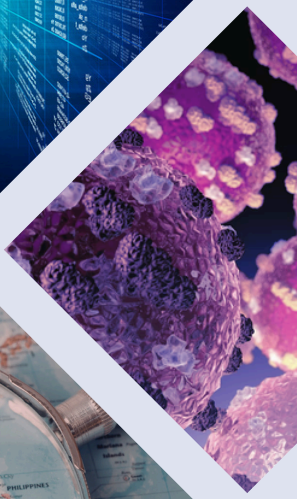

2026 MEASLES MODELLING SYMPOSIUM

Measles modelling within the context of the Western Pacific & South-East Asia regions

Jakarta, Indonesia
10–12 June

MEASLES
ANALYTICS HUB

The Measles Analytics Hub's second annual Measles Modelling Symposium features work relevant to the Western Pacific and South-East Asia regions. The symposium includes original research, best practice examples of modelling collaborations, and work relating to data, modelling, and methodological innovations.

In this booklet, presenters are featured alongside their abstracts in alphabetical order. Please consult the agenda for the order of presentations.

Dr Abhiyan Gautam

National Manager of Child Health and Immunization Services, Ministry of Health and Food Safety, Nepal

Recent Measles Outbreaks and Programmatic Adaptations in Nepal: Implications for MR Elimination Modelling

Co-authors: Balwinder Singh Chawla, Rahul Pradhan

Nepal aims to eliminate measles–rubella (MR) by 2026 under the MR Elimination Roadmap 2023–2026, which prioritizes strengthening immunization, surveillance, laboratory networks, and outbreak response. The 2026 measles outbreaks in Sarlahi and Baglung districts revealed important epidemiological shifts and immunity gaps relevant for MR elimination modelling in the WHO South-East Asia Region (SEAR).

A descriptive analysis was conducted using routine surveillance data, laboratory-confirmed cases, active case search findings, and official outbreak situation reports. Epidemiological characteristics, age distribution, and Outbreak Response Immunization (ORI) interventions were assessed.

The Sarlahi outbreak involved 34 suspected cases, primarily among individuals aged 1 month–22 years. Active case search enabled early detection, and ORI achieved 133% administrative coverage. In contrast, the Baglung outbreak was larger, with 204 suspected cases affecting individuals aged 3 months–80 years, with 62% of cases occurring among adolescents aged 10–19 years. Several severe cases required tertiary referral, although no deaths occurred. ORI targeting older age groups achieved 85% coverage. Both outbreaks disproportionately affected marginalized communities.

These outbreaks demonstrated substantial measles transmission among older age groups, challenging traditional assumptions regarding susceptibility patterns. Consequently, the National Immunization Advisory Committee (NIAC) recommended extending vaccination strategies to higher age cohorts. The findings emphasize the need for adaptive vaccination policies, strengthened surveillance, and targeted outbreak response strategies to address immunity gaps and support MR elimination efforts in Nepal and SEAR.

Dr Alpha Forna

Department of Epidemiology and Biostatistics, College of Public Health, University of Georgia

Predicting Measles Outbreak Risk in the Western Pacific and South-East Asia Regions: A Machine Learning Approach to Identifying At-Risk Countries

Co-authors: Alyssa N Sbarra, Saki Takahashi, John M Drake, Matthew J Ferrari, Amy K Winter

Despite high vaccination coverage in many countries across the Western Pacific (WPR) and South-East Asia (SEAR) regions, measles outbreaks continue to recur, threatening progress toward elimination. Predicting which countries are most at risk could help national programs and regional partners shift from reactive to proactive responses; however, doing so requires overcoming reporting delays and wide variations in data quality across the two regions.

We developed a machine learning model to predict country-level measles outbreak risk one year in advance using WHO surveillance data, vaccination coverage, and health system indicators from 187 countries. The model was trained on 2012–2018 data, calibrated on 2019–2021 data, and independently validated on 2022–2024 data, achieving strong predictive accuracy (AUC = 0.90).

When applied to WPR and SEAR, the model identified several "edge" countries, those sitting just above or below the outbreak risk threshold, where small changes in surveillance or vaccination effort could tip the balance toward or away from an outbreak. In SEAR, countries including India, Indonesia, and Myanmar were flagged among those at the highest risk, while in WPR, the Philippines, Thailand, and Papua New Guinea emerged as key edge cases requiring attention. Variable importance analysis revealed that vaccination coverage alone contributed only 6.5% to the model's predictive power, while surveillance quality and how well countries detect and report cases contributed over 40%.

This underscores a critical challenge for WPR and SEAR: countries most vulnerable to outbreaks are often the least equipped to detect them early. These results provide actionable guidance for WHO regional offices, Gavi, and national immunization programs seeking to target resources for the greatest impact. In this talk, we will present the modeling framework, highlight the specific risk profiles of WPR and SEAR countries, and discuss which countries would benefit most from targeted interventions. We will also briefly discuss recent work examining whether the standard WHO threshold of 20 cases per million for defining outbreaks remains appropriate as a global standard, or whether regions, and indeed individual countries, may require context-specific definitions that reflect their current epidemiological landscape and stage on the path toward measles elimination. Such a shift could have implications beyond modeling, informing how outbreak response triggers, resource allocation, and elimination targets are set at both regional and national levels.

Dr Arifianto Apin

Pasar Rebo General Hospital/YARSI University, Jakarta

From Hospital Cases to Population Risk: Limitations of Hospital-Based Measles Data for Modelling in Urban Indonesia

Co-authors: Masiya Mawla Putri, Nabiela El Rizqa

Measles risk modelling requires accurate estimates of population susceptibility and vaccination coverage. In Indonesia, data are often fragmented, and hospital-based datasets are increasingly used despite uncertain representativeness. This study examines the limitations of such data for informing measles risk modelling in an urban setting.

We analysed 184 pediatric measles cases from a Jakarta referral hospital (September 2025–March 2026). Variables included age, vaccination status, nutritional status, and disease severity. Data completeness and structure were evaluated against requirements for susceptibility estimation and sub-national risk mapping, with comparison to provincial surveillance trends.

Most cases occurred in children aged 1–5 years (49.5%) and were partially vaccinated (71.2%). Clinical severity was predominantly moderate (86.4%). Key limitations identified were: (1) selection bias toward moderate-to-severe cases, (2) incomplete vaccination histories, (3) absence of population denominators, and (4) limited spatial representativeness. Temporal patterns were consistent with provincial data but lacked sufficient granularity for modelling applications.

Hospital-based data provide useful signals of disease burden but are insufficient for robust measles modelling. Integration with routine immunization and surveillance data is needed to improve estimation of susceptibility and outbreak risk. Strengthening data completeness and linkage systems will support more accurate modelling and better targeting of immunization strategies in Indonesia.

Asami Anzai

National Institute of Infectious Diseases, Japan Institute for Health Security

Reconstructing Measles Population Immunity in Japan Using Sero-epidemiological Data

Japan was verified as having achieved measles elimination in 2015, but measles has persisted following importations. In recent years, notifications have increased again with the recovery of international travel, showing that measles risk can persist even under elimination and low-incidence conditions. Routine measles-containing vaccine coverage has remained below the 95% target for both the first and second doses, and a noticeable proportion of reported cases has occurred in people with a recorded history of two doses. These observations suggest that vaccination history alone may not fully describe residual susceptibility in the population. Japan also has a particular strength in its long-running national serological survey, which provides an important basis for reassessing immunity gaps after elimination.

This study aims to reconstruct age-specific population immunity profiles for measles in Japan by integrating sero-epidemiological survey data, case-based surveillance, and vaccination information. This presentation will focus on the value of using these data to assess immunity gaps, and on methodological challenges in evaluating immunity under elimination and low-incidence conditions.

Preliminary descriptive findings suggest that recent cases are not limited to unvaccinated young children, but are also seen in adolescents and adults. Cases with documented two-dose vaccination are also observed.

Even after elimination, measles risk can persist due to importation, incomplete vaccination coverage, and heterogeneous immunity across age groups. Japan provides a useful setting for developing approaches that combine serology and surveillance to identify residual susceptibility in low-incidence settings.

Dr Bimandra Djaafara

Saw Swee Hock School of Public Health, National University of Singapore

Modelling Sub-national SIA Strategies in Indonesia with Limited Spatially Granular Data

Indonesia aims to eliminate measles and rubella by 2030, yet persistent immunity gaps and heterogeneous coverage continue to challenge progress and complicate evidence-based decisions on whether to prioritise national or targeted subnational SIAs. Following co-creation of modelling aims and objectives with the WHO country office and the Indonesia Ministry of Health (see Ghosh et al.), this project was designed to evaluate the comparative effectiveness of alternative SIA strategies to support national decision-making.

At the lower administrative level (i.e. district/admin2), surveillance quality becomes much more heterogeneous, with instances of districts not reporting cases while having low vaccination coverage, making it difficult to model dynamics without strong assumptions. For this reason, preliminary analysis was conducted at the admin1 (province) level. This required adjusting vaccination coverage from administrative surveillance into 'actual' coverage; while national modelling typically relies on WHO–UNICEF Estimates of National Immunization Coverage (WUENIC), sub-national estimates require bespoke adjustments, here derived from multiple national surveys. Because provincial case data are only available annually, monthly national data from the WHO were used to fit a time-series susceptible–infected–recovered (TSIR) model and estimate SIA efficacy. These estimates were then incorporated into a deterministic age-stratified maternal–susceptible–infected–recovered (MSIR) model fitted to annual provincial data using a maximum a posteriori (MAP) approach with relatively low computational cost. The model has so far been fitted to two provinces: Jakarta (high coverage), where overall dynamics were captured although an unobserved outbreak in 2014 was predicted, and Aceh (lower coverage), where the model reproduced dynamics more closely.

In this talk, I will discuss key challenges in reconstructing population immunity, accounting for factors such as importations, and adjusting surveillance data for reporting rates. These limitations have important implications for decision-making, as uncertainty in sub-national data constrains the ability to confidently compare national versus targeted SIA strategies. I will also outline next steps, including forward simulations based on these provincial results and further development of approaches to extend inference to the district level while minimising reliance on strong assumptions.

Dr Dessie Mekonnen

Independent consultant

Lessons from Integrated Measles–Rubella and Oral Polio Vaccine (MR-OPV) Campaigns in Papua New Guinea

In 2019, the integrated measles–rubella and oral polio vaccine (MR-OPV) campaign in Papua New Guinea demonstrated the value of strong collaboration between the Government of Papua New Guinea, Gavi, the Global Polio Eradication Initiative (GPEI), WHO, UNICEF and other partners during outbreak response activities. The campaign achieved high national coverage for MR vaccination (101%) and polio vaccination (98.6%), while rapid convenience monitoring enabled immediate identification and vaccination of missed and zero-dose children. Key successes included strengthened coordination mechanisms, extensive social mobilization, capacity building of health workers, cold chain improvements, development of surveillance and adverse events following immunization (AEFI) guidelines, and enhanced microplanning processes. The campaign also highlighted the importance of integrating routine immunization (RI) strengthening into emergency responses and demonstrated that coordinated technical and financial support can improve health system performance.

As the Measles and Rubella Partnership increasingly prioritises integrated campaigns and closer collaboration with the GPEI, Papua New Guinea provides a valuable case study of where this approach has already been implemented. Several important lessons emerged. Delays in recruiting finance and RI support staff affected timely implementation, highlighting the need for rapid deployment of both technical and operational personnel during emergencies. The experience also demonstrated that RI strengthening embedded within outbreak response campaigns requires sustained post-campaign support to achieve lasting impact. While collaboration between Gavi and GPEI was effective, competing priorities at times diverted RI staff toward polio response activities, emphasising the importance of dedicated outbreak-response personnel. Persistent weaknesses in injection practices, surveillance, and microplanning further underscored the need for continued training, supervision, and investment in RI systems. Moving forward, Papua New Guinea plans to build on these gains through targeted training, strengthened surveillance, geographic information system (GIS) supported microplanning, improved AEFI systems, and sustained coordination mechanisms.

Dr Divya Kappara

Department of Mathematics, Indian Institute of Technology (IIT) Bombay

Covariate-Balanced Estimation of Measles Relative Risk in Spatially Structured Observational Data.

Co-authors: Siuli Mukhopadhyay, Subharup Guha

Observational data collected from individuals across spatially connected regions often exhibit systematic differences in covariate distributions, such as place of residence, sex, and nutritional status. In such settings, crude relative risk (RR) estimates obtained across these regions may reflect underlying covariate imbalances rather than true differences in disease risk. In addition, these data are often not fully representative of the target population, as key characteristics such as vaccine uptake and exposure prevalence may differ substantially from those in the broader population. This study aims to obtain covariate-balanced, model-based estimates of region-specific relative risks of measles infection among vaccinated and unvaccinated individuals that are representative of a target population.

We propose a unified statistical framework that integrates propensity score weighting with spatial generalized linear mixed models. The weighting component is designed to adjust for both covariate and sampling imbalances in the data. Specifically, we adopt the FLEXible, Optimized, and Realistic (FLEXOR) framework to construct a covariate-balanced pseudo- population that targets a predefined superpopulation, here the Indian population, rather than a purely data-driven sample. The approach combines multiple propensity score adjustment for district membership with externally specified population-level constraints, such as vaccine uptake and district-level population proportions derived from census or administrative data. The weights are constructed in an outcome-free manner and are optimized to maximize effective sample size subject to these constraints. Bayesian estimation is employed to facilitate model fitting and uncertainty quantification. The framework further allows the incorporation of region-level information, including migration patterns, nutritional indicators, vaccination coverage, and supplementary immunization activities.

The proposed approach produces weighted relative risk estimates of measles that differ meaningfully from crude estimates, reflecting improved adjustment for covariate and sampling imbalances as well as alignment with the target population. Incorporation of external population-level indicators leads to modified and more reliable relative risk estimates, highlighting the impact of underlying heterogeneity across regions. The framework also enables identification of significant covariate effects, along with 95% credible intervals.

This framework provides a robust methodology for estimating measles relative risk while enabling improved comparability across study regions and alignment with a target population. Its ability to account for both data imbalances and spatial dependence makes it particularly useful for public health decision-making. The approach can support more accurate identification of high-risk regions and inform targeted resource allocation.

Dr Esha Kashyap

National Disease Modelling Consortium, Indian Institute of Technology (IIT) Bombay

Strategic intensification of measles immunisation in India: Lessons learned from subnational targeting

Co-authors: Biplab Maity, Pawan Kumar, Siuli Mukhopadhyay

Measles is an acute infectious disease in humans that poses a major public health concern. In India, immunisation stands at the forefront of measles control, with routine immunisation maintaining baseline protection in the population while strategic catch-up campaigns target hard-to-reach groups.

This research proposes a deterministic age-structured compartmental model to capture measles transmission in India using public incidence data from 2000 to 2024. Our model simulates measles burden across multiple immunisation scenarios. This enables us to assess the impact of different strategic approaches to measles immunisation and provide model-based data to support future programme design. The indicators in use are averted measles cases and disability-adjusted life years per thousand vaccine doses. These indicators are projected through 2040.

Though routine immunisation mitigates measles burden, a large fraction remains under-immunised. These residual susceptible populations facilitate measles resurgence in the near future. Our model shows routine immunisation coupled with strategic catch-up campaigns targeting these susceptible clusters limit disease transmission and boost herd protection against the disease. Catch-up campaigns on broader age groups, 9–59 or 9–119 months, similar to India's supplementary immunisation activities and mission indradhanush campaign cut down substantial disease load, whereas campaigns focused on 12–23 months measles zero dose children analogous to India's zero dose implementation plan deliver more meaningful long-term reductions in measles burden with fewer vaccines.

To achieve national measles control, it is important to promote strategic intensification of measles immunisation through systematic integration of routine and targeted catch-up campaigns, prioritise under-immunised children, and preparedness for potential outbreaks.

Dr Indrajit Ghosh

Bagchi School of Public Health, Ahmedabad University

Modelling the Impact of Migration and Population Mixing on Measles Transmission in India

Measles transmission dynamics in India are affected not only by vaccination rates but also by people's mobility within the country. To evaluate whether population mixing and migration affect measles dynamics in India, we built a state-level metapopulation SIRV model incorporating census population data, live birth counts, national MCV1/MCV2 coverage, measles incidence from 2007-2016 and interstate migration rates based on Census migration matrices.

Calibration was based on reported cases from 2007-2013, while validation was performed by comparing data from 2014-2016. The calibration enabled us to simulate the general trend of decreasing measles cases between 2007 and 2013. Results from the migration sensitivity analysis suggest that population mobility can significantly affect the redistribution of measles infection risk across states. Among the most sensitive states to population mobility were Uttar Pradesh, Maharashtra, Karnataka, Tamil Nadu and Odisha.

The counterfactual simulation results indicate that population mobility does not necessarily increase the national burden but may shift susceptible and infected populations across the measles transmission network. This information should be taken into account when developing new strategies to prevent measles outbreaks in India. Additionally, SIA planning may prioritize states where susceptible buildup and migration-driven seeding interact.

Dr Indrajit Ghosh

Bagchi School of Public Health, Ahmedabad University

Collaborative modelling to inform measles vaccination strategies and elimination timelines in Indonesia

Co-authors: Bimandra Djaafara, Ahmad Watsiq, Vicka Oktaria, Stephen Chacko, Olivi Silalahi, So Yoon Sim, Megan Auzenbergs

To support Indonesia's goal of measles elimination, the Measles Analytics Hub (MAH) established a collaborative framework between the World Health Organization (WHO) Country Office, the Indonesian Ministry of Health (MoH) and international modellers. This collaboration aims to translate complex policy questions, such as the impact of achieving MR1 coverage targets and the potential discontinuation of the third MR dose (MR3), into quantifiable modelling outputs to guide national decision-making in Indonesia.

The WHO Country Office and Indonesian MoH defined priority research questions, which the MAH secretariat and modelling groups translated into specific scenarios. Researchers and colleagues from Universitas Gadjah Mada (UGM) are supporting with data cleaning and localized epidemiological expertise. This study utilizes an age-stratified, multi-compartmental model of measles transmission that captures infections in unvaccinated infants by explicitly modelling maternal immunity decay. Using a bootstrap algorithm, critical parameters are identified by fitting the model to yearly incidence data from Indonesia. Scenario analysis evaluates the impact of increased MR1 vaccination and supplementary immunization activities (SIA) on measles incidence. This methodology will also be applied to the three regions of Indonesia.

Initial results indicate that increasing MR1 coverage significantly improves outcomes (95% MR1 coverage averts ~20% cases relative to 85% baseline coverage). Specifically, scenario analysis highlights that combining routine immunization (RI) with supplementary immunization activities (SIA) targeting children aged 6 months to 4 years averts more infections in Indonesia than targeting those aged 9 months to 5 years. Region-specific model projections are being investigated. Furthermore, the collaborative framework intends to evaluate the effect of discontinuing the MR3 dose.

This collaboration demonstrates how integrating global modelling expertise with local stakeholders can effectively address specific immunization program challenges. By working closely with the WHO Country Office and Indonesian MOH throughout the analysis, the project aims to ensure that the generated evidence is directly applicable to national policy. The final communication of results includes preparation for the Regional Verification Commission meeting in September 2026 and subsequent dissemination within Indonesia, facilitated by the MOH.

Dr Krishna Prasad Paudel

Chief Consultant Pediatrician, Ministry of Health Nepal

Data Driven Microplanning for Nationwide Measles-Rubella Campaigns in Nepal

Nepal introduced the measles vaccine into the national immunisation programme in 1981, with rubella added in 2013 at 9 months of age. Since 2015, Nepal has provided a second dose of the measles–rubella (MR) vaccine at 15 months. Administrative coverage of the first MR dose has exceeded 90% since 2017, while coverage of the second dose has improved from 59% in 2017 to 90% by 2022. However, a large cohort of unvaccinated children has continued to accumulate. As a result, measles supplementary immunisation activities (SIAs) have been central to Nepal's strategy to close immunity gaps and interrupt transmission since 2004. As a geographically challenging and resource-constrained setting, Nepal has implemented multiple nationwide MR campaigns, leveraging data-driven microplanning, risk profiling, and real-time monitoring to ensure high and equitable coverage.

Analysis of SIA reports from 2012 to 2024, along with administrative and survey-based coverage data, post-campaign evaluations, and surveillance datasets, assessed campaign coverage, zero-dose reach, district-level performance variability, and post-SIA measles incidence trends. Nepal conducted multiple MR SIAs targeting children aged 9 months to 15 years, each reaching 5–6.5 million children, with administrative coverage consistently reported at over 100%, reflecting successful inclusion of missed and mobile populations. Pre-campaign risk assessment and immunity gap analysis using surveillance and coverage data enabled prioritisation of high-risk districts, including urban slums, border areas, and hard-to-reach mountain communities. Ward-level microplans, updated population denominators, and household listing ensured precise targeting, with campaign strategies adapted for seasonal migration patterns, schools, and outreach clinics. Effective monitoring, including daily reporting dashboards and rapid convenience monitoring, identified low-coverage pockets during campaigns and enabled immediate corrective actions such as mop-up vaccination and redeployment of teams. Strong community engagement, involving more than 52,000 Female Community Health Volunteers (FCHVs), played a critical role in social mobilisation, defaulter tracing, and addressing vaccine hesitancy, translating data insights into community-level action. Post-campaign surveillance showed a substantial decline in measles incidence, contributing to an overall reduction of more than 98% since 2004, with outbreaks becoming smaller and more geographically contained. SIAs also significantly contributed to reducing the number of zero-dose children by reaching marginalised populations, including remote rural communities and underserved urban settlements.

Nepal's measles campaigns have been instrumental in maintaining high population immunity (over 95%), preventing large-scale outbreaks, and advancing towards measles elimination, while also strengthening routine immunisation systems through improved microplanning, data systems, and community trust. Overall, Nepal demonstrates that well-planned, data-driven SIAs remain a powerful tool for measles elimination, with key success factors including granular data use, real-time monitoring, strong community networks, and adaptive strategies to reach missed populations; these lessons are highly relevant for countries aiming to optimise campaign effectiveness through analytics.

Dr Kyaw Kan Kaung

Deputy Director General, Disease Control, Ministry of Health Myanmar

From Surveillance to Strategy: Myanmar's Evidence-Based MR Campaign for Regional Impact

Co-authors: Tin Thitsa Lwin, Raveesha R Mugali

Myanmar, like many countries in the WHO South-East Asia Region (SEARO), has experienced significant disruptions to routine immunization services since 2021 due to the COVID-19 pandemic, natural disasters, and internal displacement. These disruptions have led to a substantial measles-rubella (MR) immunity gap, with national coverage for MCV1 and MCV2 declining to 71% and 68% respectively in 2024, down from pre-pandemic levels above 85%. An estimated 1.8 million children under five remain at risk of measles infection, with the susceptible population exceeding 2.5 times the annual birth cohort. In response, Myanmar's Ministry of Health has planned a nationwide MR follow-up campaign for November 2026 to close these immunity gaps and accelerate progress toward the 2028 regional MR elimination goal.

We collected and cleaned district-level immunization data, including live births, vaccine coverage (MCV1, MCV2, SIAs), We computed protection and susceptibility estimates by integrating routine and supplementary immunization data, assuming high vaccine effectiveness and minimal natural immunity. Results were analyzed descriptively to identify high-risk districts with immunity gaps, benchmarked against WHO targets, and visualized to guide targeted interventions. The campaign design is grounded in a robust, data-driven methodology. Immunization coverage and surveillance data were analyzed to identify high-risk townships and guide micro-planning. Differentiated delivery strategies were developed to address diverse access challenges: fixed-site and outreach sessions in accessible areas, mobile teams and community partnerships in hard-to-reach and peri-urban zones, and integrated services in areas with displaced populations. The campaign explicitly incorporates parameter assumptions and uncertainties, including population mobility and incomplete denominator data, by adopting flexible targeting and buffer vaccine stock strategies. The campaign also integrates adverse event following immunization (AEFI) monitoring and links with efforts to strengthen routine immunization and disease surveillance systems.

The campaign aims to vaccinate approximately 2.83 million children aged 9–59 months, regardless of prior vaccination status. It targets >95% MR coverage nationally and sub-nationally, with a focus on zero-dose and under-vaccinated children. The strategy includes enhanced community engagement, gender-sensitive service delivery, and coordination with ethnic health organizations and local authorities. The campaign is supported by WHO, UNICEF, Gavi, and other partners, ensuring a multisectoral approach to equitable coverage. The planning process has already improved microplanning accuracy and stakeholder alignment, setting a precedent for future campaigns.

Myanmar's 2026 MR follow-up campaign exemplifies how methodologically sound, locally led, and partner-supported strategies can address immunity gaps and prevent large-scale outbreaks. The campaign's design offers a replicable model for SEAR countries facing similar challenges. Key recommendations include maintaining high-quality surveillance, ensuring timely follow-up campaigns, integrating outbreak response with routine immunization strengthening, and prioritizing equity in service delivery. This initiative reinforces Myanmar's commitment to the 2028 MR elimination goal and contributes valuable insights for regional and global immunization strategies.

Marisa Gaetz

Gates Foundation – Institute for Disease Modeling

Understanding drivers of age shifts in Pakistan's measles cases – lessons learned from EMRO region

This talk discusses a framework for examining recent shifts in the age distribution of measles cases in Pakistan, as well as the implications of this type of analysis for vaccination policy in both the EMRO and SEARO regions. Vaccination rates and surveillance rates have both increased significantly in Pakistan over the past decade, meaning more cases are being detected even as more children are getting vaccinated. Simultaneously, observed cases are increasingly concentrated among very young children. We consider several complementary hypotheses for this age-at-infection shift: accelerated maternal antibody waning as more mothers have vaccine-derived rather than disease-derived immunity, the mechanical effect of rising immunization rates shifting the remaining susceptible population below vaccination age, and geographic heterogeneity concentrating detected cases in under-vaccinated communities.

We integrate DHS/MICS household surveys, WHO/UNICEF coverage estimates, and Pakistan's case-based surveillance linelist (2010–2025). We construct national and provincial immunity profiles to estimate reporting rates over time, disentangling surveillance expansion from transmission changes. For maternal antibodies, we use these immunity profiles and survey data to estimate the fraction of mothers in a given year with vaccine-derived versus disease-derived immunity and link these to published antibody waning estimates (Leuridan & Van Damme, BMJ 2010). We also use these immunity profiles to examine how rising immunization rates redistribute susceptibility across age groups. For geographic heterogeneity, we disaggregate case and surveillance trends by district to

We estimate that the case-based reporting rate for measles in Pakistan has increased by a factor of ~15 since 2010, suggesting that much of the observed increase in total cases reflects improved surveillance rather than rising transmission. Meanwhile, the fraction of reported cases in children under MCV1 age has more than tripled since 2010. Our maternal antibody model predicts a modest but steady decline in infant antibody levels, consistent with the growing share of vaccine-immune mothers, though the predicted decline is small relative to the observed age shift. Rising vaccination coverage is likely a larger contributor: as more children are immunized, susceptibility concentrates in younger, pre-vaccination age groups. Geographic disaggregation is in progress to determine whether the age shift is primarily a mechanical consequence of rising coverage nationwide, or whether it is concentrated in communities where low coverage sustains transmission among young children.

The shift toward younger cases reflects multiple reinforcing mechanisms. Maternal antibody waning contributes a modest but meaningful baseline effect, while the larger shift appears driven by changes in the vaccination and transmission landscapes. If rising vaccination coverage is the primary driver, this warrants investigation into whether more immunization opportunities can be offered to children under nine months of age without compromising seroconversion and vaccine efficacy. If, instead, the age shift is concentrated in communities where low coverage sustains high transmission across age groups, then closing geographic gaps in routine immunization should be the priority. The ongoing sub-national analysis will help disentangle these mechanisms.

Dr Md Ariful Islam

WHO Bangladesh

Modelling Measles-Rubella Immunity Gaps and Outbreak Predictors in Bangladesh

Bangladesh aims to eliminate measles–rubella by 2028 and has made strong progress, but subnational disparities remain a major challenge. Khulna Division, comprising ten districts, reflects these issues. While national MCV1 coverage has remained above 90%, district-level data show declining MCV2 uptake and persistent susceptibility. These immunity gaps, driven by high birth rates, disrupted vaccine supply, and irregular SIAs, increase outbreak risk. Inconsistencies across data sources further complicate analysis, highlighting the need for robust modelling approaches.

District-level coverage data (2021–2025) from CES and administrative DHIS2 systems were analysed, with administrative data validated against CES. Susceptible birth cohorts were estimated and triangulated with surveillance data; effective reproduction numbers (Reff) were calculated.

Substantial heterogeneity was observed. CES indicated large susceptible cohorts in Meherpur (237%) and Narail (123%), while adjusted DHIS2 data showed Meherpur highest (146%) and Narail lowest (2%). Susceptibility in Khulna, Kushtia, and Jhenaidah ranged from 27–46%. Reff exceeded 2 in Jashore and was above 1 in all districts, indicating sustained transmission risk. MCV2 coverage declined sharply in 2024–2025 after previously exceeding 89%. Surveillance data confirm ongoing transmission, with increasing cases in districts such as Jashore and Kushtia. Most cases (40%) occurred among children aged 1–4 years, of whom only 65% had received MCV2.

Khulna highlights persistent immunity gaps in Bangladesh's elimination efforts. Districts such as Narail, Jashore, and Kushtia require urgent attention. Discrepancies between administrative and survey data make interpretation difficult, underscoring the need for integrated modelling approaches. We seek collaboration to develop models combining coverage, susceptibility, and surveillance data to better guide targeted interventions and accelerate progress toward elimination by 2028.

Dr Nguyen Ky Nhat Minh

Department of Disease Prevention, Pasteur Institute, Nha Trang

Linking Outbreak Epidemiology to Vaccine Demand Forecasting During the 2024-2025 Measles Outbreak in Central Vietnam

Co-authors: Truong Gia Linh, Luong Cong Bao Tran, Hoang Tien Thanh, Dao The Anh, Trinh Cong Thuc, Le Hoang Thieu, Hoang Thi Hai Hang, Vo Thi Ngoc Dieu, Ha Tuan Anh, Nguyen Que Chau, Dinh Quang Nhut, Trinh Hoang Long

In 2024 and the first half of 2025, Vietnam experienced a severe measles resurgence reflecting immunity gaps caused by the COVID-19 pandemic and vaccine supply interruptions. The Central Region, a key area in the WHO Western Pacific Region, recorded a sharp rise in cases. This study describes the epidemiological characteristics of 20,975 suspected measles cases across all 11 Central provinces from January 2024 to June 2025, characterises the spatio-temporal spread of the outbreak, and applies a Seasonal Autoregressive Integrated Moving Average (SARIMA) model to forecast monthly measles vaccine demand in Khanh Hoa province for January 2025–December 2026 to support locally-led immunisation planning. Epidemiological data were collected from the provincial CDC network, and forecasting used historical immunisation data (2014–2024), with model performance assessed using standard statistical metrics.

Across all provinces, case counts rose sharply from September 2024, peaked in March 2025 (4,823 cases), and declined thereafter. Da Nang reported the highest burden, and the outbreak spread from southern provinces (peaking December 2024–January 2025) to northern provinces and urban centres (March–May 2025). A clear age shift towards older children and adults was observed compared to previous outbreaks, alongside high non-vaccination rates (67.9% overall), particularly among 9–<12-month-olds. Three coordinated mass vaccination campaigns (February–May 2025) coincided with a marked decline in case numbers.

On the 2019–2020 test set, the optimal SARIMA$(2,1,2)(1,0,1)_{12}$ model produced white-noise residuals with MAPE 8.78%, RMSE 792.53 and MAE 398.3, with a slight conservative over-prediction that is operationally acceptable for vaccine planning. For the 24-month forecast, SARIMA$(2,1,2)(1,1,1)_{12}$ was selected based on improved AIC and its ability to reproduce seasonal structure, projecting 28,026 doses in 2025 and 29,336 doses in 2026. These findings highlight persistent immunity gaps beyond routine paediatric vaccination and support targeted strategies including catch-up campaigns (including adults), early vaccination in outbreak settings, and strengthened surveillance.

Methodologically, a SARIMA model with explicit seasonal differencing is a transparent and operationally tractable tool for short- to medium-term (1-2 years) provincial vaccine planning. Limiting the forecast horizon to 24 months kept the 95% confidence interval interpretable throughout the planning period, which we recommend as a best practice for other low- and middle-income provincial CDCs. Models should be retrained quarterly or every six months, and future work will extend the framework towards SARIMAX (incorporating exogenous variables such as price, population mobility and outbreak signals) and hybrid SARIMA-machine-learning approaches to better capture non-linear shocks. This locally-led modelling collaboration directly empowers Vietnam's provincial CDCs to proactively manage vaccine procurement and prevent future stockouts.

Ong Phuc Thinh

Oxford University Clinical Research Unit, Vietnam

Serosurvey Evidence and Modelling of Immunity Gaps in Vietnam

Co-author: Marc Choisy

The 2024-2025 measles epidemic was amongst the largest in Vietnam's history since the introduction of measles-containing vaccines. We describe how we have used serological surveillance data and modelling to support the Government of Vietnam during the 2024-2025 measles epidemic by (i) identifying immunity gaps following COVID-19-related disruptions, (ii) estimating the risk of a major outbreak, and (iii) explaining why serological data provided more reliable early warning signals than immunisation registry data.

We established a national serosurveillance network that collects age-stratified residual serum samples from hospitals across Vietnam every four months. To assess changes in population immunity following COVID-19 and associated vaccination disruptions, we analysed 9,253 samples collected from 20 provinces in December 2019 and August-December 2022. Age-specific seroprevalence was modelled using generalised additive models with a logit link and thin plate spline smooth terms. To investigate discrepancies with administrative data, we conducted a focused study in Ho Chi Minh City by integrating serosurveillance data with the Ho Chi Minh City Centre for Disease Control (HCDC) serum bank. A total of 1,097 samples from children under 15 years attending major paediatric hospitals were analysed. We further translated seroprevalence estimates into outbreak risk and developed a compartmental model incorporating hospital-community transmission dynamics, informed by prior cohort data (2017-2019), to explain observed patterns.

Serological analysis revealed a decline in immunity by December 2022, with seroprevalence of 60-70% among children under 5 years and 50-60% among those aged 5-15 years, substantially lower than pre-pandemic levels of 75-80%. These findings suggested both missed vaccinations and waning immunity. In contrast, immunisation registry data from HCDC indicated >95% coverage for the first dose of measles-containing vaccine. However, city-level serological data showed persistently low immunity (60-80%), with the lowest levels observed in western districts. These estimates corresponded to a 0.72-0.86 probability of a major outbreak following a single infectious case introduction. Consistent with these predictions, the outbreak subsequently emerged in western districts and escalated into the largest measles epidemic recorded in the city, with 10,735 reported cases. Modelling results were used to inform scenarios in which hospitals can act as amplification settings due to higher contact rates and a concentration of susceptible individuals. Localised susceptibility in healthcare settings was sufficient to drive epidemics that were not detectable from immunisation registry data, regardless of its resolution.

These findings were communicated to policymakers and informed decisions to declare the outbreak and expand the target age group for reactive vaccination from children under 5 years to those under 10 years, accounting for waning immunity. More broadly, our results highlight the added value of hospital-based serosurveillance as a form of sentinel surveillance for early warning. This approach is particularly important for infections such as measles, where healthcare-associated transmission can play a critical role in outbreak initiation and propagation, and where reliance on immunisation registry data alone may underestimate true population susceptibility.

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Block-Level Risk Stratification for MR Elimination in India: Methodological Challenges and Innovations in Sub-National Immunisation Risk Mapping

Progress toward measles and rubella (MR) elimination in the WHO South-East Asia Region (SEARO) demands analytical frameworks that move beyond national and state aggregates to identify granular transmission risk. India's immunisation programme spans over 6,200 administrative blocks, with heterogeneous vaccination coverage, surveillance capacity, and demographic vulnerability. Conventional indicators mask pockets of sustained transmission, and no standardised block-level composite risk modelling framework has been established.

This work describes the methodological approach, data challenges, and innovations underlying a block-level MR risk assessment covering 6,214 blocks across India and illustrates its application through a case study. A composite risk scoring framework incorporated four domains: (i) population immunity gaps (MCV1/MCV2 trends, susceptible cohort accumulation, SIA history); (ii) surveillance quality (timeliness, specimen adequacy, laboratory turnaround, discard rates); (iii) programme delivery performance (coverage trajectory, dropout rates, integration with primary schedule); and (iv) contextual threat assessment (case burden, age distribution, population density, cross-border risk, and mobile populations). Blocks were classified into low to very high-risk tiers.

Vaccination coverage data from HMIS showed reliability gaps (e.g., sharp MCV1 declines) requiring triangulation with surveys. Vaccination status was incomplete in 13–34% of confirmed cases, limiting susceptibility modelling. Susceptible cohort estimates exceeded 100% in some blocks by 2024–25, reflecting combined data quality and programmatic issues. Variability in surveillance sensitivity introduced bias when comparing incidence across blocks. The framework applied multi-year trend analysis and composite scoring while separating surveillance quality from disease burden. A case study shows high surveillance quality can coexist with very high transmission, highlighting the need to disentangle detection from risk. We recommend incorporating uncertainty in coverage estimates, improving vaccination status recording, and developing dynamic models that capture SIA-driven catch-up. Cross-district coordination indicators are also proposed.

Block-level MR risk stratification is feasible and actionable in large programmes like India's. Improving data quality—especially for coverage and vaccination status—is critical to strengthening the precision and policy relevance of sub-national risk models. These methodological lessons are transferable to other SEARO countries pursuing elimination.

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