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Impact of Geospatial Data on Microplanning and Equity in Immunization, and related Costs in the Kasaï Province, Democratic Republic of Congo: A mixed-methods study

Dosithée Ngo-Bebe
ngobebed@gmail.com

University of Kinshasa
Marlene Joannie Bewa
Johns Hopkins Bloomberg School of Public Health
Genèse Lolimo Lobukulu
University of Kinshasa
Marcelo Ilunga Kalonji
University of Kinshasa
Yannick Kabadi Musawu
University of Kinshasa
Freddy Fefe Bangelesa
University of Kinshasa
Théophane Kekemb Bukele
University of Kinshasa
Olivia Drouhaut
Health.Enabled
Patricia Mechael
Health.Enabled
Smisha Agarwal
Johns Hopkins Bloomberg School of Public Health

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Abstract

Background

Geographic information systems (GIS) and georeferenced data are increasingly transforming public health planning by improving precision, guiding resource allocation, and reducing inequities in access to services. In the Democratic Republic of the Congo (DRC), persistent gaps in immunization coverage highlight the need for data-driven approaches. This study evaluates the impact of the Mapping for Health (M4H) project, which integrates geospatial data into immunization microplanning in Kasaï Province, on service delivery, coverage, and equity.

Methods

A mixed-methods study was conducted combining quantitative data from vaccination coverage surveys, facility observation with qualitative data from interviews, focus groups, and ethnographic observations. The sampling process resulted in 6 health zones out of 18 and 43 related health areas randomly selected. All the selected health facilities were visited and their managers interviewed. For the ethnographic study, 13 head nurses and 14 community health workers participated in focus group discussions. Data were collected from interviews, observation, vaccination coverage survey (VCS) databases, vaccination registries and from program intervention reports. NVivo 12 was used for thematic content analysis of transcripts and observation notes, while vaccination register data were cleaned, validated, and analyzed using R software. Economics data were processed through Excel.

Results

The introduction of geospatial data contributed to identifying new localities, reducing uncovered areas, improving the planning of vaccination sites and sessions, increasing vaccine orders, and recovering previously missed children. All these improvements were confirmed through quantitative data of the outputs related to the delivery of vaccination services. However, the evaluation does not provide sufficient evidence to conclude that the introduction of geospatial maps had an impact on pentavalent vaccine coverage. The study also highlighted persistent technical, institutional, and logistical challenges. Nevertheless, strong community engagement and a shared commitment to sustaining geospatial tools were expressed by all stakeholders. Each health zone benefited an estimated of $74,341.6, to cover primarily personnel expenditures, demonstrating a labor-intensive project.

Conclusions

The M4H project demonstrates that integrating geospatial data into immunization programs enhances microplanning, strengthens community engagement, and advances equity. Scaling and sustaining such approaches require continued investment, institutional capacity-building, and gender-responsive strategies.

BACKGROUND

Microplanning and geospatial approaches integration into immunization plans at the health zone and health area levels are effective [1–3]. Integrating geospatial technologies into health systems offers a transformative solution improving target population estimation, identifying underserved areas, and optimizing outreach delivery. Geostatistical methods further enable the estimation of vaccination coverage and disparities through high spatial resolution data, which are essential for effective planning [4], locating and mapping missed communities and identifying zero-dose and under-vaccinated children [5, 6]. In the Democratic Republic of the Congo (DRC), over 20% of children remain zero-dose, and disparities in service delivery exist particularly in hard-to-reach areas. Since 2019, the Mapping for Health (M4H) project has collaborated with the Expanded Programme on Immunization (EPI) to implement geospatial immunization microplans across 19 provinces, to provide accurate, enhanced, and integrated spatial, geographic, and demographic data for the identification of zero-dose children through high-resolution geospatial data integrated into planning systems. This project is also aligned with the Mashako Plan, a national public health and high-level initiative that contributes to the advancement of strengthening capacities of immunization providers and local civil society organizations engaged on vaccination services to increase immunization coverage in the DRC.

The intervention is funded by The INFUSE program of Gavi, the Vaccine Alliance, and implemented in collaboration with Flowminder, WorldPop at the University of Southampton, Flowminder, the Center for International Earth Science Information Network (CIESIN) at Columbia University and is a core component of the Geo-Referenced Infrastructure and Demographic Data for Development (GRID3) program, which blends official governmental data with data generated through novel approaches such as satellite imagery and remote sensing techniques. The intervention includes the use of geospatial data to optimize the microplanning of vaccination activities, to identify unreached

communities, zero-dose and under-vaccinated children. The project also integrated a gender and equity approach to strengthen the capacity of local civil society partners to compile, analyze, and develop gender-sensitive vaccination strategies tailored to marginalized and hard-to-reach populations.

The project products are maps and geospatial data, originally developed as dynamic digital GIS outputs, formatted into printed map layouts to ensure accessibility and usability in health facilities. GIS base layer updates are conducted periodically, with version histories from the GRID3 portal documenting recent releases in 2024 and 2025. This approach helps ensure the continued relevance and accuracy of GIS base layers used for planning and decision-making.

This evaluation builds on the first evaluation phase conducted in 2023 and published in 2025, suggesting that geospatial data and microplanning tools were produced, accepted, and used by providers. The gender intervention strengthened women's capacity to support and become more involved in vaccination activities. The results also indicated that the use of geospatial microplans may have contributed to a clear and sustained improvement trend in vaccination coverage for certain antigens. However, the short duration of observation and data collection limited the generalizability of these findings [7]. This second evaluation attempted to refine the impact measurements and to capture related costs of implementing the M4H project in the Kasaï province, according to the timetable presented in the Fig. 1 below.

The research aims at 1) assessing the barriers, facilitators and extent of geospatial data utilization and their integration into vaccination activities 2) assessing the level of community engagement and the integration of gender considerations in vaccination activities 3) evaluating the effectiveness of the M4H intervention on immunization coverage before and after the introduction of geospatial data, and 4) conducting an economic analysis of costing data related to producing and implementing geospatial tools.

METHODS

Study Design

A mixed-methods approach comparing pre- and post-intervention outcomes was used. Quantitative data assessed changes in vaccination coverage and service delivery indicators, while qualitative data explored implementation processes, contextual dynamics, community engagement and gender integration. The study design did not include a control arm due to wide differences in geographic, demographic and outcomes characteristics across provinces. The study has four aims related to (i) determine the degree of use of geospatial data and its integration into vaccination activities, (ii) assess the level of community engagement and integration of gender aspects in vaccination activities through an ethnographic approach, and (iii) assess the effectiveness of the M4H project intervention through vaccination coverages (iv) conduct an economic analysis of costing data related to producing and implementing geospatial tools.

Setting and Sampling

This study was conducted in Health Zones (HZ) and related Health Areas (HA) in Kasaï Province, where the M4H and Flowminder interventions including a gender component were implemented. The study provinces were stratified into two strata: urban and rural. For health zone sampling, we considered 33% of the total number of health zones for each stratum, totaling 6 health zone out of 18. In each of the selected health zones, 33% of health areas were also randomly selected, for a total of 43 health areas. To achieve this, we carried out simple random sampling using the Android application "*randomizer*". For the qualitative part of the study, all the selected structures were visited and their managers were interviewed, namely the 43 Head Nurses of the selected health centers and the 6 Chief Medical Officers of the selected health zones. Within the selected health centers, community health workers were purposively sampled according to their availability on the time of collecting data.

Data collection

For the direct observation, secondary data collected from vaccination registries, in-depth interviews and focus group discussions, the preparation and collection of field data took place in the province of Kasai, from April 28 to May 18, 2025.

To assess the degree of integration of geospatial microplanning tools into routine vaccination activities in health facilities, a qualitative approach was employed, combining direct structured observations in health facilities, and in-depth interviews of 43 health area managers and 6 health zone managers or their delegates, using a semi-structured guide to gather information on the barriers and facilitators.

To examine how community engagement and integration of gender into vaccination activities influenced the delivery of vaccination services, the ethnographic study included in-depth interviews (IDIs) with 13 head nurses, and two focus groups discussion with a total of 14 key

informants' community health workers (RECOs), conducted in two purposely selected health zones, that had previously received training in gender and social inclusion.

To evaluate the effect of the geospatial map and microplanning, the study used two types of secondary data: vaccination coverage survey (VCS) databases, and vaccination registry data collected from health areas within the visited health zones. The vaccination coverage surveys (VCS) were conducted in the DRC by the Kinshasa School of Public Health (KSPH) with support from technical and financial partners in nearly all 519 health zones across the 26 provinces of the DRC through a cross-sectional study design based on a modified WHO methodology to ensure representativeness at the health zone (HZ) level. Respondents included the head of household and caregivers (mother, father, or other family members) of eligible children aged 6 to 23 months within a household. The survey methodology relied on the child's vaccination card, or, in its absence, caregiver recall. Results were presented by individual data sources as well as combined sources. Reports from these VCS are publicly available and can be accessed on KSPH website: https://espkinshasa.net/ [8–10]. For the three VCS selected for this study, the sample sizes of children drawn from across the country are presented in table 1. Secondary data analyzed in this study were extracted from these surveys for the pre-intervention period (2021–2022) and the post-intervention period (2023) to determine statistical trends.

Table 1
Number of Provinces, Health Zones, Health Areas and Samples Sizes in Vaccination Coverage Surveys (2021–2023)

Year	Number of provinces	Number of health zones	Number of health areas	Children aged 6 to 23 months	Children aged 12 to 23 months
VCS 2021	26	511	2 460	87 720	51 054
VCS 2022	26	503	2 523	77 850	47 880
VCS 2023	26	509	2 712	83 250	46 990
Sources: Reports of the three vaccination coverage surveys (VCS) conducted in 2021, 2022, and 2023					

The reported VCS covered all the 26 provinces of DRC, with an increase in the number of health areas. The number of targeted children showed a decrease from 2021 to 2022 and then an slightly increase in 2023 in both categories either for children aged 6 to 23 months and those aged 12 to 23 months [8–10].

Vaccination registry data were collected from the 43 selected health areas and aggregated at the level of the six health zones. These complementary data covered the pre-intervention period (2020–2022) and the post-intervention period (2023–2024) to strengthen the analysis. Registers contained information on vaccinated children within each health area and details for all vaccine antigens.

Variables analyzed from the VCS included: Coverage rate of fully vaccinated children (2021–2023), Coverage rate of Penta 1 (2021–2023), Coverage rate of Penta 3 (2021–2023). Pentavalent is the vaccine that best reflects the overall performance and equity of vaccination among children aged 0 to 23 months [11]. Variables analyzed from vaccination registers included the number of planned vaccination sites per health area, quantity of vaccines and other supplies requested, annual number of children reached through catch-up effort, average monthly number of vaccination sessions in the health area.

A retrospective costing analysis was conducted to evaluate Mapping for Health (M4H) initiative implementation in Kasaï province between 2021–2023. Cost data were collected from the project budget, CIESIN UNOPS budget and Gavi Financial Report. Program implementation costs were categorized into five main components: personnel, operational, supplies and equipment, training, and travel and transportation. Personnel costs included salaries and fringe benefits for GIS mappers, coordinators, program management staff, contracted consultants, subcontractors and other implementation or administrative personnel. Operational costs covered office rental, utilities, and communication expenses such as internet, wireless plans, and staff phones. Both supplies and equipment, and travel and transportation excluded expenses related to training. Supplies and equipment included items such as tablets, computers, and materials used for mobilization and sensitization activities. Travel and transportation costs covered mileage reimbursements, flights, lodging, and per diems incurred during program implementation as well as GIS mapping operations. Training costs encompassed expenditures for venues, materials, meals, participant and staff travel, trainer fees, lodging, and per diems. For budget and expense line items without a specified location, costs were weighted to Kasaï Province using the geographic size relative to the total project implementation area (Haut-Katanga, Kasaï, Kasaï-Oriental, and Lomami). This ensured that only expenditures attributable to activities conducted in Kasaï were included in the analysis. Within Kasaï, costs were distributed equally across the 18 implementing health zones due to the limited availability of zone-specific expenditure data.

Data analysis

Qualitative data were recorded, de-identified, anonymized, and transcribed. NVivo 12 was used for thematic content analysis of transcripts and observation notes, following both deductive and inductive approaches. A codebook was developed to facilitate the classification of transcripts for analysis. Results were synthesized, and relevant illustrative excerpts were retained. For the VCS data, analyses were based on a structured panel database covering six health zones over three years (2021–2023). Key variables, Penta1, Penta3, and full coverage were coded as binary outcomes (1 = vaccinated, 0 = not vaccinated). To ensure representativeness and validity of hypothesis tests, analyses were weighted using survey weights in line with the sampling design. Weighted proportion tests compared proportions across 2021, 2022, and 2023 for each health zone and indicator. Associations between year and vaccination status were tested using svy: tabulate with a chi-squared test adjusted for survey design. These tests assessed the statistical significance of observed variations while accounting for sampling design. Proportions were estimated for each zone-indicator-year combination, and differences were statistically tested with 95% confidence intervals. Vaccination register data were cleaned, validated, and prepared for analysis in R software. Descriptive analyses were conducted, presenting results in frequency tables. For some variables, such as the number of vaccination sites, means were calculated separately for pre-intervention (2020–2022) and post-intervention (2023–2024) periods. For cumulative variables (e.g., number of children reached, vaccination sessions, vaccine doses ordered), data were aggregated for the two periods to improve comparability. Systematic comparisons were then performed, using either absolute figures or averages, between the pre- and post-intervention periods.

For costs analysis, costs per program outputs were calculated, and results presented through seven units cost indicators: 1) cost per one percentage point change in full immunization coverage among children aged 12–23 months, 2) cost per health area integrating geospatial data into microplanning, 3) cost per health area using geospatial data as denominators for target populations, 4) cost per new vaccination site established 5) cost per additional vaccine dose ordered, 6) cost per additional child immunized during catch-up campaigns, and 7) cost per additional vaccination session conducted.

RESULTS

Our findings are presented by study aims.

Aim 1: Determine the degree of use of geospatial data and their integration into vaccination activities

Description of study participants

Out of 43 health areas selected for the study, data of 42 health areas were validated for analysis, while all the 6 health zones delegates were included in the study (appendix 1). Most of the participants interviewed in health areas were head nurses (95.2%), men (85.7%), between 35–44 years old (40.0%), have a college degree (55.0%) and more than 10 years of professional experience (63.4%). In the absence of most of the chief medical doctors, health zones respondents were mostly nurse supervisors (IS PEV), all male, college degree holders, with more than 10 years of professional experience.

Presence, utilization and integration of geospatial maps in routine vaccination activities

The analysis of the observation guide indicates strong availability and visibility of geospatial maps in health facilities, enabling their effective use. Across the six surveyed health zones, maps were displayed in 36 of 42 health areas (86%), with the Banga Lubaka zone as an exception, where only three of six health areas displayed maps.

In-depth interviews revealed the widespread use of geospatial data particularly geographic maps across all health areas. These maps are integral to vaccination planning, guiding microplanning, session scheduling, site selection, and the choice of delivery strategies based on settlement distribution and accessibility. They are also used to identify smaller hamlets and travel routes, improving the precision and reach of immunization efforts, facilitate the identification of distances, high-priority areas or hotspots, and populations that have been missed by vaccination efforts. The integration of geospatial data into existing vaccination processes was reported by health zone representatives to be highly effective and beneficial across multiple dimensions. Their systematic use enables health teams to identify operational gaps, optimize outreach strategies, track unvaccinated children, and allocate resources more efficiently, thereby improving the overall precision and adaptability of vaccination programs.

“I plan based on the map because my localities are already located on it. From the map I can identify everything… I send the RECO into the field… to find zero-dose children.” (P9, Kalonda Ouest)

“We plan according to distances, thanks to the symbols on the maps.” (P7, Banga Lubaka)

“Before, we planned blindly; now we know exactly.” (P1, Banga Lubaka)

“With geospatial maps, the calculations we used to determine sites… have been improved.” (P6, Ndjoko Punda

“The map has become like another memory aid that helps us work well on vaccination activities.” (P27, Kakenge)

The integration of geospatial maps now extends beyond planning to encompass continuous adjustment of interventions. In the context of seasonal population movements, whether driven by agricultural activities or by displacement linked to security concerns, the use of geospatial maps has enabled more agile and responsive planning adjustments. These tools allow for the incorporation of newly identified villages and hamlets into microplans, the modification of travel routes to bypass impassable or insecure areas, and the strategic grouping of immunization sessions to optimize team mobility and resource use. Geospatial data also facilitate the rapid identification of coverage gaps, such as missed or unreached villages, thereby enabling the timely organization of catch-up sessions. Through the integration of geospatial information, vaccination teams have been able to expand the number of outreach sessions, redefine target areas, adjust the size and composition of field teams, and recalibrate vaccine dose requirements based on real-time field estimates; contributing to more equitable and comprehensive immunization coverage.

“The relays call out; the mothers don’t come… now the map shows us where to go to retrieve the children.” (P28, Kakenge)

“We know how many doses to take according to the identified target.” (P5, Banga Lubaka)

“We planned 8 sessions: 3 fixed, 5 outreach, based on the map and accessibility.” (P22, Mikope)

“We had a population of 25,192… after re-zoning, 12,591… the map helps us sort it out.” (P10, Kalonda Ouest)

While the integration of geospatial data has enhanced planning accuracy and operational efficiency, practices related to adjusting vaccination target populations remain inconsistent. In several settings, population estimates derived from geospatial data are treated as static, despite dynamic local population changes. Some health workers regularly recalibrate targets using mainly conventional demographic projections.

“We take the total population and multiply by 3.49/100 to know the annual expected numbers.” “We saw that the Makaya farm was in blue… we then vaccinated 24 to 29 children (P4, Banga Lubaka)

“My population is 6,234. I divide this population to estimate the expected target.” (P20, Mikope)

Decision making processes for geospatial maps integration

Respondents at both health-area and health-zone levels emphasized that decision-making during health-zone meetings typically follows a collaborative process involving vaccinators, supervisors, and program managers, with geospatial maps serving as a central instrument for guiding dialogue, negotiation, and consensus. These maps function not merely as visual aids but as shared cognitive frameworks that facilitate evidence-informed planning and collective problem-solving. Capacity-building activities targeting community actors and local leaders strengthened understanding of the maps’ purpose and practical application, particularly by underscoring their value in designing tailored strategies for underserved or marginalized populations and by fostering active engagement of village chiefs in vaccination planning and implementation.

The inclusion of geospatial data utilization as a criterion for eligibility under the Mashako Plan funding mechanism provided further incentives for adoption. Collectively, these measures accelerated the institutional integration of geospatial mapping into vaccination planning and contributed to more effective and data-driven immunization strategies.

“We planned eight sessions: three fixed, five advanced, based on the map and the accessibility.” (P22, Mikope)

“What motivated us was the decision to reverse the trend of poor vaccination session performance.” (P23, Kakenge)

Health zone cadres played a central role in promoting and using geospatial data to support vaccination activities, with technical and logistical backing from higher health authorities. By overseeing implementation and resource allocation based on geospatial insights, they strengthened accountability, collaboration, and continuous improvement in field operations. However, some head nurses expressed concern about the absence of systematic feedback on the data and reports they submitted.

“They do monitoring, evaluation, and make decisions based on the mistakes made.” (P1, Banga Lubaka)

“Data are shared regularly in a group, which allows adequate follow-up.” (P3, Kalonda Ouest)

Determinants of Effective and Sustained geospatial data utilization

Lack of incentives was identified, and respondents highlighted the need for stronger financial incentives to offset increased workloads from additional planning, travel, and data management. Irregular or missing bonuses, lack of transport allowances, and delayed operational funds disbursement were cited as key barriers to sustaining staff motivation and engagement. Some facilities introduced small, symbolic token of appreciation, such as snacks or refreshments. While modest, these initiatives underscore both the commitment of local teams and the broader need for more structured and sustainable incentive systems to support the effective and sustained integration of geospatial data into routine immunization practice.

"*The problem remains motivating the providers." (P6, Banga Lubaka)*

"Someone used to travel for 2 hours to vaccinate. Asking him to go even farther… he'll see it as an extra burden." (P35, Mikope)

Capacity Gaps and Training Needs

A capacity gap was observed between head nurses who received formal training and their colleagues who only received informal briefings, limiting the effective use of geospatial tools. The lack of structured and ongoing training led to skill erosion over time, reducing confidence and proficiency in applying geospatial data for planning. These findings underscore the need for sustained, competency-based capacity-building to ensure consistent and effective integration of geospatial data in routine immunization activities.

"Only the persons in charge were trained; the others only received a debrief." (P7, Banga Lubaka)

Technical and Logistical Barriers

Multiple technical and logistical constraints hinder the effective and sustained use of geospatial data in vaccination activities. Key challenges include inadequate access to smartphones, computers, printers, and reliable internet or electricity, as well as transportation difficulties that limit vaccine and material delivery to remote areas, especially during the rainy season. Additional barriers such as stock-outs of vaccination cards and limited map literacy among community health workers underscore the need for improved infrastructure, resources, and continuous technical support to optimize the use of geospatial tools in immunization planning and delivery.

"Fishermen ask us for money to rent canoes. If we don't have any, we can't reach that population." (P22, Mikope)

"There was no network; we couldn't transmit data." (P2, Banga Lubaka)

Institutional and Policy Barriers

A key challenge identified was the non-inclusion of newly created health areas in geospatial maps, raising concerns about incomplete geographic coverage and reduced planning effectiveness. The absence of updated geospatial data for these areas limits accurate resource allocation and implementation. Additionally, the lack of an institutional policy mandating the systematic use of geospatial data results in inconsistent adoption, often driven by local initiative rather than standardized practice. Resistance to change among some health personnel further constrains integration, underscoring the need for strengthened leadership engagement, and policy frameworks to institutionalize geospatial data use within immunization programs.

"Since all 18 health areas received [maps], let's extend it to all 25 because other health areas have been created." (P1, Banga Lubaka)

Positive perceptions

Vaccinators and stakeholders expressed positive perceptions of geospatial data, describing it as highly valuable and reliable for enhancing planning accuracy, improving operational efficiency, and strengthening community engagement. They expressed strong commitment to sustaining the use of these tools and emphasized the need for continued technical and financial support, regular data updates, and ongoing capacity building to ensure the long-term effectiveness and institutionalization of geospatial approaches in routine immunization programs.

Other determinants

The effective and sustained use of geospatial tools in vaccination planning and delivery is shaped by interrelated infrastructural, sociocultural, and organizational factors. Infrastructural gaps—such as poor transportation, limited digital equipment, and unreliable electricity and internet—impede both service delivery and the practical application of geospatial data. Sociocultural barriers, including weak community engagement and persistent vaccine misconceptions, further constrain impact. At the organizational level, the absence of automated systems for updating geospatial information threatens data accuracy and relevance amid dynamic population changes.

"*Mothers were stubborn about not coming. They told us with your vaccines; our children get fevers." (P28, Kakenge)*

"We were trained in 2022, in Mikope. But we need ongoing capacity-building." (P36, Mikope)

Aim 2: Assess the level of community engagement and the integration of "gender" aspects in vaccination activities

Description of study participants

For the ethnographic study, we included both In-deep interviews and Focus-group participants for the 6 health zones with a total of 27 respondents (appendix 2). Men represented the majority of respondents (18/27), most of them were between 40–49 years old (10/27), majority with a degree (12/27), almost all were married (25/27), mostly Community health workers (14/27), and with professional experience of over 10 years. Specifically, in-depth interview respondents were male, working in the rural areas (9/13), while women were mostly represented in focus groups (8/14) working also in rural areas. Focus group participants were predominantly community workers, whereas in depth interview respondents were mostly health providers.

Community engagement in vaccination activities

Community leaders and community health providers are involved in immunization activities as well as generating geospatial maps and data.

Community participation was reinforced through coordinated strategies, including the public display of monthly vaccination schedules and collaboration with community-based organizations leaders for the identification and follow-up of unvaccinated children, head nurse–led briefings, and community outreach campaigns, community radio stations support in social mobilization and information dissemination.

"My commitment is that all children in my Health Area are vaccinated… to prevent vaccine-preventable diseases." (P6, Head nurse, ESS Kamonia)

"I supervise community activities, epidemiological surveillance, and vaccination." (P11, Head nurse, ESS Tshikapa)

"We visit each household where there is a pregnant woman, a malnourished child…" (P6, Community health workers, FG Kamonia)

Community engagement in developing geospatial maps was grounded in a participatory approach involving diverse stakeholders, including community health workers, head nurses, and health zone chief medical officers. Their contributions included household enumeration, identification of key local landmarks such as churches, schools, and streets, and the validation of health area and zone boundaries to ensure the maps accurately reflected community realities.

"We were showing the strategic points of our health area, such as church X or school Y." (P1, FG Kamonia)

"I worked with the mapping officer to identify missed places." (P12, ESS Tshikapa)

Gender-Sensitive Approaches and Women's Participation in Vaccination Activities

Women played key roles in community mobilization, information dissemination, and occasionally in vaccine administration, contributing to improved coverage by ensuring children's attendance and supporting logistical arrangements. A notable shift was observed in vaccination planning, with an increased involvement of both women and men in community vaccination activities. Women's representation in community structures has grown, while a rising number of fathers now bring their children for vaccination when mothers are unavailable reflecting a gradual shift toward more equitable gender participation in immunization efforts.

"They help us mobilize and guide other women." (P10, ESS Tshikapa)

"Among our CAC presidents, 60% are women." (P13, ESS Tshikapa)

"Vaccination is no longer just a mothers' issue; fathers are also involved." (P1, FG Tshikapa).

Despite progress in promoting community engagement and gender inclusion, several challenges continue to limit full participation. Gender integration among health providers also remains limited, particularly due to the near absence of women in head nurse positions, a legacy of historical gender disparities in education. Participants also cited the lack of supportive measures, such as adequate sanitation facilities and childcare during community activities, alongside persistent social stigma, vaccine misconceptions, and religious or ethnic tensions that further hinder women's involvement in vaccination efforts. Furthermore, insufficient incentives continue to constrain female engagement in vaccination activities, despite reports of symbolic or informal support provided locally.

"Many women lack enough autonomy to participate." (P11, ESS Tshikapa)

"The mother-in-law teases the woman: in our day, we never had your vaccination business." (P4, ESS Kamako)

"Women were greatly minimized and excluded from society for a long time; our parents only schooled boys and said a woman's place is in the kitchen." (P3, FG Kamonia)

“Community workers and PRESICODESA (community organization leaders) presidents should be provided phones to record data.” (P6, FG Tshikapa)

Aim 3: Evaluate the effectiveness of the M4H project intervention through vaccination coverage surveys and vaccination activity results before and after introducing geospatial data

Vaccine coverage before and after the intervention

Analysis of Vaccination Coverage Survey (VCS) data from 2021 to 2023, based on three key indicators Penta1, Penta3, and full vaccination coverages reveals substantial heterogeneity across health zones in both temporal trends and post-intervention impacts. The years 2021 and 2022 represent the pre-intervention period, providing a baseline against which to assess trends prior to the introduction of geospatial data and mapping.

During this pre-intervention phase, a relative improvement in coverage was observed in several health zones, notably Banga-Lubaka, Kakenge, Mikope, and Kalonda-Ouest. This upward trend was consistent across all three antigens. However, a persistent gap between Penta1 and Penta3 coverage was evident throughout the period, suggesting some dropout between the first and third doses in all health zones (Fig. 2).

Across all health zones, Mikope is the only one to demonstrate a steady increase in full vaccination coverage throughout the study period. Coverage rose from 21.3% (95% CI: 9.3–41.9) in 2021 to 26.4% (95% CI: 7.5–61.4) in 2022, and further to 32.4% (95% CI: 17.0–53.0) in 2023, indicating a gradual and sustained improvement. However, the wide confidence intervals, particularly in 2022, underscore substantial variability and warrant cautious interpretation of these findings. Comparisons between 2022 and 2023, as well as between 2021 and 2023, reveal a generalized decline in several health zones. Between 2022 and 2023, decrease was particularly pronounced for Penta3 coverage and full vaccination in Banga-Lubaka, Kamonia, Mikope, and Ndjoko-Mpunda. Kalonda-Ouest, Mikope and Kakenge reported improvements in Penta3 coverage. When comparing 2021 to 2023 data, trends remain variable. Kalonda-Ouest, Kakenge, and especially Mikope show consolidated positive trends, with cumulative gains across all three indicators. Notably, Mikope experienced a substantial increase in full vaccination coverage, rising from 20.2% (95% CI: 11.9–32.3) in 2021 to 49.5% (95% CI: 42.1–56.9) in 2023. In contrast, Kamonia, Ndjoko-Punda, and Banga-Lubaka exhibited marked declines most prominently in the first two zones, where coverage decrease was observed across all three coverage indicators.

All figures for the pre- and post-intervention comparisons, including their corresponding 95% confidence intervals, are summarized in Table 4. Overall, changes observed between 2021 and 2023 are more pronounced than those between 2022 and 2023, suggesting that longer observation period captures more substantial shifts in vaccination coverage.

Table 2
Vaccination Coverage Indicators Among Children Aged 12–23 Months Between 2022–2023 and 2021–2023 by Health Zone in Kasaï Province (VCS)

Health Zones	Vaccine coverage	2022		2023		2021		2023	
		(%)	IC95%	(%)	IC95%	(%)	IC95%	(%)	IC95%
Kalonda-Ouest	Penta1	68,4	[46,2–84,5]	54,8	[39,1–69,6]	51,8	[32,9–70,2]	54,8	[39,1–69,6]
	Penta3	36,1	[16,9–61,0]	37,2	[22,2–55,2]	27,4	[14,1–46,5]	37,2	[22,2–55,2]
	Full coverage	26,4	[7,5–61,4]	32,4	[17,0–53,0]	21,3	[9,3–41,9]	32,4	[17,0–53,0]
Kamonia	Penta1	65,2	[52,8–75,7]	49,5	[38,3–60,8]	82,2	[68,3–90,9]	49,5	[38,3–60,8]
	Penta3	44,5	[36,0–53,4]	17,9	[7, 6–36, 4]	50,6	[37,9–63,3]	17,9	[7, 6–36, 4]
	Full coverage	30,3	[22,5–39,4]	10,7	[3, 1–30, 9]	44,8	[29,9–60,7]	10,7	[3, 1–30, 9]
Banga-Lubaka	Penta1	87,4	[74,0–94,4]	77,8	[65,4–86,7]	90,7	[81,0–95,7]	77,8	[65,4–86,7]
	Penta3	69,9	[60,9–77,6]	43,0	[29,5–57,6]	53,5	[41,6–65,0]	43,0	[29,5–57,6]
	Full coverage	45,7	[37,1–54,5]	29,5	[19,3–42,2]	33,5	[17,1–55,0]	29,5	[19,3–42,2]
Ndjoko-Punda	Penta1	75,4	[70,1–80,0]	62,7	[52,3–72,0]	83,6	[71,9–91,0]	62,7	[52,3–72,0]
	Penta3	34,9	[16,7–59,0]	42,1	[35,2–49,3]	49,2	[37,2–61,3]	42,1	[35,2–49,3]
	Full coverage	28,2	[14,2–48,2]	22,5	[15, 6–31, 4]	41,3	[31,4–51,9]	22,5	[15, 6–31, 4]
Mikope	Penta1	92,6	[87,0–95,9]	88,3	[79,9–93,5]	84,5	[76,2–90,3]	88,3	[79,9–93,5]
	Penta3	76,4	[60,2–87,4]	64,5	[52,7–74,8]	46,1	[35,7–56,8]	64,5	[52,7–74,8]
	Full coverage	68,9	[52,4–81,6]	49,5	[42,1–56,9]	20,2	[11, 9–32, 3]	49,5	[42,1–56,9]
Kakenge	Penta1	93,3	[79,1–98,1]	90,3	[83,5–94,4]	85,7	[76,3–91,7]	90,3	[83,5–94,4]
	Penta3	69,7	[51,0–83,5]	62,3	[46,9–75,6]	49,2	[35,8–62,8]	62,3	[46,9–75,6]
	Full coverage	40,0	[28,7–52,3]	29,8	[18,7–43,9]	35,0	[25,6–45,7]	29,8	[18,7–43,9]

Operational-level indicators of organization and delivery of vaccination services

A quantitative analysis of vaccination register data from health centers across the selected health areas highlights changes in six key indicators directly linked to the organization and delivery of vaccination services. These indicators are: (i) integration into microplanning, (ii) use of geospatial data as denominator for target population, (iii) number of vaccination sites organized, (iv) quantity of vaccine doses ordered, (v) number of children reached through catch-up activities, and (vi) number of vaccination sessions conducted. All these indicators illustrate how the introduction and use of geospatial tools influenced programmatic practices between 2020 and 2024.

Integration of geospatial data into micro-planning

Following the introduction of geospatial data and mapping tools, its integration into annual microplanning in 2024 increased, reaching 88% of the 42 health areas analyzed. Integration was complete in Kakenge, Mikope, and Ndjoko Punda, while it remained partial in Kalonda Ouest,

Kamonia, and Banga Lubaka. Prior to 2023, geospatial data were not incorporated into planning in any health zone. This substantial increase underscores a notable shift toward evidence-based microplanning and spatially informed decision-making following the intervention.

Use of geospatial data to estimate target populations

Despite progress in integrating geospatial tools into planning, their use for the estimation of target populations remained limited. By 2024, only 17% of health areas (7 out of 42) reported using geospatial data as the primary source for calculating target populations. These findings indicate that while integration into planning has advanced, the transition from traditional demographic estimation methods to geospatially informed approaches remain incomplete and uneven across zones.

Number of vaccination sites

The number of planned vaccination sites increased in five of the six health zones following the introduction of geospatial data, with the most substantial gains observed in Kakenge. Between 2020 and 2022 (pre-intervention), the number of sites remained relatively stable across all zones. From 2023 onward, a clear upward trend emerged: the number of vaccination site in Kakenge increased from 34 sites in 2022 to 56 in 2023 and 59 in 2024; in Kalonda Ouest from 55 to 57 and then to 70; and in Kamonia from 49 to 51 and then to 66. Mikope showed a similar, though more moderate, upward trend, while Banga Lubaka remained stable at 30 sites for several years, with a slight increase to 37 sites in 2024. These trends suggest that geospatial mapping contributed to more precise identification of underserved areas and informed decisions to establish additional vaccination sites.

Quantity of vaccine doses purchased

The introduction of geospatial data was also associated with increased requisition of vaccine doses and related supplies in most zones, although the magnitude and trajectory of change varied. Banga Lubaka, Kakenge, Mikope, and Ndjoko Punda recorded continuous increases in vaccine orders from 2020 to 2024 without year-to-year declines. For instance, cumulative orders in Kakenge rose from 64,310 doses in the pre-intervention period (2021–2022) to 78,140 doses post-intervention (2023–2024), while Kalonda Ouest saw an increase from 93,520 to 122,152 doses over the same periods. Kamonia and Kalonda Ouest exhibited more irregular patterns, with episodes of decline or stagnation followed by significant rebounds by 2023–2024. These patterns suggest that the use of geospatial data may have improved planning accuracy and demand forecasting, though structural or logistical constraints continued to influence supply dynamics in some areas.

Number of children reached through catch-up immunization activities in health zones

The comparison of cumulative annual numbers of children reached through catch-up vaccination activities between the pre-intervention (2021–2022) and post-intervention (2023–2024) periods revealed heterogeneous patterns across zones. Banga Lubaka, Kamonia, Mikope, and Kakenge recorded increases, indicating improved identification and follow-up of missed children. In contrast, Kalonda Ouest and Ndjoko Punda showed declines. Across the 2020–2024 period, trends were irregular, with alternating periods of progress and regression depending on the zone. Even in 2024, compared with baseline levels, results remained inconsistent.

Geospatial maps effect on vaccination sessions

A comparison of cumulative average monthly vaccination sessions before (2021–2022) and after (2023–2024) the introduction of geospatial tools reveals clear improvements across all health zones. The most substantial increases were observed in Kamonia, while the smallest change occurred in Ndjoko Punda. A pronounced upward trend was noted in the beginning of 2023, the year when geospatial data were first integrated into microplanning in most zones. Banga Lubaka and Kalonda Ouest also showed notable progress, particularly in 2024. These increases suggest potential enhancing service availability and accessibility.

All the results described above are summarized in the Table below.

Table 3: Overall variations in indicators of the delivery of vaccination services between Pre (2020-22) and Post test (2023-24) periods

	Integration of geo data in microplanning (cumulative)			Use of geo data as denominator (cumulative)			Nbr of vaccination sites organized (Average/year)			Quantity of vaccine doses ordered (cumulative)			Children reached through catch-up (cumulative)			Number of vaccination sessions conducted (cumulative)		
Health Areas by Health Zone	Pre	Post	Vari. Post -Pre	Pre	Post	Vari. Post -Pre	Pre	Post	Vari. Post -Pre	Pre	Post	Vari Post - Pre	Pre	Post	Vari. Post - Pre	Pre	Post	Vari. Post -Pre
Banga Lubaka (n=6)	0	5	5	0	1	1	30	34	4	23284	27780	4496	0	523	523	54	84	30
Kakenge (n=8)	0	8	8	0	0	0	30	56	26	64310	78140	13830	4506	5484	978	53	92	39
Kalonda Ouest (n=8)	0	6	6	0	2	2	52	64	12	93520	122152	28632	5687	5206	- 481	121	158	37
Kamonia (n=8)	0	6	6	0	2	2	46	59	13	60736	92393	31657	3368	4863	1495	95	157	62
Mikope (n=7)	0	7	7	0	2	2	28	42	14	45654	54815	9161	658	1130	472	80	100	20
Ndjoko Punda (n=5)	0	5	5	0	0	0	26	25	-1	16514	20180	3666	561	403	-158	50	51	1
Total (n=42)	0	37	37	0	7	7	212	280	68	304018	395460	91442	14780	17609	2829	453	642	189

* Vari.: Variation between Post intervention and Pre intervention of the M4H project.

Source: Data from the vaccine registries in Health Areas

Aim 4: Conduct an economic analysis of costing data related to producing and implementing geospatial tools

The total cost of implementing M4H initiative in Kasaï was estimated at $1,338,148.81. The cost of personnel accounted for the majority of the total expenditures, at 72.6% or $971,627.17, followed by travel and transportation at 12.4% or $166,331.00, operational costs at 7.8% or $ $104,126.07. and training at 2.0% or $26,212.25, supplies and equipment accounted for the smallest share at 1.8% or $22,924.25.

To calculate the estimated amount for each health zone in the province, the cost of the entire province of Kasaï was disaggregated and devised 18 health's zones that compose the Kasaï province. This led to a cost estimate of $74 341.6 per health zone, equally applied to all the 18 health zones, due to lack of specific expenditure data. For the 6 health zones of the study, these estimated costs amounted $446 049.60.

For the whole project, these cost distributions demonstrated that M4H implementation was primarily labor-intensive, with the majority of spending allocated to personnel for GIS mapping, coordination, and consultations. Non-personnel costs such as operations, supplies, travels, and trainings were accounted for approximately one quarter of total expenditures, as presented in the table below.

Table 4
Distribution of project implementation Costs in Kasaï

Cost Category	Amount (USD)	Percent of Total Costs
Personnel	$971,627.17	72.61%
Operation	$104,126.07	7.78%
Supplies and Equipment	$22,924.25	1.71%
Training	$26,212.25	1.96%
Travel and Transportation	$166,331.00	12.43%
Contingency	$46,928.07	3.51%
Total Costs	**$1,338,148.81**	100.00%
Cost per health zone in Kasaï (x/18)	**$74,341.6**	
Costs for 6 health zones of the study (x*6)	**$446,049.60**	

Cost per One Percentage Point Change in Full Immunization Coverage

Between pre- and post-intervention, vaccination coverage varied across the health zones. Kalonda-West and Mikope demonstrate the increase in full immunization coverage of 11.1% increase and 29.3% increase respectively. While Kamonia, Ndjoka-Punda, Kakenge and Banga-Lubaka experienced a significant decline of 34.1%, 18.8%, 5.2% and 4%, accordingly. Across all six health zones, the total absolute percentage change in full immunization coverage between 2021 and 2023 was 102.5 percentage points, including both positive and negative changes. The cost per one percentage point change in coverage was estimated at $4 351,70. When disaggregated by health zone, per-unit costs ranged from $2,180.11in Kamonia to $18,585.40 in Banga-Lubaka as presented in the table below.

Table 5
Cost per One Percentage Point Change in Full Immunization Coverage (12–23 months), by Health Zone in Kasaï, 2021 vs 2023

Health Zone	2021% Full immunization coverage (95% CI)	2023% Full immunization coverage (95% CI)	% point Change	Per Unit Cost (USD)
Banga-Lubaka	33.5 [17.1–55.0]	29.5 [19.3–42.2]	-4	18 585,40
Kakenge	35 [25.6–45.7]	29.8 [18.7–43.9]	-5.2	14 296,46
Kalonda-West	21.3 [9.3–41.9]	32.4 [17.0–53.0]	+ 11.1	6 697,44
Kamonia	44.8 [29.9–60.7]	10.7 [3.1–30.9]	-34.1	2 180,11
Mikope	20.2 [11.9–32.3]	49.5 [42.1–56.9]	+ 29.3	2 537,26
Ndjoko-Punda	41.3 [31.4–51.9]	22.5 [15.6–31.4]	-18.8	3 954,34
Kasaï			**|102.5|**	**4 351,70**

Costs per unit of variation in indicators of the delivery of vaccination services between Pre-test (2020-22) and Post-test (2023-24) periods are summarized in the table below

Table 6
Costs per unit of the variation in outputs indicators of delivery of vaccination services

Health Areas by Health Zone	Integration of geo data in micro-plans		Use of geo data as denominator		Number of new vaccination sites organized		Quantity of vaccine doses ordered		Children reached through catch-up		Nbr of vaccination sessions conducted	
	Vari. Post - Pre	Per-Unit Cost	Vari. Post -Pre	Per-Unit Cost	Vari. Post - Pre	Per-Unit Cost	Vari. Post -Pre	Per-Unit Cost	Vari. Post - Pre	Per-Unit Cost	Vari. Post - Pre	Per-Unit Cost
ZS de Banga Lubaka (n = 6)	5	**14 868,32**	1	**74 341,60**	4	**18 585,40**	4 496	**16,54**	523	**142,14**	30	**2 478,05**
ZS de Kakenge (n = 8)	8	**9 292,70**	0	**-**	26	**2 859,29**	13 830	**5,38**	978	**76,01**	39	**1 906,19**
ZS de Kalonda Ouest (n = 8)	6	**12 390,27**	2	**37 170,80**	12	**6 195,13**	28 632	**2,60**	– 481	**-154,56**	37	**2 009,23**
ZS de Kamonia (n = 8)	6	**12 390,27**	2	**37 170,80**	13	**5 718,58**	31 657	**2,35**	1 495	**49,73**	62	**1 199,06**
ZS de Mikope (n = 7)	7	**10 620,23**	2	**37 170,80**	14	**5 310,11**	9 161	**8,12**	472	**157,50**	20	**3 717,08**
ZS de Ndjoko Punda (n = 5)	5	**14 868,32**	0	**-**	-1	**-74 341,60**	3 666	**20,28**	-158	**-470,52**	1	**74 341,60**
Total (n = 42)	**37**	**12 055,39**	**7**	**63 721,37**	**68**	**6 559,55**	**91 442**	**4,88**	**2 829**	**157,67**	**189**	**2 360,05**

*** Vari.: Variation between Post intervention and Pre intervention of the M4H project.**

Cost per Health Area Integrating Geospatial Data into Microplanning

Between the pre- and the post-intervention, a total of 37 health areas integrated geospatial data into their microplanning processes. The overall cost per health area integrating geospatial data was estimated at $12,055.39. Zone-specific costs ranged from $9,292.70 in Kakenge and $10,620.23 in Mikope to $14,868.32 in both Banga-Lubaka and Ndjoko-Punda.

Cost per Health Area using Geospatial Data as Denominators for Target Populations

Across all six health zones, seven health areas began using geospatial data as denominators for estimating target populations. The overall cost per health area using this approach was estimated at $63,721.37. Zone-specific costs were highest in Banga-Lubaka at $74,341.60 due to a single health area adopting the system, while lower per-unit costs were observed in Kalonda-West, Kamonia, and Mikope at $37,170.80 each.

Cost per New Vaccination Site Established

Across all six health zones, 68 new vaccination sites were established between pre- and post-intervention, with the cost per site estimated at $6,559.55. Per-unit costs varied widely by health zone, ranging from $2,859.29 in Kakenge to $18,585.40 in Banga-Lubaka.

Cost per Additional Vaccine Dose Ordered

Between the pre- and the post-intervention, the total number of vaccine doses ordered across the six health zones in Kasaï increased by 91,442 doses. The overall cost per additional dose ordered was estimated at $4.88. Zone-specific costs ranged from $2.35 in Kamonia to $20.28 in Ndjoko-Punda. Zones with higher ordering volumes, such as Kamonia and Kalonda-West, achieved lower per-unit costs, while areas with smaller incremental orders incurred higher costs per additional dose.

Cost per Additional Child Immunized during Catch-up (Recovered Child)

Across all six health zones, the number of children immunized through catch-up campaign in Kasaï increased by 2,829 children. The overall cost per additional child immunized was estimated at $157.67. Zone-specific costs ranged from $49.73 in Kamonia and $76.01 in Kakenge to $157.50 in Mikope and $142.14 in Banga-Lubaka. Similar to the trends observed in full immunization coverage, the differences in coverage across health zones likely reflect not only actual variations in vaccination performance but also improvements in the accuracy of population denominators.

Cost per Additional Vaccination Session

Across all six health zones, the total number of vaccination sessions increased by 189 between the pre-and post-intervention. The overall cost per additional session was estimated at $2,360.05. Zone-specific costs varied from $1,199.06 in Kamonia to $3,717.08 in Mikope, with an outlier value of $74,341.60 in Ndjoko-Punda due to only one additional session.

The table below summarizes the per-unit cost estimates for each of the seven program indicators described above.

Table 7
Summary of Per-Unit Costs for All Output Indicators, in Kasaï

1	**Output Indicators**	**Per Unit Cost (USD)**
	Cost per one percentage point change in full immunization coverage	**4 351,70**
2	Cost per health area integrating geospatial data into microplanning	12 055.39
3	Cost per health area using geospatial data as denominators for target populations	63 721.37
4	Cost per new vaccination site established	6 559.55
5	Cost per additional vaccine dose ordered	4.88
6	Cost per additional child immunized (via catch-up campaign)	157.67
7	Cost per additional vaccination session	2 360.05

DISCUSSION

Adoption and Use of Geospatial Tools

The high proportion of health facilities displaying geospatial maps (88%) and the generally positive feedback from providers indicate early ownership and perceived utility of geospatial tools for immunization microplanning. It has been shown that spatial tools visualization has improved awareness and planning confidence at health areas level. However, concerns related to increased workload echo broader implementation research showing that digital and geospatial innovations often shift, rather than reduce, the burden of work unless accompanied by institutional support, task reallocation, and incentives [1, 12]. Sustained adoption therefore depends on embedding geospatial data use, supported by adequate logistics, financing, supervision, and workforce motivation, while monitoring a constellation of factors related to technology, users, organization, and the political context [1, 7, 12–14]. In addition, technical improvements with regular data updates and a better integration into official EPI procedures need to be implemented [15–19]. Monitoring the risks and errors induced by technology is essential to maintaining user confidence [20–22].

Consistent with studies from Nigeria and other sub-Saharan African contexts, geospatial data improved the identification of hard-to-reach settlements, outreach routes, and underserved populations, reinforcing its value for equity-oriented microplanning [2, 5, 6, 23]. Nevertheless, resistance to using geospatial population estimates as denominators reflects a well-documented tension between administrative data systems, survey's data and modeled spatial estimates [3, 24].

Evidence suggests that a phased, hybrid approach—combining geospatial denominators with routine administrative data and progressively strengthening user confidence through training and feedback—can facilitate acceptance and more accurate planning [1, 25].

Community Engagement and Gender

Community health workers, local leaders, and women played a critical role in validating geospatial information by confirming settlement locations, landmarks, routes, and population movement patterns. Participatory mapping approaches have been shown to improve data accuracy, legitimacy, and local ownership, while strengthening trust between communities and health services [26–28]. Institutionalizing community validation within routine microplanning can therefore enhance both technical quality and social accountability. However, health workers (RECOs) claim very often for incentive bonuses due to extra workload caused by geospatial data, as their status of unpaid volunteers does not encourage them to make additional efforts in support of routine vaccination activities [29, 30].

The active involvement of women as community relays, vaccinators, and mobilizers is particularly noteworthy, as gender-inclusive delivery strategies have been associated with improved access, acceptability, and uptake of immunization services [31, 32]. However, the persistent underrepresentation of women in senior facility leadership positions reflects structural gender inequities within the health systems, which was not explicitly addressed during the intervention.

Effects on Coverage Versus Service Performance

This evaluation does not provide sufficient evidence to conclude that the introduction of geospatial maps led to measurable improvements in pentavalent vaccine coverage. While one health zone showed a modest increase, wide confidence intervals indicate substantial uncertainty. These findings must be interpreted in the context of broader national and global trends, which documented stagnation or declines in routine immunization coverage during the same period [8, 33, 34]. Similar disruptions and reversals in coverage have been reported globally, particularly in fragile and conflict-affected settings [34].

In contrast, several operational performance indicators improved following the introduction of geospatial tools. Integration of maps into annual microplans, increases in the number of planned vaccination sites and sessions, improved requisition of vaccines and supplies, and higher numbers of children reached through catch-up activities suggest enhanced organization and efficiency of service delivery. Comparable findings have been reported in studies linking geospatial microplanning to improved service readiness, outreach efficiency, and resource allocation, recognizing such intermediate operational gains as critical precursors to longer-term improvements in coverage and equity [7, 25, 35].

Economic Considerations

The cost analysis indicates that personnel expenditures accounted for nearly three-quarters of total costs, underscoring the labor-intensive nature of geospatial data production, validation, and use. Similar cost structures have been observed in other GIS-supported health interventions, where human capital represents the principal input during early implementation phases [35]. While the estimated cost per additional child immunized through catch-up activities appears high, this finding is consistent with evidence showing that outreach to remote, sparsely populated, and underserved populations entails higher marginal costs [36]. As geospatial systems mature and become institutionalized, economies of scale and efficiency gains may reduce unit costs over time.

Study Strengths

This study has several important strengths. First, its mixed-methods design enabled triangulation of quantitative service and coverage indicators with qualitative insights from providers and community actors, offering a nuanced understanding of both outcomes and mechanisms. Second, inclusion of multiple health zones and related health areas with heterogeneous geographic and operational contexts enhances the internal validity and relevance of findings for provincial-level decision-making. Third, the combined analysis of coverage outcomes and operational performance indicators responds to calls in the literature to move beyond coverage alone when evaluating health-system innovations, particularly those targeting planning and management processes.

Study Limitations

Several limitations should be acknowledged. The absence of a control province or comparison area limits causal attribution, as concurrent national and contextual factors may have influenced observed trends. The relatively short post-intervention observation period constrained assessment of longer-term effects on immunization coverage. Data quality remains a concern, as routine facility registers may suffer from incompleteness and reporting errors, despite ongoing national efforts to strengthen health information systems. In addition, reliance on secondary data limited the ability to explore household-level determinants of vaccination uptake or to fully capture population mobility dynamics.

Research and Programmatic Implications

To maximize the impact of geospatial data on immunization outcomes, routine integration of maps into microplanning, supervision, and review meetings is essential. However, these data need to be supported by regular updates to maintain its accuracy. Geospatial innovations

should be aligned with strengthened logistics, supply-chain management, and supportive supervision. Institutionalization within EPI guidelines, coupled with financial and non-financial incentives, will be critical for sustainability. Future evaluations should adopt longer time horizons, quasi-experimental designs where feasible, and mixed indicators capturing equity, efficiency, and resilience. Strengthening gender equity and community participation, when using geospatial data into decision-making processes, may further enhance the equity impact of geospatial approaches.

Conclusion

Overall, the findings indicate that the use of geospatial data—particularly maps—substantially improved vaccination microplanning and operational performance, while also fostering community engagement and attention to gender considerations. The intervention achieved key intermediate outcomes, including improved identification of target populations and greater efficiency in vaccination operations. However, the study does not provide conclusive evidence of an impact on pentavalent vaccine coverage within the observation period.

The substantial financial investment and labor-intensive nature of the project underscore the importance of institutionalization and efficiency gains for sustainability. Increases in output and performance indicators can reasonably be interpreted as early improvements in service delivery that may, over time, translate into more equitable and resilient immunization systems if geospatial tools are embedded in routine decision-making.

Declarations

Ethics approval

The Mapping for Health Study has been reviewed and cleared by the Kinshasa School of Public Health Internal Review Board. The study was also registered with BMC Central International Standard Randomized Controlled Trial Number ISRCTN65876428 on 3/11/2021. The research team obtained informed written consent from all study participants prior to their engagement in the research study.

Competing interests

The authors declare no competing interests.

Author Contribution

DNB is the Principal Investigator and led the research process on behalf of the Kinshasa School of Public Health. MJB and SA guided on the study design, provided inputs in data analysis, contributed in the manuscripts and supported the review to ensure the scientific validity. GLL, MIK, YKM collected data and performed first analyses and drafted the manuscript with FFB and TKB. PM and OD led the overall research design and interactive process on behalf of health.enabled. All co-authors participated in the interactive process of the writing of the manuscript, and for its validation before its submission for publication.

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Data Availability

All key data are provided within the manuscript and can be requested via email to ngobebed@gmail.com.

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Figures

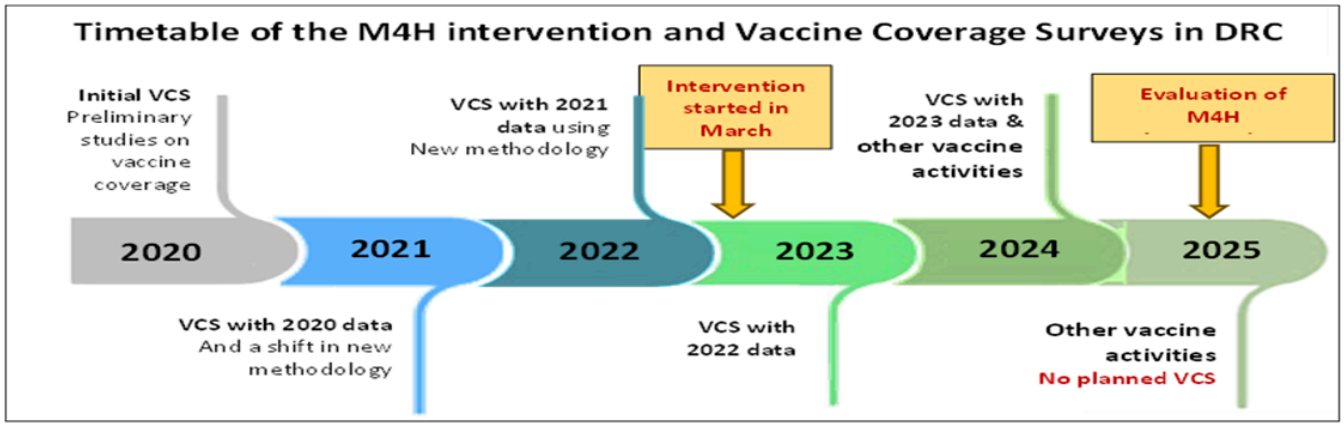


Figure 1

M4H implementation timeline

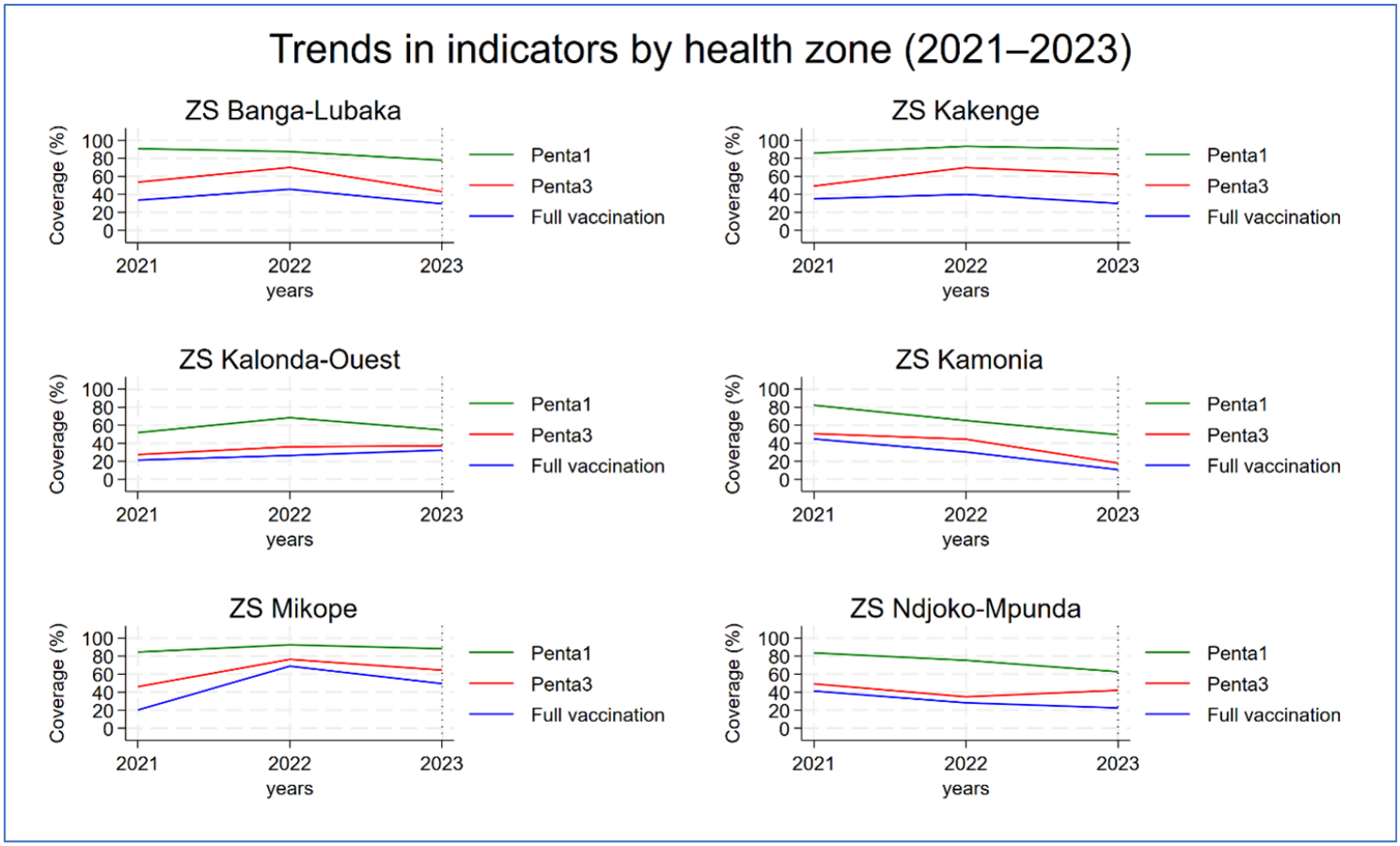


Figure 2

Trends in Combined Vaccination Coverage Indicators by Health Zone, 2020–2023 (VCS)

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