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A Bayesian Hierarchical Model for the Methodological Evaluation and Efficiency Gains of Public Health Surveillance Systems in Nigeria

Adebayo Adeyemi[1], **Ngozi Eze**[1,2], **Chinwe Okonkwo**[2,3]

Covenant University, Ota | *Babcock University* | *Department of Internal Medicine, Agricultural Research Council of Nigeria (ARCN)*

Correspondence: aadeyemi@yahoo.com

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ABSTRACT

Public health surveillance systems are critical for disease control, yet their methodological evaluation in resource-limited settings often lacks robust statistical frameworks to quantify efficiency and identify improvement pathways. This study aimed to develop and apply a novel Bayesian hierarchical model to methodologically evaluate the efficiency of public health surveillance systems and estimate potential gains from targeted interventions. We constructed a Bayesian model $y\{ij\}\ sim\ text\{Poisson\}(\lambda\{ij\})$, $log(\lambda\{ij\}) = \alpha + \beta\ X\{ij\} + ui + vj$, where ui and vj are random effects for state and disease syndrome. The model was fitted to national surveillance data, using Markov chain Monte Carlo for inference to estimate posterior distributions for key performance parameters. The model identified substantial heterogeneity in system completeness, with a posterior probability of 0.92 that integrating community health workers could improve reporting timeliness by at least 40% in six northern states. The 95% credible interval for the overall system sensitivity gain from this intervention was [28%, 52%]. The Bayesian hierarchical model provides a rigorous methodological tool for surveillance evaluation, demonstrating that significant efficiency gains are achievable through geographically and functionally targeted enhancements. Resource allocation should prioritise integration of community-based reporters in identified high-impact regions. The modelling framework should be adopted for routine system performance monitoring and strategic planning. Bayesian inference, health systems, efficiency, disease monitoring, health policy, statistical modelling This paper introduces a novel application of Bayesian hierarchical modelling for the methodological evaluation of public health surveillance, providing a quantifiable framework for prioritising investments to maximise system efficiency.

Keywords: *Bayesian hierarchical modelling, public health surveillance, methodological evaluation, sub-Saharan Africa, efficiency gains, resource-limited settings*

Article Highlights

- Model identifies substantial heterogeneity in surveillance system completeness across regions.
- Posterior analysis shows high probability of ≥40% timeliness gains from community health worker integration.
- 95% credible interval for overall system sensitivity gain: 28% to 52%.
- Framework enables geographically and functionally targeted enhancements for maximum impact.

Core Modelling Insight

The Bayesian hierarchical model $y_{ij} \sim \text{Poisson}(\lambda_{ij})$, $\log(\lambda_{ij}) = \alpha + \beta X_{ij} + u_i + v_j$, with state and syndrome random effects, provides a rigorous tool for quantifying surveillance performance and improvement pathways.

This study provides a methodological framework for evidence-based surveillance investment in resource-limited settings.