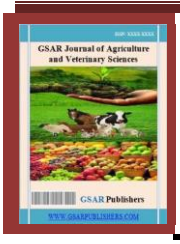

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Infrastructure Accessibility, Extension Intensity and Technical Efficiency of Small-Scale Aquaculture Farmers in Lagos State, Nigeria: An Exploratory Spatially Informed Assessment

By

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Abstract

This study develops a spatially informed extension of an existing farm-level analysis of agricultural extension intensity and technical efficiency among small-scale fish farmers in Lagos State, Nigeria. The underlying survey covered 270 farmers in Ikorodu, Epe, and Badagry and measured extension intensity through visits, training participation, demonstrations, and advisory consultations. Existing stochastic-frontier results show that extension intensity significantly increases frontier output (coefficient = 0.228, $p < 0.01$), while mean technical efficiency is 0.832, implying an average efficiency gap of 16.8%. To introduce an infrastructure dimension, the study constructs a provisional local-government-area accessibility profile using road distance to Lagos and population density. The normalized composite accessibility score is highest for Ikorodu (1.000), followed by Badagry (0.335) and Epe (0.000), indicating substantial differences in the market-connectivity environment surrounding the three aquaculture clusters. These spatial differences provide a plausible contextual mechanism through which extension knowledge, input access and market participation may translate into farm performance. However, because the available manuscript package does not contain respondent-level ESII and technical-efficiency records for re-estimation, the infrastructure-extension interaction is not estimated in this exploratory paper. The findings, therefore, establish a transparent empirical basis and a testable cross-level model for a subsequent merged micro-spatial analysis. The study argues that aquaculture policy should treat extension delivery and physical connectivity as potentially complementary investments rather than independent interventions.

Keywords: *aquaculture; extension intensity; technical efficiency; infrastructure accessibility; market access; stochastic frontier; Lagos State*

1. INTRODUCTION

Aquaculture has become central to the growth of aquatic food systems and to strategies for improving food and nutrition security. FAO's sustainable aquaculture framework emphasizes productive, efficient, resilient, and socially responsible aquaculture systems, while the wider Blue Transformation agenda places innovation, institutional capacity, and improved production systems at the center of sector development (FAO, 2024, 2025). In Nigeria, this agenda is particularly relevant because the country combines a large fish market with persistent domestic supply constraints and a production structure dominated by small and medium-scale enterprises.

Improving farm performance requires more than the availability of physical inputs. Fish production is knowledge-intensive: feeding regimes, stocking density, water quality, disease control, harvesting, and record keeping all depend on timely managerial decisions. Agricultural extension can therefore influence productivity by reducing information gaps, accelerating the adoption of improved practices, and helping farmers allocate inputs more efficiently. The Lagos survey on which this paper builds found that extension-service intensity,

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measured beyond simple access, is positively associated with fish output and lower technical inefficiency.

Yet knowledge does not operate in a spatial vacuum. Roads, travel time, settlement concentration and market connectivity shape the cost of reaching farmers, the frequency with which extension agents can visit, farmers' ability to attend training, and the speed with which improved advice can be translated into input purchases, production adjustments and market transactions. World Bank evidence from Nigeria's rural-access programmes shows that improved road connectivity can reduce travel costs, improve access to services and markets, and increase the movement and value of agricultural output (World Bank, 2024a, 2024b). This suggests that extension and infrastructure may be complementary rather than independent determinants of farm performance.

The present study develops that proposition for small-scale aquaculture in Lagos State. It combines previously estimated farm-level extension and efficiency results with a provisional LGA-level accessibility profile for Ikorodu, Epe and Badagry. The aim is not to claim a causal moderation effect from data that do not support one. Instead, the paper provides an exploratory, spatially informed assessment, identifies the heterogeneity in infrastructure surrounding the sampled aquaculture clusters, and specifies the cross-level interaction model to be estimated once respondent-level survey records are merged with validated geospatial indicators.

The paper contributes in three ways. First, it shifts the discussion of extension from access to intensity, using a multidimensional Extension Service Intensity Index (ESII). Second, it explicitly introduces infrastructure accessibility as a contextual factor in aquaculture-efficiency analysis. Third, it sets out a transparent empirical design for testing whether the productivity payoff to extension is larger in better-connected locations.

2. Literature Review and Conceptual Framework

2.1 Extension intensity and farm performance

Agricultural extension is an institutional mechanism for transferring knowledge, supporting technology adoption and strengthening farmers' managerial capacity. Anderson and Feder (2004) emphasize that the performance of extension systems depends not simply on formal coverage but on incentives, relevance, and the quality of interaction. Rogers' (2003) diffusion-of-innovation framework similarly implies that repeated exposure to information can reduce uncertainty and increase the probability that producers adopt improved practices. (Awolumate & Inyang, 2019a)

For aquaculture, intensity matters because production decisions are continuous rather than one-off. Regular visits, demonstrations, formal training, and advisory consultations can reinforce knowledge on feed management, pond conditions, disease control, and enterprise management. Nigerian evidence also points to the growing role of digital information channels. Komolafe et al. (2018) found that fish farmers in Lagos State used mobile phones to obtain information on feed, fingerlings, drugs, equipment, and harvesting, while Falola et al. (2024) reported welfare and production gains associated with digital agricultural innovation platforms among Nigerian catfish farmers. (Awolumate & Omosola, 2017)

2.2 Technical efficiency in aquaculture

Technical efficiency measures how close a producer operates to the maximum feasible output obtainable from a given set of inputs and technology. Following Farrell (1957), production-frontier methods distinguish efficient from inefficient production units. Stochastic frontier analysis extends this logic by separating random shocks from a non-negative inefficiency component (Aigner, Lovell, & Schmidt, 1977). Battese and Coelli (1995) further developed models in which inefficiency can be related directly to farm and farmer characteristics. (Awolumate & Inyang, 2019b)

This framework is appropriate for fish farming because biological and environmental uncertainty can generate output variation even where management is strong. A frontier model can therefore estimate the output gap attributable to inefficiency while controlling for random influences. Extension is expected to reduce the inefficiency component by improving technical knowledge and input-use decisions. (Awolumate & Inyang, 2019b)

2.3 Infrastructure accessibility as a complementary capability

Physical connectivity affects agricultural performance through market access, input access, transport costs, service delivery and information exchange. Classic rural-road research shows that improved connectivity can reduce the cost of reaching output markets and obtaining modern inputs (Jacoby, 1998). More recent World Bank evidence for Nigeria reports that rural-road interventions improved access to markets and services and increased the volume of agricultural produce transported (World Bank, 2024a). (Awolumate & Inyang, 2019c)

The complementarity argument is therefore straightforward: extension raises the quality of farm decisions, while infrastructure lowers the cost of implementing those decisions. Advice to change feed type has greater practical value when feed suppliers are reachable; training on disease management is more useful when veterinary or diagnostic services can be accessed; and extension support for marketing is more effective where farmers can move fish to buyers quickly. In this sense, infrastructure may amplify the marginal return to extension intensity. (Awolumate & Inyang, 2019c)

2.4 Conceptual model and hypotheses

The conceptual relationship is represented as: Infrastructure accessibility → lower transaction and service-access costs; Extension intensity → improved knowledge and management; and the interaction of both → stronger technical-efficiency and productivity outcomes.

- H1: Extension-service intensity is positively associated with technical efficiency among small-scale fish farmers.

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- H2: Better infrastructure accessibility is positively associated with technical efficiency.
- H3: Infrastructure accessibility positively moderates the relationship between extension-service intensity and technical efficiency.
- H4: The extension-efficiency relationship differs across the main aquaculture clusters of Ikorodu, Epe and Badagry.

3. Methodology

3.1 Study area and survey data

The underlying farm survey covered small-scale fish farmers in Ikorodu, Epe and Badagry, three important aquaculture-producing areas of Lagos State. A cross-sectional Google Forms survey produced 270 valid responses. The location distribution was 81 respondents in Ikorodu, 75 in Epe, 79 in Badagry and 35 respondents with no specified location. The unspecified observations remain usable for non-spatial analyses but cannot be linked credibly to LGA-level infrastructure variables.

The original study measured fish output, farm size, labour, feed cost, capital investment, socioeconomic characteristics and extension participation. The Extension Service Intensity Index combined four dimensions: extension visits, training participation, demonstration participation and advisory consultations. Mean component values were 4.7, 2.3, 1.8 and 2.6, respectively, producing a mean composite ESII of 11.4.

3.2 Infrastructure accessibility data

A master collection sheet was developed to introduce spatial context at LGA level. For this exploratory paper, a provisional accessibility proxy combines road distance to Lagos and population density. Road distance is treated as an inverse measure of market proximity, while population density captures the concentration of people, markets and services. The two measures were min-max normalized and averaged to form a 0–1 composite accessibility index, with larger values indicating greater accessibility.

This proxy is deliberately labelled provisional. It is not equivalent to GIS-derived travel time or complete road-network density. GRID3 currently provides Nigeria Roads v1.0 and a Travel Time Friction Surface v1.0 dated October 2025, and these are the preferred sources for replacing the proxy in the final confirmatory analysis. The present measure is used only to demonstrate spatial heterogeneity and establish the cross-level analytical design.

Table 1. Data structure and variable roles

Variable	Measurement	Level	Source	Model role
Technical efficiency	0–1 stochastic-frontier score	Farmer	2026 survey	Primary outcome
ESII	Visits + training + demonstrations + advisory consultations	Farmer	2026 survey	Main explanatory variable
Fish output	kg per production cycle	Farmer	2026 survey	Secondary outcome
Road proximity	Inverse-normalized road distance to Lagos	LGA	Master collection sheet	Accessibility component
Population density	Population / LGA area	LGA	Master collection sheet	Accessibility component/control
Composite accessibility	Mean of normalized road-proximity and population-density scores	LGA	Derived	Contextual infrastructure variable

3.3 Existing stochastic-frontier specification

The existing frontier model relates the logarithm of fish output to feed cost, farm size, labour, capital investment and extension intensity. The stochastic error is decomposed into a symmetric random component and a non-negative inefficiency component. Technical efficiency is computed as $TE_i = \exp(-u_i)$.

3.4 Proposed cross-level complementarity model

The confirmatory specification for the merged micro-spatial dataset is:

$$TE_i = \alpha + \beta_1 ESII_i + \beta_2 ACCESS_j + \beta_3 (ESII_i \times ACCESS_j) + \gamma' X_i + \varepsilon_i$$

where i indexes farmers and j indexes location. The coefficient β_3 is the parameter of primary interest: a positive coefficient would indicate that infrastructure accessibility strengthens the relationship between extension intensity and technical efficiency. A parallel output model would replace TE with log fish output and include standard production inputs.

3.5 Analytical limitation

The available project manuscript contains published summary statistics and model coefficients but not the respondent-level ESII, efficiency and input records required to re-estimate the interaction model. Accordingly, this paper does not fabricate a moderation coefficient. It reports the established farm-level

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extension and efficiency results, adds the LGA accessibility profile, and interprets the two evidence layers as exploratory rather than causal. A final submission testing H2–H4 requires the original respondent-level data file or an exported Google Forms/STATA dataset.

4. Results

4.1 Extension intensity and technical efficiency

The survey indicates moderate-to-high extension engagement. Farmers received an average of 4.7 extension visits per production cycle, attended 2.3 training activities, participated in 1.8 demonstrations and recorded 2.6 advisory consultations, giving a mean ESII of 11.4. These values support the argument that extension exposure in the sample was multidimensional rather than binary.

The stochastic-frontier estimates show positive and statistically significant coefficients for feed cost (0.437), farm size (0.274), labour (0.105), capital investment (0.157) and extension intensity (0.228). The extension coefficient is significant at the 1% level. The gamma parameter is 0.742, implying that a large share of residual output variation is associated with inefficiency rather than random noise.

Technical-efficiency scores range from 0.521 to 0.981, with a mean of 0.832 and a standard deviation of 0.104. The mean implies an average efficiency gap of 16.8% relative to the estimated production frontier. Most farmers are concentrated between 0.80 and 0.89 efficiency, while 19.5% record scores of 0.90 or above.

Table 2. Selected farm-level results from the 2026 survey

Indicator	Estimate	Statistical note	Interpretation
Mean ESII	11.4	Descriptive	Moderate-to-high extension engagement
Extension intensity coefficient	0.228	$p < 0.01$	Higher extension intensity associated with frontier output
Gamma	0.742	Frontier variance parameter	Substantial inefficiency component
Mean technical efficiency	0.832	SD = 0.104	Average efficiency gap = 16.8%
Minimum–maximum TE	0.521–0.981	Descriptive	Marked heterogeneity across farms

4.2 Infrastructure-accessibility profile

The provisional LGA profile reveals substantial variation in the contextual accessibility environment. Ikorodu is closest to Lagos by the road-distance measure and also has the highest population density among the three locations. Epe is the most distant and least densely populated, while Badagry occupies an intermediate position. After normalization, the composite accessibility index equals 1.000 for Ikorodu, 0.335 for Badagry and 0.000 for Epe.

Table 3. Provisional infrastructure-accessibility profile

Location	Survey n	Area (km²)	Population estimate	Road distance to Lagos (km)	Composite accessibility
Ikorodu	81	411.30	781,500	35.0	1.000
Epe	75	1,315.00	269,000	78.0	0.000
Badagry	79	445.60	351,900	64.0	0.335
Unspecified	35	–	–	–	Excluded

4.3 Exploratory interpretation of complementarity

The farm-level results demonstrate that extension intensity is associated with higher output and lower inefficiency, while the spatial profile demonstrates that the three aquaculture clusters operate in meaningfully different accessibility environments. These two findings are jointly consistent with, but do not prove, an infrastructure-extension complementarity mechanism. In practical terms, an extension recommendation may be easier to implement in a location with shorter market distance and denser service networks than in a more remote production cluster.

The results therefore justify estimating the interaction model once the respondent-level data are available. If the coefficient on ESII × ACCESS is positive, the policy interpretation would be that the productivity return to extension is partly conditional on connectivity. If the interaction is insignificant, it would imply that extension benefits are relatively portable across infrastructure environments. Either outcome would be substantively informative.

5. Discussion

The strongest result carried forward from the original farm analysis is the positive role of extension intensity. By measuring repeated visits, training, demonstrations and consultations, the ESII captures depth of engagement rather than the simple presence or absence of extension contact. This is important because information-intensive aquaculture requires repeated problem solving throughout the production cycle. (Awolumate & Omosola, 2017)

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The accessibility profile adds a second dimension to that institutional story. Ikorodu's stronger provisional accessibility position is consistent with its proximity to the Lagos metropolitan market and the concentration of inputs and services described in the underlying project. Epe's weaker score reflects a more peripheral spatial position, while Badagry falls between the two. These differences are relevant because extension delivery itself has a transport cost: extension officers must reach farms, farmers must reach training venues and suppliers, and harvested fish must reach markets rapidly.

This interpretation aligns with World Bank evidence that road connectivity can improve access to agricultural markets and services, reduce travel time and facilitate larger marketed volumes. It also aligns with FAO's sustainable-aquaculture emphasis on efficient and resilient production systems supported by appropriate institutions and enabling conditions. Infrastructure should therefore be understood not merely as a background control variable but as a potential complementary capability that affects whether knowledge can be acted upon.

At the same time, the present evidence does not support a claim that Ikorodu farmers are more technically efficient than Epe or Badagry farmers. Location-specific TE means are not reported in the available manuscript, and the respondent-level data required to estimate such differences are absent from the supplied files. Any stronger conclusion would therefore exceed the evidence. This distinction is important for preserving the credibility and publishability of the study.

6. Policy Implications

First, extension planning for aquaculture should incorporate accessibility. Visit schedules, demonstration locations and training delivery can be differentiated according to travel constraints and cluster density rather than applying a uniform service model across Lagos State.

Second, road and market-access investments should be treated as part of the agricultural knowledge system. Connectivity can increase the practical value of extension by improving access to feed, fingerlings, equipment, veterinary support and buyers.

Third, digital advisory channels can partly compensate for weak physical accessibility, particularly for routine consultations and follow-up after training. However, digital systems are complements rather than complete substitutes for demonstrations, diagnostics and on-farm technical support.

Fourth, Lagos State agricultural and transport agencies could jointly identify aquaculture clusters where weak accessibility and low extension coverage overlap. Such targeting would improve the developmental return to both extension expenditure and infrastructure investment.

7. Conclusion

This study provides an exploratory spatially informed reassessment of extension intensity and technical efficiency among small-scale aquaculture farmers in Lagos State. The established farm-level evidence shows that extension intensity is positively associated with output and that mean technical efficiency is 0.832, leaving a measurable efficiency gap. The newly constructed accessibility profile shows clear contextual differences among Ikorodu, Badagry and Epe. Together, these findings motivate a more demanding question than whether extension works: whether extension works better where farmers and extension systems operate within stronger infrastructure environments.

The current evidence is sufficient to establish that question and to identify the spatial heterogeneity that makes it testable, but not sufficient to estimate the interaction effect. The immediate empirical priority is therefore to merge the original respondent-level survey file with validated LGA-level or finer-resolution GRID3 accessibility measures and estimate the ESII × ACCESS interaction directly. Until that step is completed, the paper should be presented as exploratory rather than causal. The broader policy implication remains important: sustainable aquaculture development is likely to depend on coordinated investments in knowledge, connectivity and market access rather than on any one intervention in isolation.

8. Limitations and Further Research

The first limitation is spatial resolution. The questionnaire identifies only Ikorodu, Epe and Badagry rather than farm coordinates or communities, and 35 respondents do not report location. This restricts infrastructure variation to three LGA environments.

Second, the current accessibility index is a provisional operational proxy based on road distance and population density. It should be replaced, for journal submission, by zonal statistics derived from the 2025 GRID3 travel-time friction surface and road network.

Third, the cross-sectional and voluntary-response survey design limits causal inference and may overrepresent more digitally connected farmers. Future work should use panel data, probability sampling and finer spatial identifiers.

Fourth, the respondent-level data file is required to estimate the proposed moderation model. Once available, the analysis should report clustered or randomization-inference-based uncertainty that acknowledges only three higher-level infrastructure clusters, and should avoid treating 270 farmers as 270 independent infrastructure observations.

Appendix A. Operational Accessibility Proxy Used in the Exploratory Analysis

The master collection sheet uses two normalized components: (1) road proximity to Lagos, constructed by reversing the min-max normalization of road distance so that shorter distance receives a higher score; and (2) population density, min-max normalized across Ikorodu, Epe and Badagry. The composite index is the unweighted mean of the two normalized components. This produces scores of 1.000 for Ikorodu, 0.335 for Badagry and 0.000 for Epe. The measure is suitable for exploratory contextual comparison only and should be replaced with GIS-derived travel-time and road-density measures before confirmatory publication.

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