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# Spatial distribution of the piscivorous predator *Varanus niloticus* for efficient management of fish farms in the Republic of Bénin

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**ABSTRACT**
*Objectives*: Aquaculture in Bénin suffers economic losses from the Nile monitor lizard, *Varanus niloticus*. This study aimed to map the spatial distribution of *V. niloticus* in Southern Bénin and identify the key environmental factors influencing its abundance to guide targeted control strategies.
*Methodology and Results*: Using field surveys across 39 communes and spatial statistics, the predator's distribution pattern was analysed. The relationship between abundance and environmental variables was modelled using linear regression. Results revealed a significant spatial cluster of high *V. niloticus* abundance in the southeastern part of Bénin. A single-variable model using mean temperature explained a high proportion of the variance in abundance ($R^2$ = 0.854). The prediction map shows a gradient of decreasing abundance from the warm southeast to the cooler northwest. Validation with reserved field data confirmed a strong correlation ($r = 0.88$) between predicted and observed values.
*Conclusions and application of findings:* This study conclusively identifies mean temperature as the primary driver of the Nile monitor lizard (*Varanus niloticus*) distribution in Southern Bénin's aquaculture zones. This finding enables the creation of a definitive Predator Risk Map, pinpointing the warmer southeastern region as a high-risk hotspot. These results provide a scientific basis for a paradigm shift in management, moving from uniform, often ineffective, control to a targeted and cost-efficient strategy. Resources for mitigation (e.g., fencing subsidies, technical support) can now be strategically prioritized for high-risk areas, maximizing impact. Farmers in these zones can be proactively advised to implement stronger protective measures. Meanwhile, new aquaculture development can be encouraged in lower-risk zones. This data-driven approach directly helps reduce economic losses, safeguards investments, and enhances the overall sustainability and profitability of Bénin's vital aquaculture sector by focusing efforts where they are most needed.
**Keywords:** Aquaculture, Pest Management, Spatial Ecology, Nile Monitor Lizard, West Africa.

## INTRODUCTION

Aquaculture is a vital source of protein, livelihoods, and economic development across Africa (*FAO, 2022*). In Bénin', the sector has experienced significant growth, yet its sustainability is persistently challenged by piscivorous predators, which cause direct stock losses and damage to pond infrastructure (*Otieno, 2019*). Among these predators, the Nile monitor lizard *Varanus niloticus* stands out due to its size, intelligence, and adaptability (*Bennett, 2019*). This large reptile is a formidable predator, capable of decimating fish stocks and undermining the economic viability of farms (Adelakun *et al., 2016*). Despite its notoriety among farmers, a critical knowledge gap exists: a comprehensive, scientific understanding of its spatial distribution and the environmental drivers that influence its presence is lacking (*Kose, 2025*). Current predator control measures are often reactive, localized, and applied uniformly without a regional perspective on risk (Mcinturff *et al., 2020*). The rapid development of aquaculture in Southern Benin, the country's primary production zone, makes it imperative to move towards evidence-based, precision management (*Dagoudo et al., 2023*). The distribution of wildlife, including pests, is seldom random but is structured by a complex interplay of environmental factors (*Kotta et al., 2019*). For ectothermic predators like *V. niloticus*, climatic variables such as temperature are likely paramount, influencing metabolism, activity patterns, and reproductive success (Enriquez-Urzelai *et al., 2020*). Furthermore, landscape features and human activities can create ecological niches that either favour or deter their presence (*Biah et al., 2024*). Identifying these interactions is essential for anticipating zones with intense predator pressure. Thus, this research addresses the knowledge gap through geospatial and statistical modelling. The primary objectives were to: (1) map the spatial structure and identify potential aggregation hotspots of *Varanus niloticus* in Southern Benin, and (2) quantify the influence of key environmental variables, particularly temperature, on its distribution. The findings are expected to provide fish farmers, extension services, and policymakers with a scientific basis for targeted monitoring and efficient management of this piscivorous predator, thereby enhancing the resilience and productivity of Benin's aquaculture sector (*Pennells et al., 2025*).

## MATERIAL AND METHODS

***Study Area :*** The study was conducted in Southern Bénin (Figure 1, the country's primary aquaculture zone. Located in West Africa between 1°33'37" and 2°47'36" east longitude and 6°09'20" and 7°46'31" north latitude, the region covers 17,440.26 km². The climate is sub-equatorial, comprising a prolonged rainy season (April–October; >1,000 mm/year) and a distinct dry season from November to March. The area is characterized by a dense hydrographic network, including the Ouémé, Couffo, Mono, and Zou river basins , and is dominated by sedimentary plateaus, structural plains, and alluvial plains (Djihouessi and Aina, 2018).

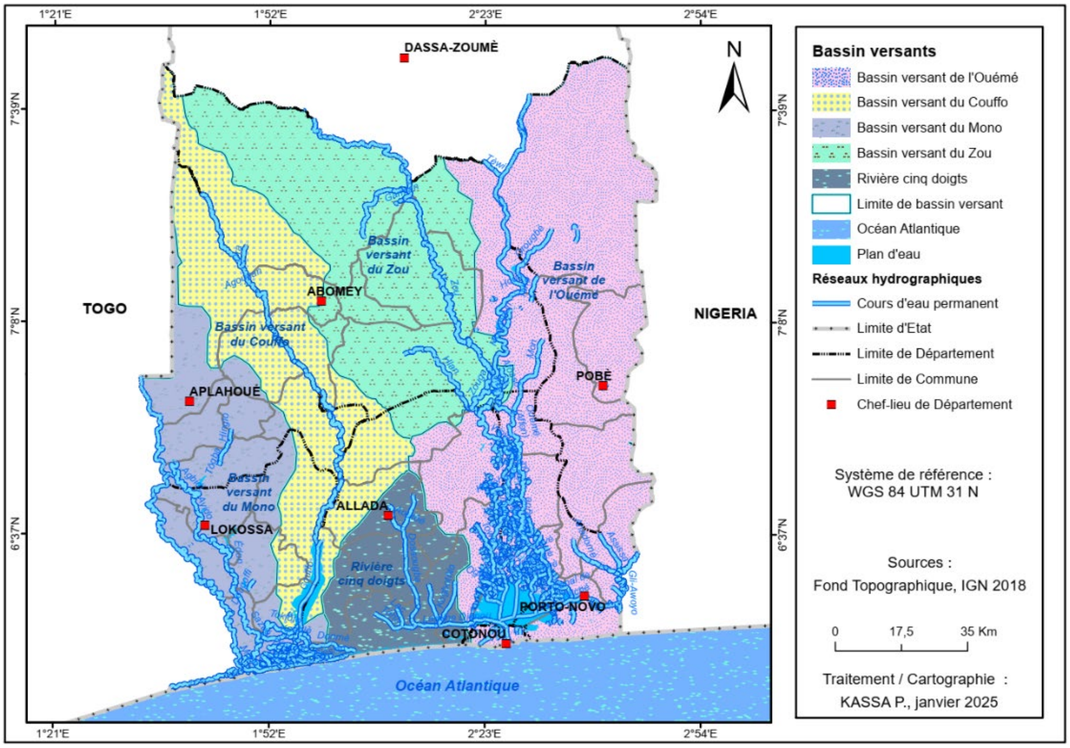


**Figure 1:** Map of the study

***Data Collection and Spatial Analysis:*** Data collection took place between April 2022 and April 2024. Field missions were carried out during each season, both during the day and at night, at various aquaculture sites to record predator activity. Since it was not feasible to cover all 748 aquaculture sites, a non-probabilistic sampling method based on purposive selection was employed according to specific criteria. These included: geographical accessibility for transporting staff and equipment, the presence of varied aquaculture infrastructure, a minimum distance of 2 km between selected sites to prevent recording the same predator species twice, and the consent of each site's owner. The study ultimately comprised 39 sampled sites. Descriptive, longitudinal, and prospective cross-sectional surveys were conducted. The presence and abundance of *Varanus niloticus* were surveyed across 39 communes. Spatial analysis was performed using ArcGIS 10.4 to understand the distribution structure. Key spatial indices were calculated, including the centroid, mean centre, and standard deviational ellipse. Global spatial autocorrelation was assessed using Moran's I index, while local clusters of high and low abundance were identified using the Getis-Ord Gi* statistic.

***Environmental Variables and Modelling:*** Several environmental variables were considered, including temperature, precipitation, humidity, visibility, atmospheric pressure, wind speed, and NDVI (Normalized Difference Vegetation Index). Data for these variables were interpolated across the study area from meteorological station records using various methods (Kriging, IDW), with the method yielding the lowest prediction error selected for each variable. The association between *V. niloticus* abundance and environmental factors was investigated using linear regression. Initially, the data structure was examined using Principal Component Analysis (PCA). Among the tested models, the one showing the highest adjusted $R^2$ value was chosen as the best fit. The resulting model was evaluated for normality of residuals and homogeneity of variances (Breusch-Pagan test). The validated model was then applied spatially to create a prediction map of *V. niloticus* distribution. Model accuracy was further tested by comparing predicted values with 15 randomly selected, reserved field observation points.

## RESULTS

**Spatial organization of *Varanus niloticus* distribution:** The spatial distribution of *V. niloticus* (Figure 2) showed a mean canter shifted 8.148 km southeast of the geographic centroid, indicating a concentration in the southeastern part of the study area. The standard deviational ellipse had axes of 39.62 km and 45.15 km with a rotation angle of 87.20°, covering 23 of the 39 communes (76.56% of frequencies). The evaluation of Moran's autocorrelation index gives the following results: Moran's Index = 0.041; Expected Index = -0.03; Variance = 0.007835; Z-Score = 0.77. Since Moran's I is approximately 0, there is no significant spatial autocorrelation in the regionalized random variable. Consequently, Varanus niloticus abundance at one location cannot be predicted from the values observed at another location based on the distance between them. This apparent independence could have occurred by chance, so it is important to confirm whether spatial independence holds throughout the study area. The statistical test for independence of the regionalized variable yielded the following results: Observed General G = 0.000012; Expected General G = 0.000009; Variance of General G = 0.000000. According to a Z-Score equal to 2.43 at a 0.001 significance level, this test qualifies the interpretation of Moran's autocorrelation index and indicates the existence of clusters in which autocorrelation is expressed at the local scale.

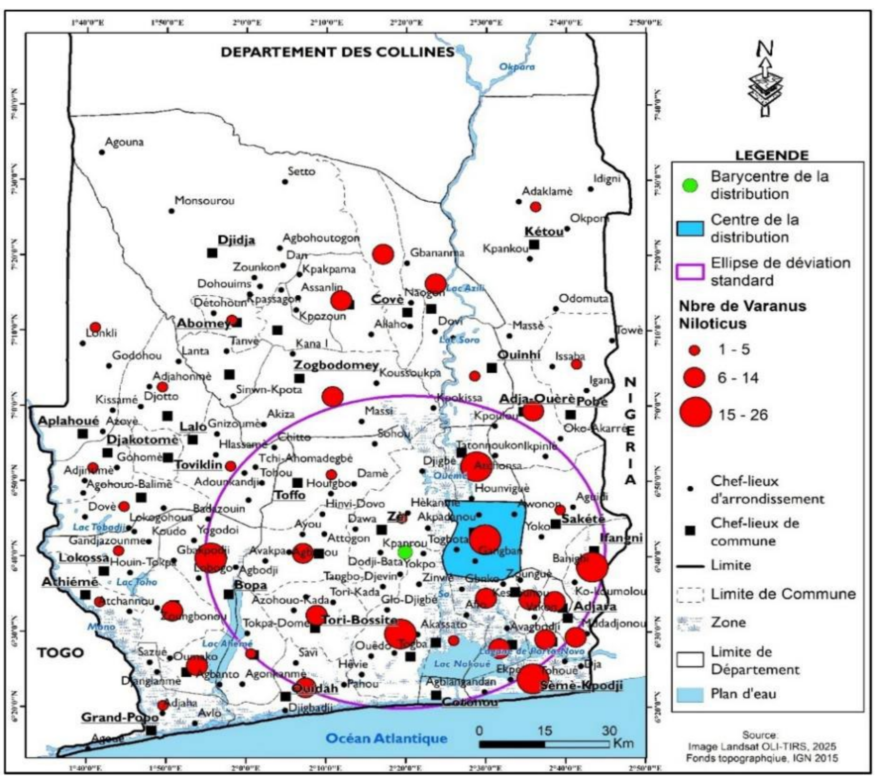


**Figure 2:** Spatial distribution of *Varanus niloticus*

**Analysis of local spatial configurations:** The analysis of the spatial structure of predators (Figure 3) showed that, despite the overall spatial independence, spatial clusters were present, indicating the existence of spatial autocorrelation at the local level. Hence, it is important to locate these clusters and examine the factors driving the aggregation of similar values at specific sites. For this purpose, the analysis of local spatial configuration was carried out by calculating the Getis-Ord Gi* index. The results of the evaluation of the Getis-Ord Gi* index provide the following statistics for the 39 communes: minimum: -2.36; maximum: 2.79; 3.43; mean: 0.37; standard deviation: 1.36; and cumulative value: 14.33. The classification of the Gi* Z-score into three classes using Jenks' natural breaks method and the spatial mapping of the results highlight three major spatial groups (Figure 3). In the north, low Gi* Z-score values are concentrated, corresponding to a zone of low concentration of *Varanus niloticus*. In the southwest of the study area, average Gi* Z-score values are concentrated, while in the southeast, high Gi* Z-score values are concentrated. The southeast is therefore an area of high concentration of *Varanus niloticus*. The hypothesis of a structured pattern in the spatial distribution of *Varanus niloticus* is thus confirmed. The frequencies and clusters exhibit a clear spatial orientation, indicating that the observed distribution is unlikely to be random.

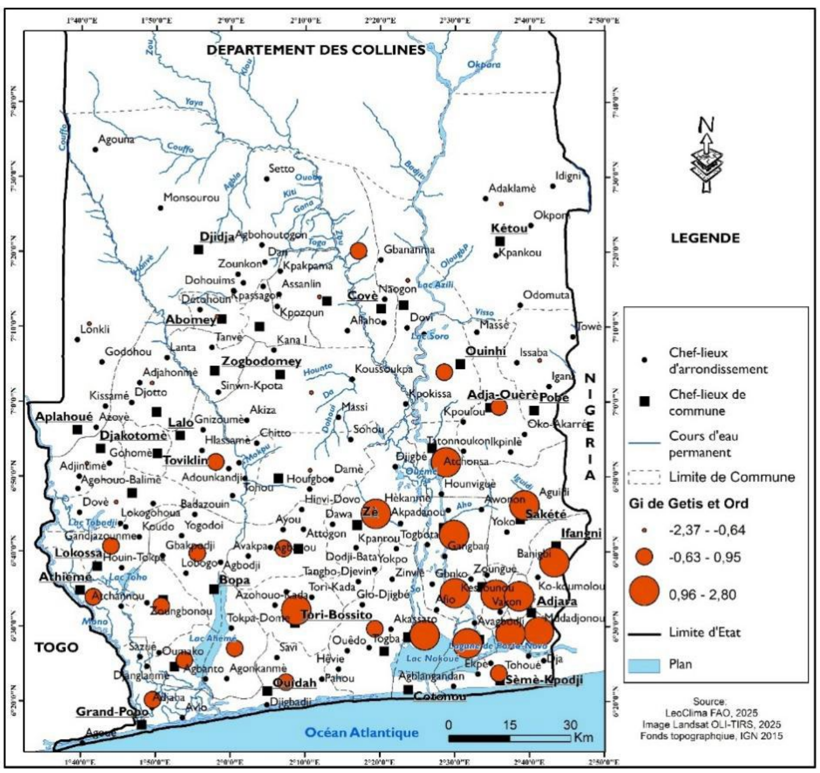


**Figure 3 :** Spatial configuration of *Varanus niloticus according to index Getis and Ord*

**Environmental determinants of *Varanus niloticus* spatial patterns*:***The regression models of the spatial distribution of *Varanus niloticus* reveal that the coefficient of determination indicates that 84.7% of the variance in *Varanus niloticus* is explained by average temperature (Table 1).

**Table 1:** Value of the Coefficient of Determination for the Best Model of *Varanus niloticus*

| Model | Number of Variables in the Model | Name of Variables | $R^2$ | Adjusted $R^2$ |
|---|---|---|---|---|
| 1 | 5 | Visibility; Humidity; Temperature; Number; Rainfall; PV | 0.367 | 0.307 |
| 2 | 1 | Temperature | 0.854 | 0.847 |

The p-value from the Fisher test was below 0.0001. Therefore, the chance of error is under 0.1%, demonstrating that the explanatory variable meaningfully explains the variance in *Varanus niloticus* (Table 2).

**Table 2:** Results of the Fisher Test for the Best Model of *Varanus niloticus*

| Source | DF | Sum of Squares | Mean Squares | F | Pr > F |
|---|---|---|---|---|---|
| Model | 1.000 | 772.131 | 772.131 | 128.817 | <0.0001 |
| Error | 22.000 | 131.869 | 5.994 | | |
| Corrected Total | 23.000 | 904.000 | | | |

Based on the Type III Sum of Squares, only the average temperature variable provides significant information to explain the variability of the dependent variable *Varanus niloticus* (Table 3).

**Table 3:** Distribution parameters of *Varanus niloticus* in relation to environmental variables

| Source | Value | Standard Error | t | Pr > \|t\| |
|---|---|---|---|---|
| Constant | -1543.110 | 136.578 | -11.298 | <0.0001 |
| Temperature | 56.763 | 5.001 | 11.350 | <0.0001 |

The equation is expressed as: *Varanus niloticus* = -1543.109 + 56.76 × Temperature

**Model Evaluation and Cartographic Representation of the Equations:** The evaluation of regression models helps to assess how well the model fits real-world conditions. This evaluation was carried out in two ways: residual analysis and comparison of the theoretical model results with empirical data. For residual analysis and equation formulation, a linear model is statistically valid only if the residuals are normally distributed. The confidence level retained for this validity is 95%. For *Varanus niloticus*, the probability linked to the normality test of the residuals is higher than the critical threshold of 5% (W = 0.731; p-value = 0.731; Figure 4), which means that the residuals are normally distributed. In conclusion, the model is validated.

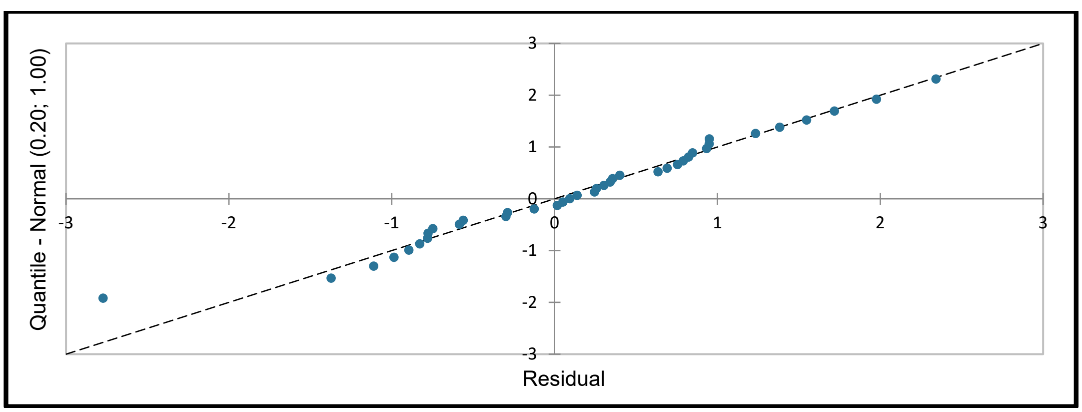


**Figure 4**: Q-Q Plot of the Residual Fit for *Varanus niloticus*

**Forecasting the spatial distribution of *Varanus niloticus:*** The analysis of the prediction map of *Varanus niloticus* (Figure 5) shows a decrease in the species from the southeast to the northwest. This pattern closely resembles that observed for temperature. It thus appears that the northwest is not favourable for the proliferation of *Varanus niloticus*, since the model predicts relatively low abundances there. Conversely, the south and east of Bénin present the best ecological conditions for the species' proliferation.

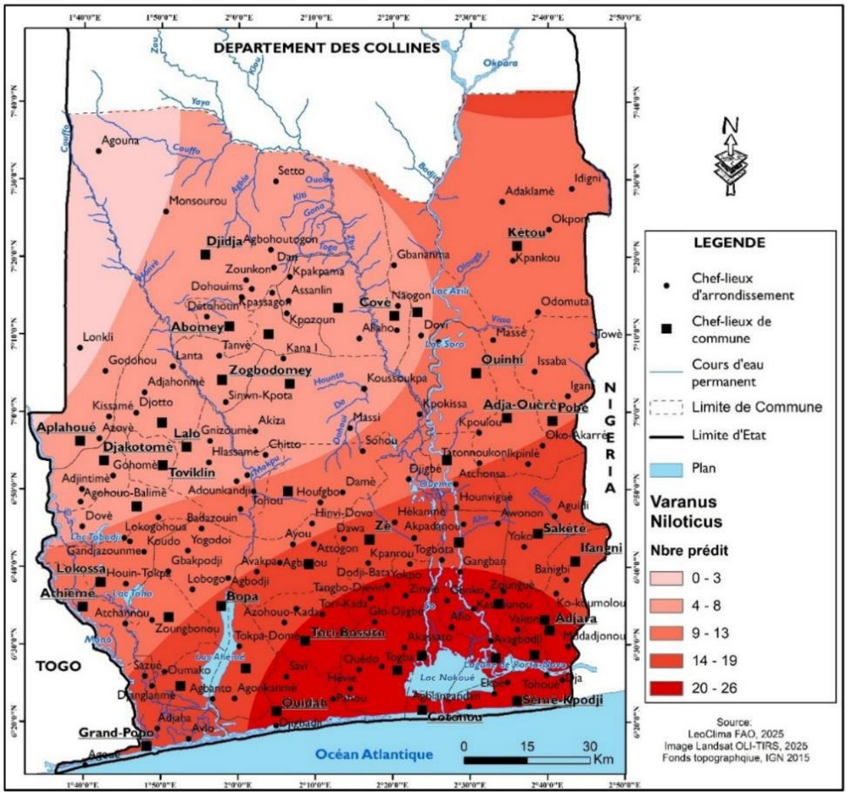

**Figure 5:** Predicted Spatial Distribution of *Varanus niloticus*

The predicted data were compared with field data. Fifteen (15) points were randomly selected out of the 39 points in the sample. These 15 points (38.5% of the sample) were used to compare the models with empirical data. For *Varanus niloticus*, the correlation coefficient between the observed distribution and the predicted distribution is 0.88, indicating a strong positive correlation. This means that the predicted values are consistent with the field data (Figure 6).

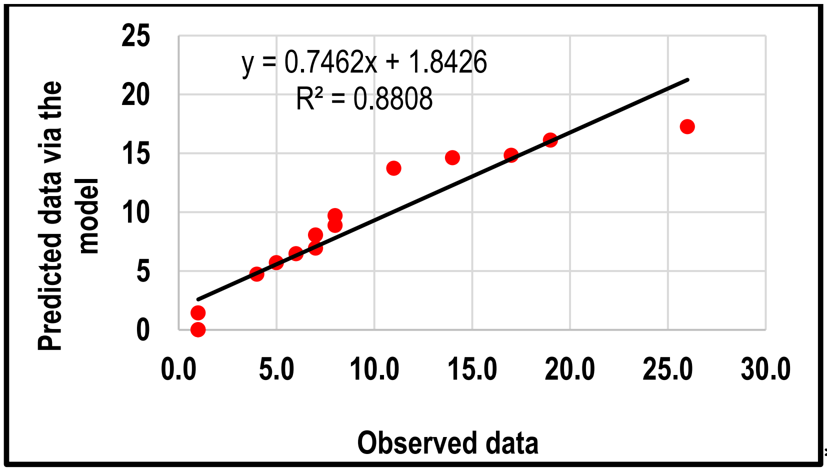


**Figure 6:** Relationship Between Predicted and Observed *Varanus niloticus* Field Values

## DISCUSSION

The findings of this study provide a clear and actionable insight into the ecology of a major aquaculture pest in Southern Bénin. The spatial analysis conclusively demonstrates that the distribution of *Varanus niloticus* is highly structured, with a significant hotspot identified in the southeastern part of the country. This non-random pattern is crucial for moving beyond generic control measures towards a targeted, risk-based approach to predator management, a strategy increasingly advocated in integrated pest management (*Zhou et al., 2024*). The most significant finding is the overwhelming influence of mean temperature on the predator's abundance, explaining 84.7% of the spatial variance. This strong correlation is ecologically sound. As ectotherms, monitor lizards rely on external environmental temperatures to regulate their body metabolism and activity levels (*Taylor et al., 2020*). Warmer temperatures in the southeastern region likely enhance their physiological processes, including digestion, growth, and overall activity, allowing for higher foraging rates and reproductive success (*Butler, 2019*). This result aligns with the known biology of varanids and supports findings from other regions where temperature is a key range-limiting factor for reptiles (*Biber et al., 2023*). The generated prediction map, which shows a gradient of abundance declining towards the cooler northwest, serves as a direct risk map for fish farmers and is a powerful tool for spatial planning (*Lazagabaster et al., 2024*). The initial result from Moran's I, suggesting spatial randomness, highlights a critical point in ecological studies: global indices can mask important local patterns (*Bavaud, 2024*). The subsequent Getis-Ord Gi* analysis was essential for uncovering the significant local aggregation in the southeast. This underscores the importance of using multiple spatial statistics to obtain a complete picture of species distribution, a practice now standard in landscape ecology (*Taylor et al., 2022*). For the aquaculture industry in Bénin, these results have immediate practical implications. Farmers in the high-risk southeastern zone should be prioritized for support and training in proven predator mitigation strategies, such as reinforcing pond dikes and installing protective fencing (Mcinturff *et al., 2020*). In lower-risk areas, resources can be allocated more efficiently. Furthermore, in the context of climate change, rising temperatures could potentially expand the suitable habitat for *V. niloticus*, making this study a critical baseline for future monitoring and adaptation planning (Dossa *et al.*, 2025). While temperature was the dominant factor, future research should investigate other potential influences not captured in this model, such as the abundance of alternative prey, direct human persecution rates, and specific pond management practices (e.g., feed types, stocking densities) that might attract or deter predators (*Otieno, 2019; Adelakun et al., 2016*). Nevertheless, by identifying temperature as the primary driver and mapping its effect, this study provides a powerful and validated tool for the efficient and sustainable management of *Varanus niloticus* in Beninese fish farms.

## CONCLUSION AND APPLICATION OF RESULTS

This study successfully demonstrates that the distribution of the piscivorous predator *Varanus niloticus* in Southern Bénin is spatially structured, with a significant hotspot in the southeastern region. This study established that mean air temperature is the paramount environmental driver, accounting for over 84% of the observed spatial variation in its abundance. The robust predictive model generated a reliable risk map that delineates zones of high, medium, and low predator pressure. These findings provide a scientific foundation for transforming predator management from a blanket approach to a precision-based strategy. From this study, it recommends that aquaculture development programs and extension services use these risk maps to prioritize interventions and allocate resources effectively, focusing intensive mitigation efforts on the high-temperature, high-risk southeastern zones. This targeted approach will ultimately reduce economic losses, enhance the profitability of fish farms, and contribute to the sustainable growth of the aquaculture sector in Bénin.

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