International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print); 2222-5234 (Online)
Website: https://www.innspub.net
Email contact: info@innspub.net
Vol. 27, Issue: 4, p. 150-158, 2025

RESEARCH PAPER | OPEN ACCESS

Comparative analysis of the influence of temporal, seasonal and behavioral factors using XGBoost for predicting traveled distances

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Key words: Predictive modeling, XGBoost, Pastoral mobility, Burkina Faso

DOI: https://dx.doi.org/10.12692/ijb/27.4.150-158 Published: October 19, 2025

ABSTRACT

Cattle farming are essentially based on the exploitation of natural pastures. Determining the distances traveled by animals in extensive livestock farming remains a major challenge in the West African sub-region. The objective of this study was to develop a robust predictive model of the daily distance traveled by animals in pastoral systems, exploiting the capabilities of the XGBoost algorithm. This study evaluated pastoral cattle movements in two municipalities in different agroecological zones of Burkina Faso. Tracking carried out with mini-GPS devices made it possible to collect positioning data on the movement of grazing animals over three distinct seasons. The daily distance traveled was modeled with an XGBoost algorithm whose performance was validated by cross-validation. Post-modeling analyses then made it possible to interpret the model and identify factors influencing herd behavior. Performance was good, with a coefficient of determination R of 0.92 and an average error of only 245 meters. Variable importance analysis revealed a dominance of grazing time (69.4%) and travel speed (22.3%) in predicting distances traveled. The XGBoost method offers a robust alternative to traditional statistical models. This approach opens up concrete prospects for the development of decision-support tools that enable livestock farmers and managers to more effectively plan rangeland use, reduce environmental impact, and improve animal welfare.

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INTRODUCTION

Pastoralism is vital for 200 million herders worldwide and contributes significantly to the economy of many countries (Kerveno *et al.*, 2024). It is based on the movement of herds and plays a major role in the Sahelian region (Mouhamed, 2024). It is a type of livestock farming that revolves around the constant interaction between three elements: the herder, their herd, and the territory they utilize (Knockaert *et al.*, 2024). Burkina Faso had a total of 32,416,008 head of cattle, sheep, and goats in 2023 (INSD-BURKINA, 2025). Cattle farming is mainly based on the use of natural pastures, whose low productivity affects milk performance (Neya *et al.*, 2025). Indeed, the scarcity and degradation of natural pastures strongly influence the behavior of animals on natural grazing lands (Djohy *et al.*, 2024). The movement behavior of animals in pastoral environments represents a major scientific and socio-economic challenge in regions of extensive livestock farming. In the face of dwindling resources, cattle farming must adapt to ensure the food security of livestock and diversify incomes (Adedigba *et al.*, 2023). Insecurity over a few years has been at the heart of debates on pastoralism in West Africa (Rangé *et al.*, 2020). These movements largely determine the efficiency of production systems. In a context of global changes where pressures on pastoral resources are increasing, understanding the determinants of mobility becomes crucial for sustainable land management. Sustainable management of pastoral areas requires taking into account the plurality of actors, their strategies, and their capacities to adapt systems to changing institutional and ecological contexts (Ibrahim *et al.*, 2018).

The recent emergence of machine learning methods offers new perspectives for analyzing these complex systems, allowing for the modeling of sophisticated relationships without presupposing specific mathematical forms (Qiao *et al.*, 2021; Kharrachi *et al.*, 2024; Wen *et al.*, 2024). Although the distance traveled is a key integrative indicator for quantifying animals' energetic effort and their use of space in pastoral environments, its accurate prediction remains a persistent scientific challenge. The aim of this study was to develop a robust predictive model of the daily distance traveled by animals in pastoral systems, leveraging the capabilities of the XGBoost algorithm.

MATERIALS AND METHODS

Study site

This study was conducted in two villages in Burkina Faso, namely the village of Banakélédaga in the commune of Bama and Nabadogo in the commune of Sabou. The commune of Sabou is located in the northern Sudanian zone in the Centre-Ouest region. It is situated at 12°04'00" north and 2°14'00" west. The commune of Bama is located 20 km north of Bobo-Dioulasso in western Burkina Faso, in the southern Sudanian zone. It is situated at 11°23'59" north and 4°25'46" west. The selection of these sites was made deliberately based on their accessibility and their representativeness in terms of local pastoral practices. Data were collected during the rainy season (RS), the hot dry season (HDS), and the cold dry season (CDS) over six consecutive days of observation.

Study methodology

Spatio-temporal tracking system for herds

In order to better understand the pastoral behavior of cattle, a GPS tracking system was set up. The study focused on two herds grazing in different agroecological zones. Within each herd, three cows were equipped with a collar containing a mini-GPS. These devices, programmed to record a position every 5 seconds, captured the daily movement of the animals on the pasture with high precision. Data collection took place over five consecutive days during each of the three periods: the cool dry season, the hot dry season, and the rainy season. The raw data collected (date, time, geographic coordinates, and altitude) were extracted and compiled using I-gotu GPS software for analysis. The position data were imported into QGIS 3.34.12 software to be reprojected into the Universal Transverse Mercator (UTM) format. The Cartesian coordinates were then calculated following the reprojection. The raw data underwent a quality control process that included checking for outliers using the quartile method, normalizing distributions, encoding categorical variables using one-hot encoding, and confirming the absence of missing data. A preliminary exploratory analysis was conducted, including descriptive statistics (mean, standard deviation, range), correlation matrices between continuous variables, Shapiro-Wilk normality tests, and analysis of variance to assess interseasonal differences.

Modeling with XGBoost

The estimation of the daily distance traveled by the animals was based on the use of the XGBoost algorithm. This algorithm represents an advanced implementation of Gradient Boosting machines, a family of algorithms known for their high performance in supervised learning, both for regression and classification (Ibrahem *et al.*, 2021). The XGBoost model was configured for regression ('reg:squarederror') with 150 estimators and a maximum depth of 6. A learning rate of 0.1 was applied, combined with 80% sampling of the data and features per tree. To limit overfitting, L1 (α=0.1) and L2 (λ=1) regularizations were implemented, along with an early stopping criterion. The model was evaluated using a 70/30 split (training: n=60; test: n=26) and validated through a 5-fold cross-validation procedure. Its performance was measured using pqre;eters such us R, RMSE, MAE, and MAPE.

Post-modeling analysis

The analysis was conducted in the RStudio environment (v4.3.0), using the xgboost package for modeling, caret for preprocessing, ggplot2 for visualization, and dplyr for data manipulation. Reproducibility was ensured by setting a fixed random seed of 42. Model interpretation included calculating variable importance (Gain, Frequency, Coverage), analyzing residuals to check for homoscedasticity and normality, and exploring variable-response relationships using partial dependence plots and interaction analyses.

RESULTS

Descriptive characteristics of grazing and movement behavior

Fig. 1 presents boxplots of the distance traveled, grazing time, and speed, according to the variables village, day, and season. At the village level, the dispersion of the distance traveled was greater in Nabadogo. As for grazing time, the median was higher in Nabadogo. There was a progressive decrease until Day 6, particularly marked for distance (a reduction of about 30% between Day 1 and Day 6). For speed, the peak was observed on Day 1 (0.45 m/s) followed by stabilization from Day 2 (0.35 m/s). In the hot dry season (HDS), the median distance traveled was 14,000 m and grazing time was 18,000 s, with a minimum speed (0.25 m/s). In rainy and dry cold seasons, intermediate profiles suggest more favorable feeding conditions.

Fig. 2 shows the distribution of movement types according to the season. Three types of movement were identified: slow, moderate, and fast. The analysis reveals significant variations in the distribution of movement types depending on the village and the season. The village of Banakélédaga in the Bama village exhibits a mobility profile dominated by moderate and fast movements, with a complete absence of slow movements during the rainy season (RS) and the hot dry season (HDS). A predominance of fast movements is observed in the hot dry season (67%), while the cold dry season (CDS) is characterized by a majority of moderate movements (94%). The village of Nabadogo shows a different profile. This profile is characterized by a high prevalence of moderate movements in RS (89%) and CDS (83%), and a total absence of rapid movements in SSC. This same season is marked by a notable proportion of slow movements (40%), a phenomenon absent in other periods.

Fundamental relationships and development of the predictive model

Fig. 3 shows the relationship between grazing time and distance traveled by village. This analysis reveals several trends. Animals that spend more time grazing consistently travel greater distances. This distance ranges from about 5 km for the shortest grazing times to more than 15 km for longer durations. A difference between villages was observed. For the same grazing time, the village of Banakélédaga exhibits the greatest distance traveled. Speeds varied between 0.2 and 0.5 m/s. The higher the speed, the greater the distance traveled. The distribution of speeds also appears to differ between villages. The village of Banakélédaga shows a higher proportion of medium-to-large points (speeds of 0.4-0.5 m/s) compared to a predominance of small-to-medium points (0.2-0.3 m/s) for Nabadogo.

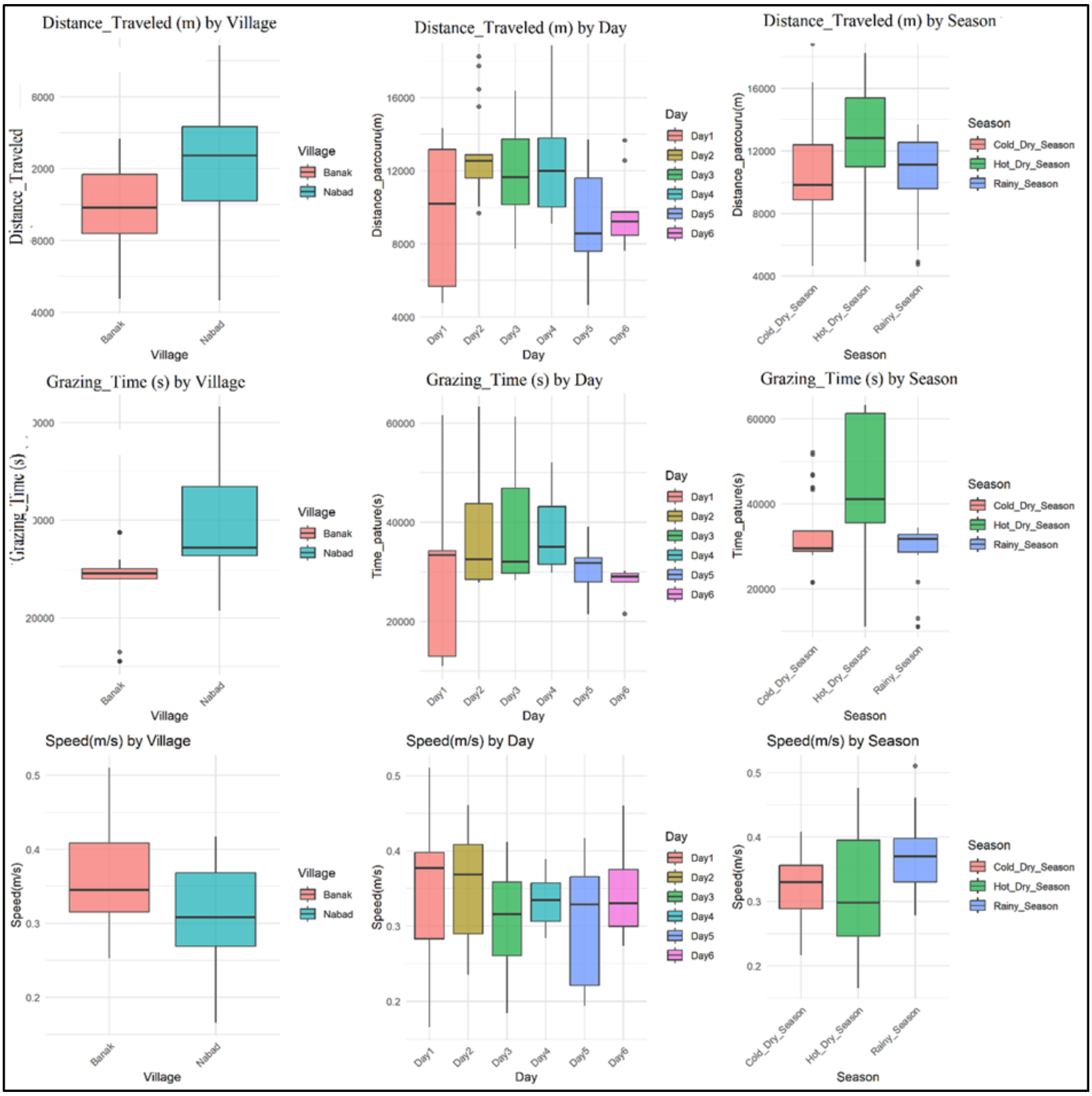

Fig. 1. Boxplot of the distance traveled, grazing time, and speed, according to the variables village, day, and season

Table 1 presents the relative importance of variables in the XGBoost model for predicting distances traveled. The analysis reveals the dominance of grazing time (69.4% of gain) and movement speed (22.3% of gain) in predicting distances traveled, with these two variables alone accounting for 91.7% of the model's predictive power. The variable specific to the village of Banakélédaga (2.8%) and that of the hot dry season (HDS) (1.9%) emerge as secondary factors. Daily and seasonal mobility variables show a marginal influence (≤1.1%).

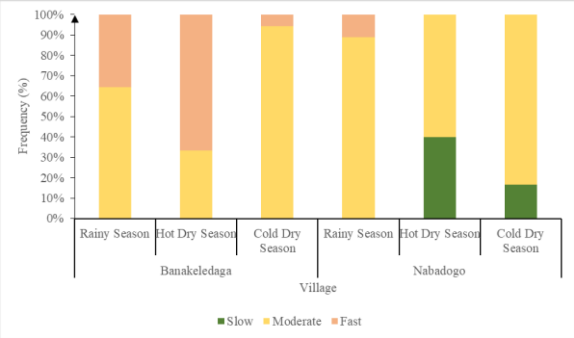

Fig. 2. Distribution of types of travel according to the seasons and villages

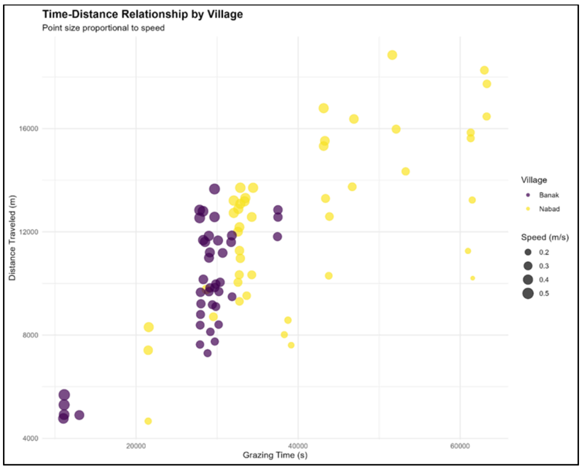

Fig. 3. Distribution of the time-distance relationship according to the villag

Table 1. Relative importance of variables in the XGBoost model for predicting distances traveled

Feature	Gain (%)	Cover (%)	Frequency
Grazing_time_s	69.392	40.391	33.792
Speed_m_s	22.325	36.726	31.427
Village_Banak	2.803	4.004	6.406
Season_SSC	1.942	3.455	5.288
Day_Day2	1.091	4.309	6.578
Day_Day4	0.821	2.672	3.869
Day_Day6	0.493	1.995	2.494
Season_SSF	0.487	2.739	3.826
Day_Day5	0.478	2.042	3.224
Day_Day3	0.093	1.217	2.322
Village_Nabad	0.076	0.450	0.774

Legend: Village_Banakéledaga: village of Banakélédaga; Village_Nabadogo: village of Nabadogo; HotDry_Season: Hot Dry Season; ColdDry _Season: Cold Dry Season; Day_Day (1,2,3,4 and 5): For the collection days.

The cover metric indicates that grazing time and speed concern 40.4% and 36.7% of the observations, respectively. Usage frequency corroborates this hierarchy, with respective usage of 33.8% and 31.4% for these two main variables.

The model equation presents the simplified prediction model derived from the XGBoost analysis. The coefficient of 693.9 for grazing time indicates that an increase of one second in grazing time results in a predicted increase of 694 meters in distance traveled. The high coefficient for speed (2232.5) reflects its disproportionate impact on distance, where an increase of 0.1 m/s in average speed predicts an increase of 223 meters in distance traveled.

The contributions of categorical variables, although more modest, reveal significant contextual effects: animals from the village of Banakélédaga travel on average 84 meters more than those from Nabadogo, the SSC season adds 97 meters to the distances traveled compared to other seasons, and day 2 shows an increase of 33 meters compared to other days.

Predicted distance = 693.9 × Grazing time + 2232.5 × Speed + 84.1 × Village_Banakélédaga + 97.1 × Season_SSC + 32.7 × Day_Day2 (Model equation)

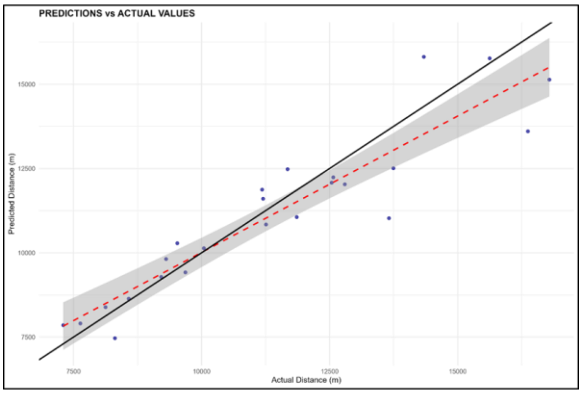

Fig. 4. Distance prediction

Performance and validation of the prediction model

Fig. 4 shows the performance of the model in predicting actual versus predicted distances. The predicted distance ranged between 7,500 and 15,000 m. The model demonstrates good prediction capability. The error distribution is homogeneous. This spatial asymmetry in the scatter plot suggests a systematic underestimation of high values by the model, with an apparent inability to accurately predict the upper extremes of the real data. The dynamics of prediction errors appear to increase proportionally with the magnitude of the actual values, with absolute deviations rising from approximately 2,500 m for values around 7,500 to over 5,000 m for observations at 15,000 m.

Table 2. Overall performance of the XGBoost model for predicting travelled distances

Metric	Value
R	0.86065741
RMSE	1043.87063
MAE	760.951995
MAPE	6.19323278
Correlation	0.92771623

Legend: R: Coefficient of determination; MRSE: Root Mean Square Error (in meters); MAE: Mean Absolute Error (in meters); MAPE: Mean Absolute Percentage Error; Correlation: Correlation coefficient between observed and predicted values.

The XGBoost model demonstrates high predictive performance with a coefficient of determination R of 0.861, indicating that 86.1% of the variance in distances traveled is explained by the model (Table 2). The strong correlation of 0.928 between observed and predicted values confirms the robustness of the predictions. In terms of absolute accuracy, the model has a mean absolute error (MAE) of 760.95 meters and a root mean square error (MRSE) of 1043.87 meters. The relative error MAPE of 6.19% highlights the model's excellent relative accuracy, with an average error of less than 6.2% compared to the actual distances traveled.

Table 3 shows that the performance of the XGBoost model was evaluated over three distinct seasons: RS (rainy season), SSC (hot dry season), and CDS (cold dry season). The coefficient of determination R ranges between 0.958 and 0.990, indicating excellent predictive capability, regardless of the season. Absolute accuracy, measured by MRSE, shows optimal performance during the SP season (MRSE = 243.21 m) compared to 746.86 m for the SSC season. The mean residuals, all positive, indicate a slight tendency of the model to overestimate the distances traveled, particularly pronounced during the SSC season (+139.37 m). The predicted average distances vary significantly between seasons, with a maximum value observed during CDS (12,391.62 m) and similar values during SP and SSF (around 10,600 m).

Table 3. XGBoost model performance for predicting distances traveled per season

Season	Mean predicted distance	Mean residual	MRSE	R
Rainy Season	10564.1028	59.1674786	243.21159	0.9899005
Hot Dry Season	12391.6226	139.366377	746.85753	0.9581361
Cold Dry Season	10689.7079	30.1518735	602.23479	0.9637840

Legend: The predicted average distance values are presented with the corresponding confidence interval of ± RMSE. The mean residual indicates the model bias (positive values = systematic overestimation). MRSE: Root Mean Square Error; R: Coefficient of determination.

DISCUSSION

Descriptive features and relationships of the predictive model

The disparities in mobility parameters observed between the different villages suggest the existence of determining factors that influence daily movement patterns. The high prevalence of so-called rapid mobility recorded in Banakélédaga in SSC could indicate human impact on the grazing area and passage corridors. These factors could be associated with the level of economic development and investment in the area. As for the complete absence of slow movements (0% in the village), this could be explained by the accessibility of the grazing and corral areas. Access to land, forage quality, and water availability are taken into account by livestock farmers in managing their herds (Adedigba *et al.*, 2023). Indeed, the village of Banakélédaga is a peri-urban area located near the city of Bobo Dioulasso and the classified Dindéresso forest. Studies on the vulnerability of communities surrounding the classified Dindéresso forest have shown that the village of Banakélédaga stands out with relatively favorable indicators, presenting a low exposure level (0.4) and a low final vulnerability level for the area (Millogo *et al.*, 2024). The mobility profile of the cattle herd in Nabadogo was characterized by predominantly slow and moderate movements, with an absence of rapid movements. This reflects a comfortable grazing probability without too many restrictions.

This situation results in the availability of pastoral resources with fewer constraints related to their accessibility. Seasonality strongly impacts the type of mobility in both villages. There is an alternation between moderate and slow mobility types noticeable in RS and CDR. This alternation could highlight the significant influence of climatic conditions on mobility behaviors. The analysis emphasizes a clear contrast in the concept of agroclimatic factors on mobility. This situation corroborates the findings of Malzac *et al.* (2024), according to which herd mobility depends on the season.

The villages of Banakélédaga and Nabadogo operate according to distinct paradigms. The long distances covered by the animals and grazing times aim to reduce grazing speed in order to maximize grazing efficiency and optimize the use of available resources. These strategies adopted by the herders could be due to several factors. First, the gradual depletion of easily accessible forage resources, which forces the animals to travel greater distances to find fodder, and the behavioral adaptation of animals, which adjusts their movement speed according to resource availability. In the face of environmental changes, adaptation strategies vary depending on agroclimatic zones (Ouédraogo *et al.*, 2010). The overall pattern emerging from the analysis shows that the SSC experiences a period of food shortage for livestock, which has a significant impact on mobility behaviors. These constraints could translate into an amplification of intercommunity differences, with an increase in the observed differences in terms of grazing distance and time between various locations. A change in daily dynamics has been observed, with a reduction in mobility parameters, notably the distance traveled and the speed of movement. These results highlight the crucial importance of seasonal factors in the strategies of space use by animal herds. The observed differences suggest either greater efficiency of animal movements in certain areas or different environmental conditions between the two studied zones. These results indicate that the village of origin significantly influences the movement behavior of the animals. Our results showed a fundamental and significant relationship between the season, the village, grazing time, and the distance traveled by the animals, thus confirming the observations made by Chebli *et al.* (2019). The systematic correlation observed between grazing duration and the distance traveled can be explained by the forage resource exploitation strategy described by Ouoba/Ima (2021). There is a mobility to other regions of the country during the dry season when local resources no longer meet their expectations in terms of forage and water. Our results align with those of Fillol *et al.* (2020), confirming the need to supply early warning systems with relevant information.

Performance and validation of the prediction model

The overall validation metrics confirm the remarkable ability of the XGBoost model to capture complex cattle movement patterns. The XGBoost model has been used by several authors in the context of prediction. Indeed, Ndiaye *et al.* (2025) utilized this model for soil type classification. The coefficient of determination R of 0.861 and the relative error MAPE of 6.19% obtained in our study indeed exceed the performance reported by other authors (Ibrahem *et al.*, 2021; Kharrachi *et al.*, 2024). However, our results contradict those found by Diop (2024). The author found a low coefficient of determination R compared to the RandomForest model in estimating the unrealized potential yield.

This significant improvement in performance could be explained by the ability of the XGBoost algorithm to model nonlinear and complex relationships between spatial and temporal variables. The seasonal robustness of the model, reflected by R coefficients exceeding 0.95 for the three seasons studied, validates its applicability under contrasting agroclimatic conditions. This result demonstrates the model's ability to achieve high predictive performance despite significant seasonal variations characterizing Sahelian pastoral systems. However, the observed performance degradation during the hot dry season (HDS), with an MRSE reaching 746.86 m compared to only 243.21 m in the rainy season (RS), reveals the model's limitations in the face of extreme climatic conditions. The tendency to systematically underestimate extreme values, although moderate with average residuals not exceeding 140 m. This bias could be explained by the difficulty of capturing the full range of behavioral variance in training datasets. The model, although efficient, does not escape this structural limitation. All animals showed the most significant weight fluctuations during the rainy season (Bechir *et al.*, 2011), which aligns with our results. From a practical standpoint, the accuracy achieved opens concrete prospects for improving pastoral management systems.

The demonstrated robustness of the model justifies its adaptation to similar agroecological contexts, with caution regarding its exclusive use for decision-making under extreme conditions.

CONCLUSION

This research was conducted within the framework of predicting animal movements in pastoral systems. The central issue was to determine the distances traveled by livestock using the XGBoost algorithm. The study convincingly demonstrated the ability of the XGBoost algorithm to predict the distances traveled. The model achieved an exceptional level of performance, reflected by a coefficient of determination (R) of 0.92 and a mean absolute error of only 245 meters. These results provide a positive answer to the research questions and confirm the hypothesis that ensemble methods are relevant for modeling complex animal behaviors.

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