LOT QUALITY ASSURANCE SAMPLING FOR IMPROVING HEALTH SYSTEMS IN LOW RESOURCE SETTINGS: A DECISION-MAKING TOOL TO EMPOWER HEALTH OFFICERS AND INFORM HEALTH POLICY

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Abstract. Lot-quality assurance sampling (LQAS) is a classification method, developed in the 1920s for industrial quality control. In 1991, a WHO consultation on epidemiological and statistical methods for rapid health assessments recommended that LQAS be developed further to monitor health programmes in low resource settings. LQAS is used to manage health services performance quickly and relatively inexpensively in a defined geographical area. We review the statistical underpinnings of LQAS and methodological extensions, presenting recent applications in health in a low resource country.

Standard LQAS methodology is a two-stage sampling approach defined in a catchment area (CA), stratified by supervision areas (SA). Communities are selected in each SA with probability-proportional-to-size; typically, one respondent, sampled randomly in each community, is interviewed with a structured questionnaire. LQAS health surveys traditionally measure binary outcomes, classifying SA-level coverage indicators as having reached a predefined target. Classification is based on a decision rule, determined from binomial or hypergeometric distributions. Data from multiple SAs is aggregated to provide CA-level coverage estimates with a confidence interval.

During 2003-2015, LQAS household surveys were completed in up to 65 Ugandan districts to monitor health indicators. LQAS was rolled out as a national health sector monitoring system in 2009 and the data merged into one super-database, permitting cross-time and cross-space epidemiological studies to take place as secondary data analysis. One study looked at factors associated with facility-based delivery (FBD) adjusting for multiple factors simultaneously, spatial heterogeneity, and time trends. The statistical model formulated a nascent early warning system to identify districts expected to have low prevalence of FBD in the immediate future. LQAS is an attractive tool for evaluating health services. The scaling up of LQAS in low resource countries provides numerous opportunities to design and conduct complex statistical analyses and evaluations to inform health policy and formalise our understanding of health systems.

Keywords. Biostatistics, Medicine, Epidemiology, Survey Statistics, Statistics and Society, Spatial statistics, Spatio-temporal statistics, Lot-Quality Assurance Sampling, LQAS.

Résumé. Le Lot-quality assurance sampling (LQAS) ou échantillonnage par lots pour l'assurance de qualité, a été mis au point dans les années 1920 dans l'industrie afin de vérifier la qualité de lots d'articles avant livraison. En 1991, une consultation de l'OMS sur les méthodes épidémiologiques et statistiques utilisées pour l'évaluation rapide des programmes de santé recommanda l'utilisation du LQAS. Le LQAS permet de gérer, rapidement et à peu de frais, la performance des services de santé dans une région géographique donnée. Nous présentons les fondements statistiques du LQAS et certaines extensions méthodologiques, ainsi qu'une application en Ouganda.

La méthode standard LQAS est un échantillonnage à deux étapes, défini dans une zone d'intervention (ZI), stratifié par aires de santés (AS). Les communautés sont sélectionnées dans chaque AS avec une probabilité proportionnelle à la taille ; en général, un seul répondant par population cible, sélectionné aléatoirement dans chaque communauté, est interviewé à l'aide d'un questionnaire structuré. Les enquêtes de santé LQAS mesurent habituellement des réponses binaires, et permettent de déterminer si les taux de couverture des indicateurs ont atteint une valeur cible prédéterminée au niveau des AS. La classification de chaque indicateur est établie avec une règle de décision calculée à partir de la loi binomiale ou hypergéométrique. Les données des AS sont agrégées pour estimer les taux de couverture avec un intervalle de confiance à l'échelle de la ZI.

Entre 2003 et 2015, des enquêtes de santé LQAS ont été menées dans jusqu'à 65 districts de l'Ouganda pour le suivi d'indicateurs de santé. Le LQAS a été déployé en 2009 comme système de suivi au niveau national du secteur de la santé, et les données ont été regroupées dans une supra-base de données. La construction de cette base de données a permis de développer des analyses épidémiologiques secondaires à travers le temps et l'espace. L'étude présentée ici se focalise sur les facteurs associés avec l'accouchement dans une structure sanitaire, avec un ajustement simultané de plusieurs facteurs, de l'hétérogénéité spatiale, et de l'évolution temporelle. Un système d'alerte précoce est ensuite construit partir du model statistique permettant d'identifier les districts présentant des valeurs faibles pour cet indicateur dans un avenir proche. Le LQAS est un outil attrayant pour évaluer les services de santé. Le déploiement du LQAS dans les pays en développement fournit de multiples opportunités de concevoir et mener des analyses statistiques et évaluations à grandes échelles temporelles et géographiques afin d'informer les politiques en matière de santé et de formaliser notre compréhension de ces systèmes de santé.
Mots-clés. Biostatistique, Médecine, épidémiologie, Statistique d'enquête, statistique et société, Statistique spatiale, spatio-temporelle, Lot-Quality Assurance Sampling, LQAS, Echantillonnage par lots

1 Introduction

LQAS is a method to evaluate a programme by analysing data collected from a small sample. It was developed in the 1920s for quality control in the industry(1). During the mid-1980s it was adapted to the health sciences (2, 3). In 1991, a World Health Organization (WHO) report on epidemiological and statistical methods for rapid assessment of health systems concluded that the LQAS was, among the available methods, the most practical and encouraged its development to continue to monitor the health programmes (4-6). LQAS became a practical management tool for conducting baseline surveys and monitoring health services and needs.

2 LQAS adapted to health

LQAS divides the program area or catchment area (CA) into smaller areas that provide services and called supervision areas (SAs). In Uganda, districts (the CAs) are divided into counties and then further divided into sub-counties (the SAs). Each surveyed district iss stratified into 4 to 7 SAs, based upon how district teams delivered services. A sample of 19 respondents per target group is selected in each SA (or 24 if the CA is comprised of 4 SAs). Two levels of analysis are conducted: First, LQAS classifies Supervision Areas (SA) as high or low performance relative to a predetermined target set for an indicator (or in comparison with the average for the indicator for a catchment area). LQAS classifies SAs using a decision rule "d" that optimizes identification of low performance SAs. For each SA, a sample of "n" individuals in a client group is evaluated, and a "d" selected that determines the cut-off number of SA with adequate performance, below which the SA is classified as low performance for a specified indicator. The decision rule "d" depends on the sample size, the thresholds for classifying high and low performance, and the selection of two misclassification errors: the probability of misclassifying an area with high coverage as low (α error), and the probability of misclassifying an area with very low coverage as high (β error). SAs with intermediate performance are classified as high or low depending on how close they fall to the relevant thresholds. Second, by combining multiple SAs data, we can determine the average coverage for the entire CA with 95% of reliability and +10% of margin error.

3 Example in Uganda

The aim of our study is to identify the simultaneous correlates of facility-based delivery (FBD), in order to provide a framework for prioritizing districts for support. Our objectives consisted of assessing variations in FBD over time and space, fitting a statistical model to identify factors associated with FBD (2003-2011 data), and use the model to predict FDB district coverage in 2012 and validate prediction with the 2012 data.

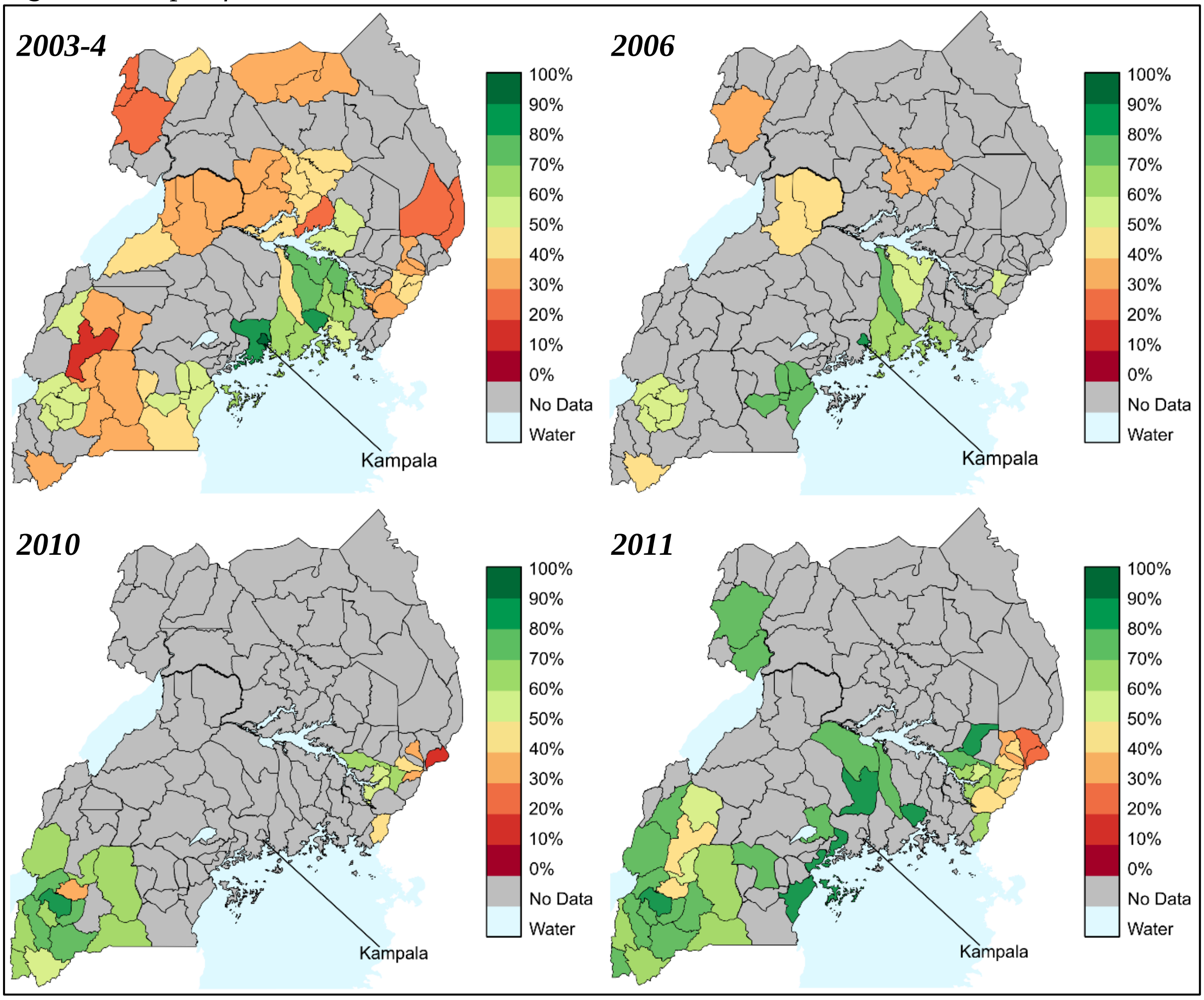
Data In 2003, the Uganda AIDS Commission (UAC), with the support of The World Bank, introduced Lot Quality Assurance Sampling (LQAS) methodology to monitor HIV-related indicators, including condom use, at the district and sub-district level. It was introduced during 2003 into 19 (of the then 56) districts comprising the country, expanded to 11 more in 2004 and repeated into 12 districts in 2006. In 2009, USAID provided funding to support the roll out of LQAS as a national health sector monitoring system. One component was to align and merge all relevant data into one super dataset, with the purpose of making it available for wider use by the public during 2014 through the Ministry of Local Government. By 2013, LQAS surveys had been completed in 65 of the current 112 districts comprising the country. Many of the districts implemented surveys at one or more time points from 2003–2015. Each time point included data collection by structured questionnaires in up to six respondent groups: youths 15–24 years, women 15–49 years, men 15–54 years, mothers with infants 0–11 months, mothers with children 12–23 months, mothers with children 24-59 months, and orphans and other vulnerable children. As these data were collected and integrated into the superset, several cross-time and cross-space epidemiological studies could take place in the form of secondary data analysis(1, 7-11).
This study focuses on the indicator "percentage of mothers of children 0-11 months who delivered their last baby in a health facility". The data consisted of 18,098 women pregnant in the last year at time of survey. The individual covariates available were mother's age, mother's education level, year, while the district-level covariates were number of health facilities per capita, population density, road density, wealth index, and altitude.

Statistical analysis Our analysis consisted of 3 phases: FBD mapping, model construction, and prediction of priority districts and population strata in them. All analyses were conducted with R version 2.15 and the package maptools.

<u>FBD mapping</u>: We classified mothers as giving birth either at home or in a health facility and plotted on a map the percentage of mothers with FBD for each district surveyed. One map was produced for each cluster of survey years: 2003-04, 2006, 2009-10, and 2011. We calculated 95% confidence intervals (CI) using clustered bootstrapping (12), a non-parametric error estimation method which takes into account residual spatial correlation of the indicator. We used forward selection based on the Akaike Information Criterion to include significant interaction terms between the covariates.
<u>Model</u>: Using all 2003-2011 data, we fitted a logistic regression model to investigate factors simultaneously associated with FBD. The covariates which showed significant non-linearity were base-2-log-transformed before been incorporated into the model. We validated the model in three stages: by comparing it to a null spatial model, by constructing a ROC curve to assess the fitted values were correctly classified, and by using two-fold Monte Carlo cross-validation (CV) algorithm.
<u>Prediction of priority districts in 2012</u>
Using the model, we selected the lower and upper most strongly associated values of known demographics to construct a confidence range for the predicted 2012 FBD status. The confidence ranges were then categorized into 4 groups (low, medium, high, unclear) to display the results concisely.

Results Figure 1 displays the percentage of mothers of children aged 0-11 months with FBD for different points in time.

Figure 1: Maps of the indicator



The model results (Table 1) showed that mothers who are more likely to give birth in a health facility: have primary school education or higher level; live either in the capital (Kampala) or in a districts with more infrastructure (health facilities, roads), higher wealth index, less mountainous terrain; were interviewed in recent years rather than earlier years.

Table 1: Logistic regression model for delivery in a health facility in Uganda

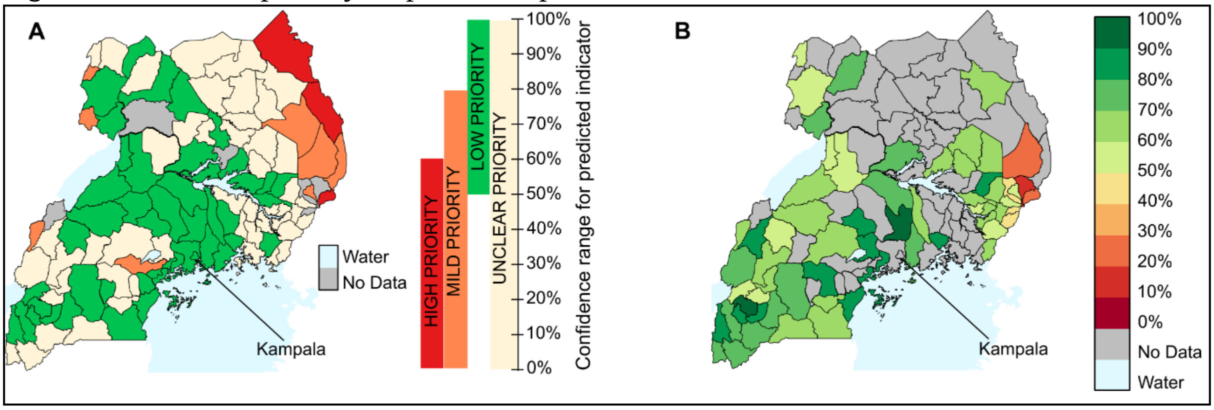
Covariates	**Odds Ratio [95%CI]**
Age	0.98 [0.97, 0.99]
Education (Primary)	1.59 [1.42, 1.78] *
Education (Secondary)	3.37 [2.88, 3.94] *
Education (Post-Secondary)	10.4 [6.28, 18.1] *
Number of health facilities per capita	1.12 [1.02, 1.23] *
Road density	1.13 [1, 1.26] *
Population density	0.97 [0.90, 1.06]
Living in Kampala	8.38 [2.24, 23] *
District wealth index	1.38 [1.24, 1.53] *
Standard Dev altitude	0.89 [0.84, 0.94] *
Mean altitude	1 [0.9997, 1.001]
Year of survey	1.08 [1.04, 1.13] *

* A 95%-significant positive or negative effect. Confidence intervals were calculated using clustered bootstrapping with 1,000 iterations.

The CV results showed that for 95% of the districts surveyed in 2012, the absolute difference between the predicted and observed coverage was less than or equal to 20%; while for 77% of the surveyed districts, this absolute difference less than or equal to 15%.

The range of FBD was correctly predicted in 93.4% of the 2012 surveyed district (Figure 2). The priority map identifies many north-eastern districts as being mild or high priority, as they have some of the lowest indicator values.

Figure 2: Predicted priority map and comparison with unseen data



4 Conclusion

LQAS is an attractive tool for evaluating health services. The scaling up of LQAS in low resource settings provides numerous opportunities to design and conduct complex statistical analyses and evaluations to inform health policy and formalise our understanding of health systems. In our example, the Ugandan superset provides a wealth of data to conduct various epidemiological data-mining studies and complex analyses. Such results inform health programmes and health policy on large time and geographical scales. The construction and ownership of this superset by the Uganda government is also a striking example of improving monitoring and evaluation and strengthening health systems in low resources countries.

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