Vaccine xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Vaccine

journal homepage: www.elsevier.com/locate/vaccine

High resolution age-structured mapping of childhood vaccination coverage in low and middle income countries

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A R T I C L E I N F O

Article history:
Received 28 July 2017
Received in revised form 24 January 2018
Accepted 2 February 2018
Available online xxxx

Keywords:
Measles vaccine
Demographic and Health Surveys
Bayesian geostatistics
Coverage heterogeneities

A B S T R A C T

Background: The expansion of childhood vaccination programs in low and middle income countries has been a substantial public health success story. Indicators of the performance of intervention programmes such as coverage levels and numbers covered are typically measured through national statistics or at the scale of large regions due to survey design, administrative convenience or operational limitations. These mask heterogeneities and 'coldspots' of low coverage that may allow diseases to persist, even if overall coverage is high. Hence, to decrease inequities and accelerate progress towards disease elimination goals, fine-scale variation in coverage should be better characterized.

Methods: Using measles as an example, cluster-level Demographic and Health Surveys (DHS) data were used to map vaccination coverage at 1 km spatial resolution in Cambodia, Mozambique and Nigeria for varying age-group categories of children under five years, using Bayesian geostatistical techniques built on a suite of publicly available geospatial covariates and implemented via Markov Chain Monte Carlo (MCMC) methods.

Results: Measles vaccination coverage was found to be strongly predicted by just 4–5 covariates in geostatistical models, with remoteness consistently selected as a key variable. The output 1×1 km maps revealed significant heterogeneities within the three countries that were not captured using province-level summaries. Integration with population data showed that at the time of the surveys, few districts attained the 80% coverage, that is one component of the WHO Global Vaccine Action Plan 2020 targets.

Conclusion: The elimination of vaccine-preventable diseases requires a strong evidence base to guide strategies and inform efficient use of limited resources. The approaches outlined here provide a route to moving beyond large area summaries of vaccination coverage that mask epidemiologically-important heterogeneities to detailed maps that capture subnational vulnerabilities. The output datasets are built on open data and methods, and in flexible format that can be aggregated to more operationally-relevant administrative unit levels.

1. Introduction

Health policy decision-making based on spatially heterogeneous vaccination has resulted in a shift from pursuing coverage targets at the national-level to ensuring that high coverage levels are evenly distributed across provinces or districts [1]. While this likely represents a more effective strategy over targeting country-level goals, administrative area summaries may still mask important geographical inequities in coverage [2]. Small regions of susceptibility formed by spatial clustering of unvaccinated individuals can sustain disease transmission, even when high overall vaccination coverage is achieved. Continued disease circulation can also be driven by age cohorts that are missed by routine vaccination, unless they are removed from the susceptible population

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https://doi.org/10.1016/j.vaccine.2018.02.020
0264-410X/© 2018 The Author(s). Published by Elsevier Ltd.

through natural infection or vaccination campaigns that target broader age ranges [3,4].

To better capture heterogeneities in vaccine coverage, two general options exist, either increasing the intensity of surveys or using statistical modelling approaches. The former is costly, and therefore modelling approaches that leverage existing survey data, spatial relationships between survey clusters and relationships with geospatial covariates have become increasingly popular in mapping key development indicators at high spatial resolution. Driven by rapid increases in computing power, rising availability of a range of detailed geospatial datasets and advances in statistical methods, recent examples include the mapping of age structures [5], poverty [6], malaria prevalence [7], sanitation [8] and literacy [9] within Bayesian geostatistical frameworks that enable quantification and mapping of uncertainty in estimates. These efforts have revealed new insights into the spatial heterogeneities of health and development metrics, as well as producing more precise estimates of populations at risk or affected when combined with high resolution population maps (e.g. [10]).

Here we explore the potential of geostatistical approaches to modelling age-structured vaccination coverage across three countries, using measles vaccine as an example. Geolocated cluster survey data are combined with a library of candidate geospatial layers capturing covariates such as urbanicity, remoteness and poverty, to test their ability to predict vaccination coverage at high spatial resolution and estimate numbers covered when combined with population maps.

2. Methods

Fig. 1 depicts an overview of the modelling approach used in this work from data assembly to model outputs, using Nigeria as an example. Each stage is described in the following sections, and in greater detail in supplemental materials.

2.1. Measles vaccination coverage data

The Demographic and Health Surveys (DHS) program conducts nationally representative household surveys that provide data on a wide range of demographic and health indicators in low and middle income countries [11]. Cross-sectional data on the spatial distribution of measles vaccination coverage in children under 5 years of age for Cambodia, Nigeria and Mozambique were obtained from the DHS database [12]. For each child surveyed, the measles vaccination status, i.e. whether they had ever received a measles vaccine or not, as determined from the vaccination card or as reported by the mother, was extracted. In this definition of measles vaccination coverage, used by the Demographic and Health Surveys program [12–14], there is an implicit assumption that the child has at least received the first dose of measles containing vaccine (MCV-1), but could also have had the second dose (MCV-2). Other information obtained included the child's age in months at the time of the survey and the centroid of the cluster from which the child's household was selected. To maintain confidentiality, DHS cluster centroids are randomly displaced up to 2 km in urban areas and 5 km in rural areas [15], and this displacement was accounted for during covariate data extraction following recommended approaches [16]. For each country, only the most recent survey was used, corresponding to 2014, 2011 and 2013 for Cambodia, Mozambique and Nigeria, respectively. Overall, 22,897 children in these countries were vaccinated against measles out of a total of 45,297 children with complete records. Fig. S1 (supplemental material) maps the cluster locations and the proportions of under-5 s vaccinated in each country. For a variety of reasons, vaccination coverage is often evaluated by age [2,17,18]. In this work, we defined four age intervals relevant to coverage assessments: <9 months, 9–11 months, 12–23 months and 24–59 months, and also analysed coverage in the under 5 year age category (i.e. <59 months).

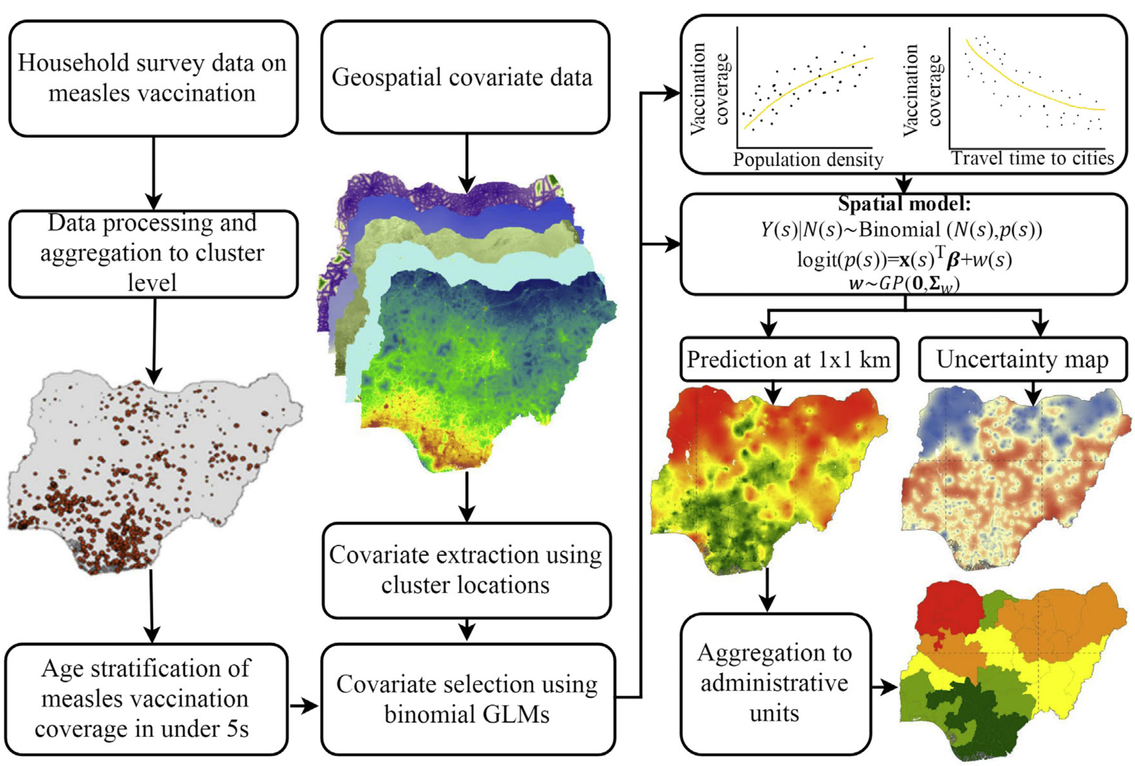

Fig. 1. A schematic diagram of the modelling approach used to produce high resolution age-structured estimates of vaccination coverage.

Please cite this article in press as: Utazi CE et al. High resolution age-structured mapping of childhood vaccination coverage in low and middle income countries. Vaccine (2018), https://doi.org/10.1016/j.vaccine.2018.02.020