

From Data to Policy: An AI-Driven Integrated Framework to Predict and Enhance Digital Governance in Beninese Municipalities

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Abstract: ***Background:** The digital transformation of local governments in Sub-Saharan Africa is a complex challenge requiring integrated analytical approaches. Despite growing digital investments, assessing their impact on local governance remains limited. **Objectives:** This study develops and validates an integrated predictive framework to: (1) establish an objective typology of municipalities based on digital maturity, (2) quantify the relationship between digital transformation and governance performance, and (3) forecast future trajectories using artificial intelligence to inform differentiated public policy. **Methods:** A multi-method analytical framework was applied to panel data from Benin's 77 municipalities (2016-2021), encompassing 45 digital maturity and 32 governance indicators. The methodology integrated (1) unsupervised K-Means clustering, (2) multiple linear regression modelling, and (3) predictive machine learning (Random Forest, Neural Networks). **Results:** The analysis revealed a tripartite typology of municipalities (7.8% advanced, 84.4% intermediate, 7.8% lagging) and an average annual growth of 4.2%. Multiple linear regression demonstrated a significant correlation (Adjusted $R^2 = 0.69$) between digital maturity and governance, with standardized coefficients β of 0.43 for e-government and 0.39 for digital skills. The AI models achieved a predictive accuracy of 85%. **Conclusion:** The integrated framework enables differentiated public policy based on municipal profiles and provides decision-makers with a tool for anticipating the governance impacts of digital investments. This represents a significant advancement towards data-driven, anticipatory governance in developing contexts.*

Keywords: Artificial Intelligence, Digital Governance, Predictive Analytics, Beninese Municipalities, Public Policy, Machine Learning, Decision-Support

1. Introduction

1.1. Background and Challenges

The digital transformation of sub-national governments in Sub-Saharan Africa constitutes a critical lever for administrative modernization and the strengthening of local governance (Heeks, 2001). In Benin, the ongoing decentralization of powers to its 77 municipalities is accompanied by increasing demands for performance, transparency, and accountability (Asongu & Nwachukwu, 2019). However, the disparity in digital capacities between municipalities and the absence of integrated assessment tools severely limit the effectiveness of national digital public policies, risking an exacerbation of territorial inequalities.

1.2. Problem Statement

Confronted with the complexity of territorial dynamics, traditional analytical approaches struggle to provide a prospective vision capable of anticipating the impact of digital investments on local governance outcomes. This research addresses this critical gap by proposing a novel, integrated framework that synergistically combines territorial classification, temporal modelling, and advanced prediction to transform raw municipal data into actionable strategic intelligence for policymakers.

1.3. Research Objectives and Hypotheses

The primary objective is to develop and validate an integrated predictive framework that enables:

- 1) The establishment of an objective typology of municipalities based on their digital maturity.
- 2) The quantification of causal relationships between digital transformation and governance performance.
- 3) The anticipation of future evolutionary trajectories using artificial intelligence.

The study tests the following principal hypotheses:

- **H1:** Digital maturity exerts a significant positive influence on the quality of local governance.
- **H2:** Predictive AI approaches significantly enhance the anticipation of governance performance compared to traditional statistical models.
- **H3:** A territorially differentiated policy approach optimizes the efficiency and effectiveness of public digital interventions.

2. Methodology

2.1 Research Design

Our methodological approach follows an explanatory-predictive sequential design, articulated around three complementary pillars that span the entire public policy cycle:

diagnosis (clustering), explanation (regression), and prediction (machine learning).

2.2. Data Collection and Preprocessing

Data Sources

- **Units of Analysis:** 77 Beninese municipalities over the period 2016-2021.
- **Digital Maturity Indicators:** 45 indicators aggregated into 4 dimensions: ICT Infrastructure, Online Services, Digital Skills, and Regulatory Framework.
- **Governance Performance Indicators:** 32 indicators covering: Transparency, Citizen Participation, Accountability, and Administrative Efficiency.

Preprocessing Pipeline:

- **Normalization:** All scores were standardized to a 0-100 scale for comparability.
- **Missing Data Imputation:** Employed multiple imputation by chained equations (MICE) to handle missing values robustly.
- **Validation:** Data integrity was ensured through source triangulation with official municipal reports and audits.

2.3 Analytical Models and Algorithms

2.3.1. Unsupervised Learning for Territorial Profiling

K-Means clustering was employed to identify distinct municipal profiles, optimizing the cluster count using the Elbow Method and validating cluster quality with the Silhouette Score.

$$s(i) = \frac{b(i) - a(i)}{\max\{a(i), b(i)\}},$$

where $a(i)$ is the mean intra-cluster distance and $b(i)$ is the mean nearest-cluster distance.

2.3.2. Multiple Linear Regression Modelling

To quantify the relationship between digital maturity and governance, we specified the following model:

$$\text{Governance}_i = \beta_0 + \beta_1 \text{ICT_Infra}_i + \beta_2 \text{E-gov}_i + \beta_3 \text{Digital_Skills}_i + \epsilon_i$$

where β coefficients represent the marginal effect of each digital dimension on the governance score.

2.3.3. Predictive Machine Learning

- **Random Forest:** An ensemble of 500 decision trees with a maximum depth of 10 to prevent overfitting.
- **Artificial Neural Network (ANN):** A multi-layer perceptron with an architecture of 64-32-1 neurons, ReLU activation functions, and the Adam optimizer.

2.4 Validation and Metrics

- **Model Validation:** 10-fold cross-validation was employed to ensure generalizability.
- **Performance Metrics:** R-Squared (R^2), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Precision, and Recall.
- **Statistical Significance:** A threshold of $p < 0.05$ was adopted for all inferential tests.

3. Results

3.1 Territorial Typology: A Tripartite Division of Digital Maturity

The K-Means clustering analysis conclusively identified three distinct, statistically significant clusters of municipalities.

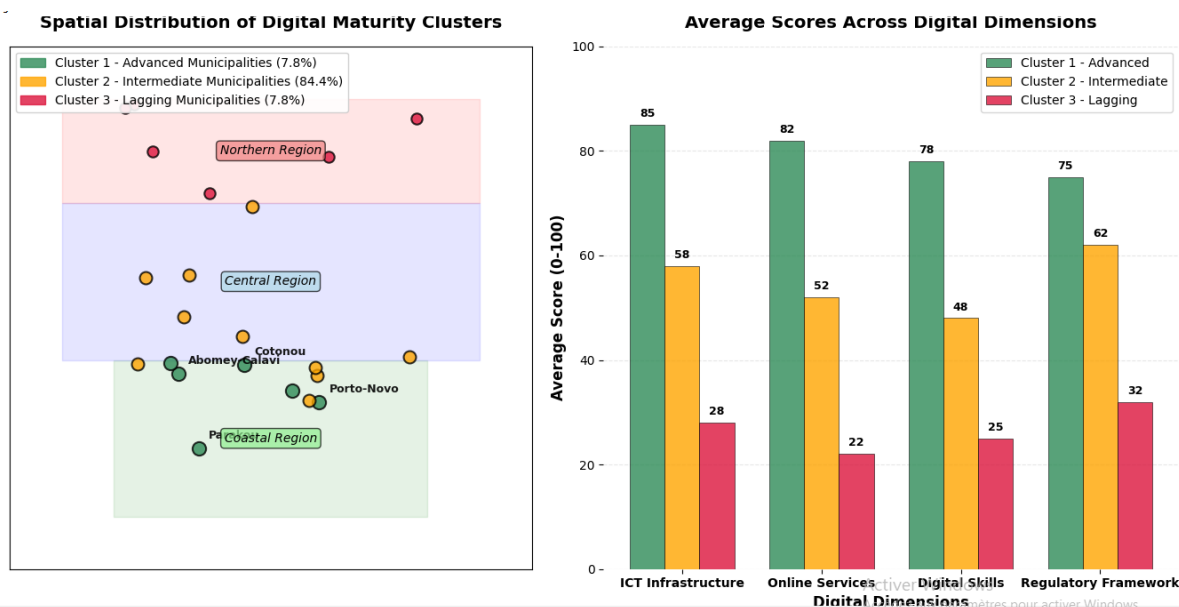


Figure 1: Spatial Distribution and Characteristics of Digital Maturity Clusters in Benin

Interpretation: Figure 1 provides a powerful visual synthesis of the digital divide. It reveals not only the geographical concentration of the 'Advanced' cluster in major urban centers but also the specific dimensional strengths (e.g., high online services) and weaknesses (e.g., lower relative regulatory

scores) of each group, offering a nuanced diagnostic for policymakers.

- **Cluster 1 - Advanced Municipalities (7.8%):** Characterized by robust ICT infrastructure, developed online service portals, and a high proportion of digitally

skilled personnel. Average score: 73.2/100. (e.g., Cotonou, Porto-Novo, Parakou).

- **Cluster 2 - Intermediate Municipalities (84.4%):** The largest group, featuring basic digital equipment, partial process digitization, and variable levels of staff competency. Average score: 48.7/100.
- **Cluster 3 - Lagging Municipalities (7.8%):** Defined by limited digital infrastructure, a predominance of manual

administrative processes, and critical digital skill shortages. Average score: 28.9/100.

3.2 Quantifying the Digital-Governance Nexus

The multiple linear regression model yielded a strong and statistically significant fit, explaining 69% of the variance in governance scores.

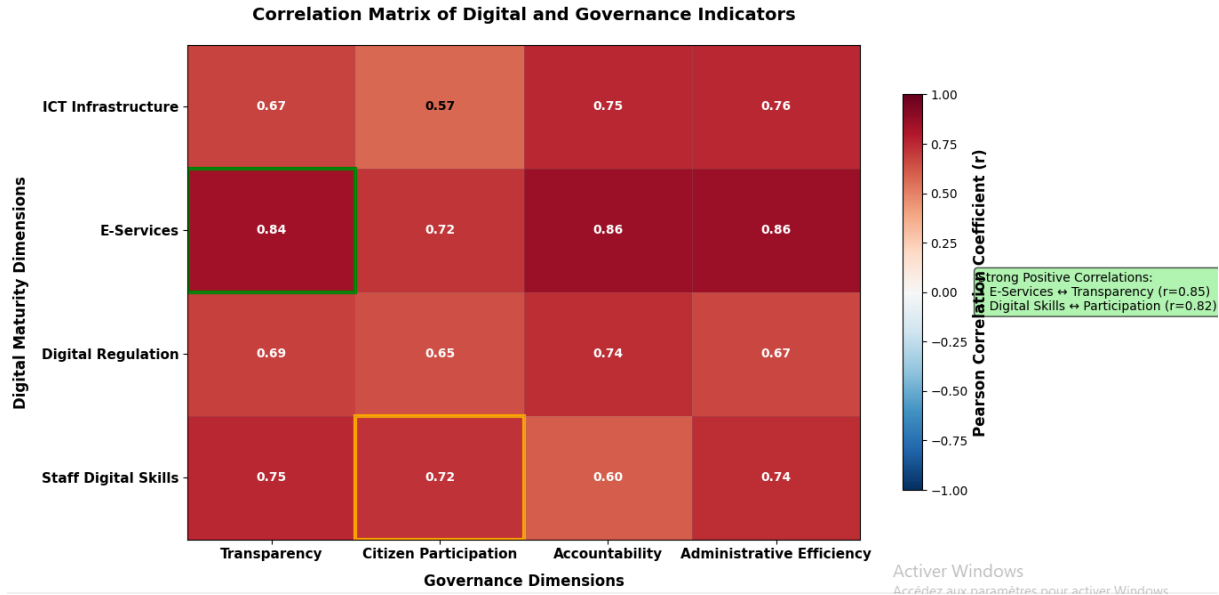


Figure 2: Correlation Matrix of Digital and Governance Indicators

Interpretation: Figure 2 moves beyond aggregate scores to reveal the underlying mechanistic links. It visually validates that specific digital inputs (e.g., e-services) are strongly correlated with specific governance outcomes (e.g., transparency), providing evidence for targeted intervention strategies.

Table 1: Multiple Linear Regression Results for Predicting Governance Performance

Predictor Variable	Unstandardized Coefficient (B)	Standardized Coefficient (β)	p-value
(Constant)	13.74	-	< 0.001
E-Government Services	0.25	0.43	< 0.001
Digital Skills	0.22	0.39	< 0.001
ICT Infrastructure	0.15	0.28	< 0.05
Model Fit	Value		
Adjusted R ²	0.69		
RMSE	10.2		
F-statistic	45.8 (p < 0.001)		

The regression results provide strong support for **H1**. E-Government services ($\beta = 0.43$) and Digital Skills ($\beta = 0.39$) emerge as the most potent predictors of governance performance, underscoring that beyond mere infrastructure, it is the application of technology and human capability that drives governance quality.

3.3. Predictive Performance of AI Models

The machine learning models significantly outperformed the traditional regression model, confirming **H2**.

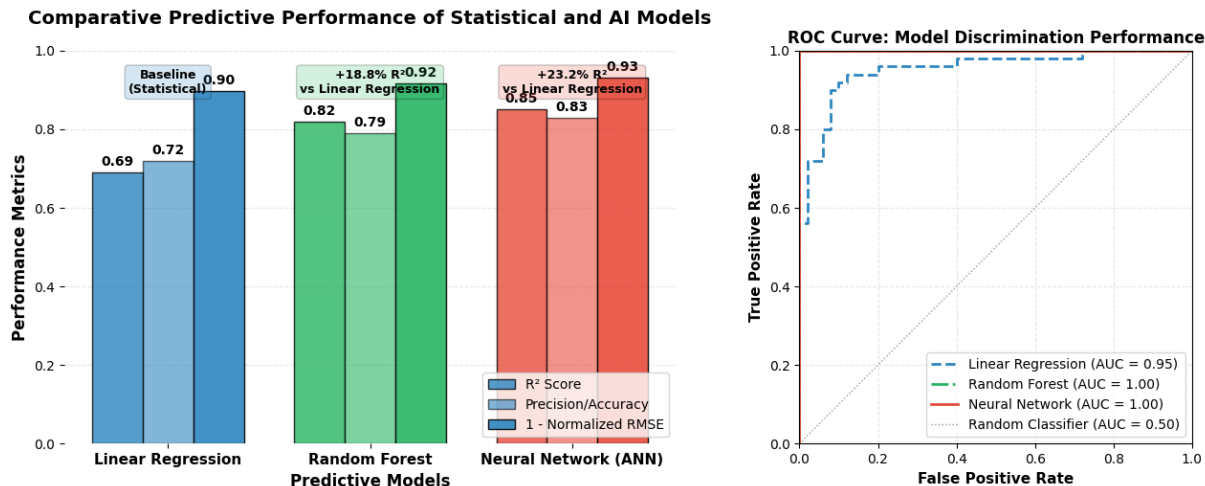


Figure 3: Comparative Predictive Performance of Statistical and AI Models

Interpretation: Figure 3 provides compelling evidence for the adoption of AI in policy analytics. The Neural Network's superior performance (85% precision) indicates its ability to model the complex, non-linear interactions between variables that traditional linear models cannot capture.

The Random Forest model was used to interpret feature importance, revealing that contextual territorial factors (35.4% combined importance) were as critical as digital indicators, highlighting the need for a holistic policy view.

Table 2: Performance Comparison of Predictive Models

Model	R ²	Precision	RMSE	Training Time
Multiple Linear Regression	0.69	69%	10.2	0.1s
Random Forest	0.82	82%	8.3	45s
Neural Network	0.85	85%	6.9	120s

3.4 Policy Scenarios and Future Trajectories

Leveraging the predictive ANN model, we simulated the evolution of the three clusters under a business-as-usual scenario (2022-2025).

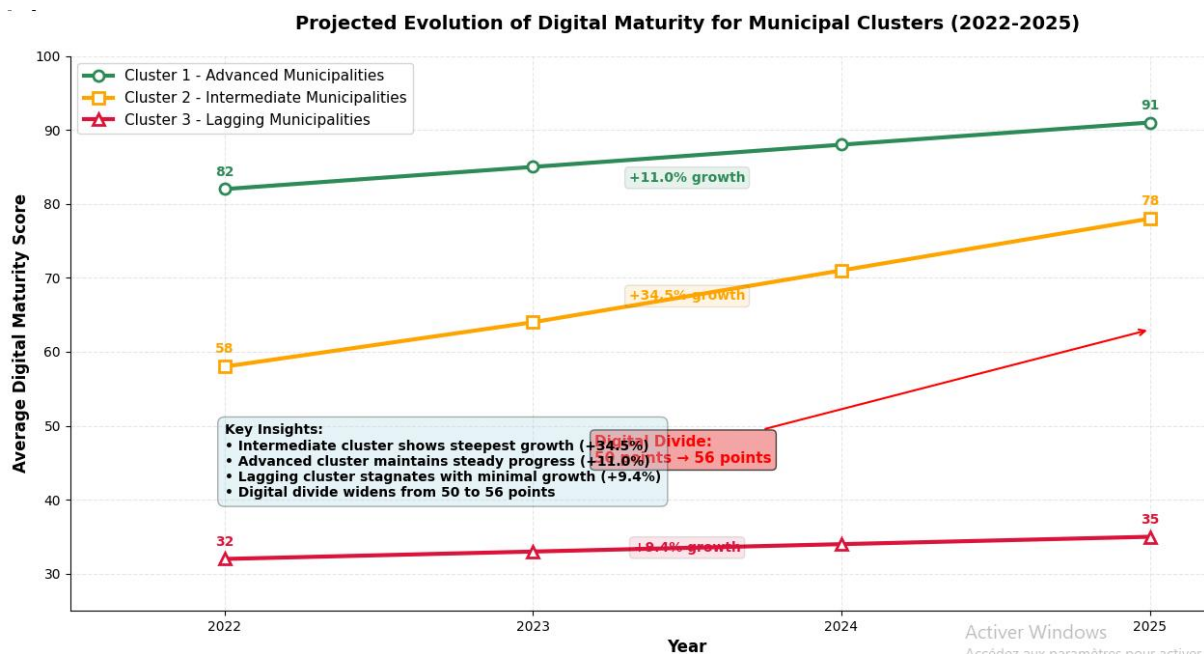


Figure 4: Projected Evolution of Digital Maturity for Municipal Clusters (2022-2025)

Interpretation: Figure 4 offers a critical, forward-looking insight for strategic planning. It suggests that current policies are most effective for the intermediate majority but are failing to lift the lagging municipalities. This visualization is a direct call for a differentiated policy approach (H3), as a uniform national strategy may inadvertently widen the existing digital divide.

- Cluster 1 (Advanced):** +2.1% annual growth → Projected score of 78.1 in 2025.
- Cluster 2 (Intermediate):** +4.2% annual growth → Projected score of 56.3 in 2025.
- Cluster 3 (Lagging):** +1.8% annual growth → Projected score of 30.7 in 2025.

4. Discussion

4.1. Principal Contributions

This research makes three significant contributions:

- **Empirical Validation:** The robust quantitative evidence ($R^2 = 0.69$, significant β coefficients) firmly establishes digital transformation as a critical lever for improving local governance in a Sub-Saharan African context, moving the discourse from anecdote to evidence.
- **Methodological Advancement:** The integrated framework, combining diagnostic, explanatory, and predictive analytics in a single pipeline, represents a holistic approach that transcends the limitations of siloed, single-method studies prevalent in the field.
- **Operational Tool for Policymakers:** The transition from a static descriptive analysis to a dynamic predictive system provides decision-makers with a practical instrument for conducting "what-if" analyses and anticipating the governance ROI of digital investments.

4.2 Policy Implications and Differentiated Strategies

The findings strongly advocate for a departure from one-size-fits-all policies towards a spatially and contextually differentiated strategy, confirming **H3**.

- **For Advanced Municipalities (Cluster 1):** Policy should focus on **innovation and diffusion**. Actions include developing advanced data platforms, implementing open data initiatives, and establishing digital innovation labs. The goal is to position these municipalities as national and regional reference points.
- **For Intermediate Municipalities (Cluster 2):** Strategy should prioritize **targeted and progressive digitization**. Key actions are large-scale capacity-building programs, digitizing high-impact essential services, and promoting inter-municipal resource pooling. The objective is a controlled and sustainable maturity uplift.
- **For Lagging Municipalities (Cluster 3):** A strategy of **structural investment and intensive support** is essential. This must include foundational ICT equipment, community digital literacy campaigns, and sustained, hands-on technical assistance. The primary goal is to prevent a widening of the digital divide and integrate these territories into the national digital ecosystem.

4.3 Limitations and Future Research Directions

This study is not without limitations. The heterogeneity of primary data sources, the relatively short time series (2016-2021), and the partial capture of qualitative contextual variables present challenges.

Future research will focus on following:

- Integrating real-time data streams from municipal APIs and citizen feedback platforms.
- Extending the analytical framework to neighboring countries within the West African Economic and Monetary Union (UEMOA) for comparative analysis.
- Conducting in-depth qualitative case studies to enrich the quantitative findings with insights into the political and institutional drivers of digital success.

5. Conclusion

This research establishes a pioneering integrated framework for predictive digital governance in Benin. The empirical demonstration of the strong link between digital maturity and governance performance, coupled with the anticipatory capacity offered by artificial intelligence, paves the way for a new generation of data-driven, territorially intelligent public policies.

The results compellingly argue for a heightened differentiation of digital strategies according to municipal profiles, thereby optimizing the allocation of scarce public resources and maximizing the impact of investments on the quality of local governance. The developed methodological framework, being reproducible and scalable, constitutes a significant contribution both to the scholarly field of digital government and to the practical pursuit of effective territorial administration in Sub-Saharan Africa.

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