were calculated to assess systematic differences between indices across the water quality gradient. The analysis revealed a systematic positive bias between indices, with NSF-WQI producing consistently higher values than CCME-WQI (mean difference ≈ 20 units).

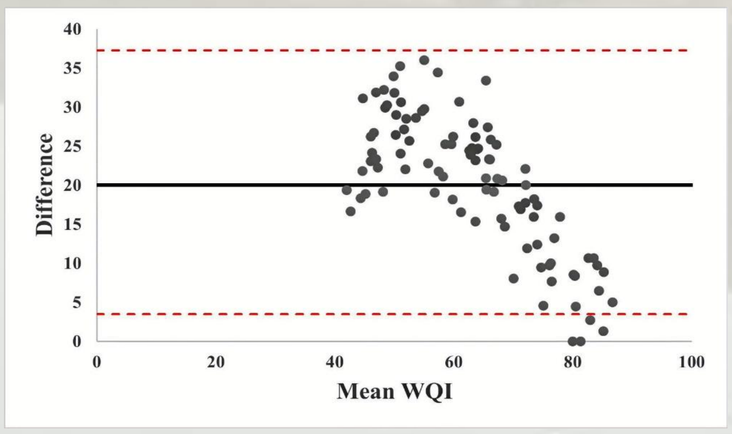


Figure 4. Bland–Altman comparison (NSF-WQI minus CCME-WQI).

DISCUSSION

Implications for farm monitoring

Water quality in livestock ponds in the southwestern Iberian Peninsula showed clear **seasonal differences** between wet and dry periods. High temperatures and reduced rainfall in the Mediterranean climate can decrease water availability, causing some ponds to dry out during the dry season.

Physical, chemical and biological parameters provide farmers with information on pond water quality. These indicators have been studied across different locations using a range of methods, including remote sensing.

Water quality information supports informed decisions on livestock, big game and grazing management.

Water quality indices concerns

The CCME-WQI is widely used to assess surface water quality because it is easy to apply and allows flexible selection of water quality parameters and The NSF-WQI has also been applied across diverse surface water systems.

Both indices have been applied and evaluated in several countries using parameters similar to those considered in this study. Their application to water bodies comparable to livestock watering ponds supports their potential suitability for these systems.

CONCLUSIONS

Physical, chemical and biological parameters showed marked differences between wet and dry seasons, with the Interannual differences being important, with 2023 recording the highest pond water quality according to both indices.

The NSF-WQI classified most samples as good or fair, whereas the **CCME-WQI** assigned a substantially higher proportion to marginal or poor categories. Heatmaps showed recurrent low CCME-WQI values in several ponds during summer campaigns, while NSF-WQI values exhibited a more buffered response, indicating differences in index sensitivity.

Interannual patterns were more clearly differentiated by the CCME-WQI, which provided a more conservative screening tool for livestock ponds. Seasonal monitoring captured post-summer deterioration in water quality.

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