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Geographic inequalities, and social-demographic determinants of reproductive, maternal and child health at sub-national levels in Kenya

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Abstract

Background Global initiatives have emphasized tracking indicators to monitor progress, particularly in countries with the highest maternal and child mortality. Routine data can be used to monitor indicators for improved target setting at national and subnational levels. Our objective was to assess the geographic inequalities in estimates of reproductive, maternal and child health indicators from routine data at the subnational level in Kenya.

Methods Monthly data from 47 counties clustered in 8 regions, from January 2018 to December 2021 were assembled from the District Health Information Software version 2 (DHIS2) in Kenya. This included women of reproductive age receiving family planning commodities, pregnant women completing four antenatal care visits, deliveries conducted by skilled birth attendants, fully immunized children at 1 year and number of maternal deaths at health facilities, from which five indicators were constructed with denominators. A hierarchical Bayesian model was used to generate estimates of the five indicators at the at sub-national levels(counties and sub counties), adjusting for four determinants of health. A reproductive, maternal, and child health (RMCH) index was generated from the 5 indicators to compare overall performance across the continuum of care in reproductive, maternal and child health across the different counties.

Results The DHIS2 data quality for the selected 5 indicators was acceptable with detection of less than 3% outliers for the Facility Maternal Mortality Ratio (FMMR) and less than 1% for the other indicators. Overall, counties in the north-eastern, eastern and coastal regions had the lowest RMCH index due to low service coverage and high FMMR. Full immunization coverage at 1 year (FIC) had the highest estimate (79.3%, BCI: 77.8—80.5%), while Women of Reproductive age receiving FP commodities had the lowest estimate (38.6%, BCI: 38.2–38.9%). FMMR was estimated at 105.4, (BCI 67.3–177.1)Health facility density was an important determinant in estimating all five indicators. Maternal education was positively correlated with higher FIC coverage, while wealthier sub counties had higher FMMR.

Conclusions Tracking of RMCH indicators revealed geographical inequalities at the County and subcounty level, often masked by national-level estimates. These findings underscore the value of routine monitoring indicators

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as a potential for evidence-based sub-national planning and precision targeting of interventions to marginalized populations.

Keywords Reproductive, Maternal, Child

Background

Women and children experience the worst health outcomes from preventable diseases globally and particularly in low- and middle-income countries (LMICs) [1, 2]. The highest rates of maternal, and child deaths are in sub-Saharan Africa countries [3]. In 2020, the global estimate of MMR was 233 deaths per 100,000 live births while the MMR in the African Region was 531 deaths per 100,000 live births. The African Region accounted for 69% of global maternal deaths in 2020 [4]. The Global under 5 mortality in 2020 was 38 per 1,000 live births while the in the African region the estimate was almost double at 72 deaths per 1,000 live births [5]. The Kenya MMR has stagnated at 362 deaths per 100,000 live births, with an under 5 mortality rate of 52 deaths per 1,000 live births [6]. It is therefore important to improve health service delivery strategies and interventions across the continuum of care in reproductive, maternal, and child health (RMCH) to ensure accountability and outcomes. To assess progress in coverage of essential RMCH interventions, global monitoring initiatives including Global Strategy for Women's, Children's and Adolescents' Health [7] and Countdown to 2030 [8] have emphasized monitoring and evaluation through tracking of priority indicators against global and national targets [9–11]. However, aggregated estimates at national level mask existing inequalities within counties which are associated with disparities in wealth, urban/rural residence, and geographical access to health services [12–14].

A key strategy for achieving equitable health service access is examining geographical inequalities and targeting interventions to populations in need to ensure no one is left behind [15]. Demographic and Health Surveys and Multiple Indicator Cluster surveys have mainly been utilized to track progress in coverage of RMCH interventions at population level and consequently highlight geographic inequalities [16, 17]. However, due to the high costs, these household-cluster surveys are done once in a five-year interval, or longer which restricts assessment of short-term temporal trends and data are representative of larger geographic administrative sampling strata. Routine health information systems provide an alternative for examining inequalities at fine spatial and temporal resolution given that the data is collected monthly at facility level and can be analyzed at facility, subcounty, and county level. The District Health Information System Software version 2 (DHIS2) is a free open source, web-based database and application for collecting, processing, and analyzing health information. It is currently in use in 80 LMICs [18] as a primary data source to generate health statistics for monitoring health service utilization and trends to guide evidence-based decision making in allocation of limited resources at subnational levels [19–21]. DHIS2 was adopted in Kenya in 2011 serving as a harmonized platform for routine data management and health service reporting at the health facilities [22]. Kenya adopted a devolved system of governance introducing two tiers of government; a national government and 47 semiautonomous county governments used for policy planning. Following decentralization, county governments are mandated to ensure healthcare service delivery within county health while the national government through the ministry of health is responsible for managing of national referral hospitals, developing health policies and providing capacity building [23].

Routine data has been used to evaluate performance of specific indicators along the Reproductive Maternal Newborn Child Adolescent Health (RMNCAH) continuum of care against national and subnational targets. This has included several indicators [24–26]. Family planning uptake, antenatal care during pregnancy and deliveries by skilled birth attendants have been established as effective approaches in reducing the risk of maternal mortality [27–29]. Accelerated increase in high impact RMNCAH interventions and consequent decline in maternal and child mortality will require targeting of interventions specific to these indicators. An advantage of using routine data is that these indicators can be monitored routinely and estimated at granular levels for improved understating of health service coverage uptake and outcomes for RMNCAH and more broadly.

In order to assess and compare overall implementation and impact of RMNCAH interventions and outcomes between regions, countries and subnational geographies, composite RMNCAH indices have been developed using a mix of survey and routine DHIS2 data. Composite indices have also been used to make comparisons of outcomes and impact over time. Examples include the RMNCAH sub index [30] which forms part of the Universal Health Coverage Service Coverage index (UHC SCI), among others [31–34].

This study sought to answer three questions; 1. What are inequalities at national and subnational level in routine RMCH indicators in Kenya, 2. Can a composite

RMCH index (RI)using routine DHIS2 data be used to effectively assess inequalities across the counties for target setting, and 3. What are the effects of physical and sociodemographic determinants of health on RMCH outcomes. Therefore, the main aim of the study was to assess the geographic inequalities (across counties and sub counties) in indicator estimates from routine DHIS2 data for five selected reproductive, maternal and child health indicators. Secondary objectives were to measure overall RMCH performance across the counties in Kenya through a composite RMCH index (RI)using routine DHIS2 data, and finally to assess the effect of physical and sociodemographic determinants of health on RMCH indicator estimates.

Methods

Study setting, design and selection of indicators

Five indicators within the RMCH framework were selected for this study, based on availability, across the 47 counties in Kenya covering a period of four years from January 2018 to December 2021. Data on these indicators was extracted from the Kenya DHIS2. In December 2021, 9803 health facilities reported their service delivery data in DHIS2 against an expected 10,133 facilities, giving a reporting of 97%. These health facilities included clinics, dispensaries, health centres and hospitals, of which 46% were government facilities, 44% private, and 10% Faith based or NGO facilities. Data was extracted at facility level and then aggregated to the smallest sub-national decision-making unit- the sub-county (unit of analysis) and further aggregated to county and national level results. The data represented individuals who sought care for RMCH services(numerators) and the target population(denominators) as expounded in Table 1. The sub-county and county boundary shapefiles were generated from county integrated development plans [32].

Despite having more than 15 RMNCAH indicators aggregated in DHIS2, only 5 indicators were selected for assessment of RMNCAH intervention and development of a composite RMCH index as shown in Table 1. For FP, WRA receiving FP commodities was used as a proxy for access to FP commodities. The Couple Year Protection (CYP)could not have been used due to limitations in using it as part of a composite index. Use cases from Kenyan hospitals show that the neonatal information flow to DHIS2 is suboptimal with a corresponding lack of confidence in the quality of data and so still birth and neonatal mortality rates were not included [33]. Immunization coverage was included to measure child health since reporting rates are high in Kenya. Indicators like proportion of children under 5 with diarrhea treated with zinc ORS and proportion of children under 5 with diarrhea managed with amoxicillin DT at the facility were not included because reporting on them begun in 2020. The routine nutritional monitoring of children under 5 in health facilities is low with only about a third of children being presented to facilities for growth monitoring [34–36] and so proportion of children under 5 who were underweight or stunted were not included.

Table 1 Definitions and description of indicators and data elements extracted from the DHIS2 for study period

Indicator definition	Numerator	Denominator
Percentage of women of reproductive age (15–49 years) receiving family planning (F) commodities *An estimate of access to FP commodities by WRA visiting health facilities	Number of women of reproductive age (15–49 years) receiving family planning (FP) commodities	Total number of women of reproductive age (15–49 years)
Percentage of pregnant women attending four antenatal care visits (ANC4)	Number of pregnant women attending four antenatal care visits (ANC4)	Estimated number of pregnant women *Within DHIS2, the yearly projections of estimated number of pregnant women is computed based on population and crude birth estimates from most recent available census
Percentage of deliveries conducted by skilled birth attendants (SBA)	Number of deliveries conducted by SBA	Total number of estimated deliveries *Within DHIS2 projected estimates of deliveries are derived from estimated pregnancies
Facility maternal mortality rate (FMMR) *Number of maternal deaths occurring in a facility per 100,000 deliveries	Number of maternal deaths reported at health facility level	Total number of deliveries in the health facility *Since this is at facility level, the denominator is the actual number of deliveries at the facility, multiplied by 100,000
Percentage of fully immunized children (FIC[1]) under 1 year	Number of fully immunized children (FIC) at 1 year	Number of Infants at 1 year

FIC: Fully immunised children (1 dose BCG, 3 doses of DPT-Hep B-Hib, 3 doses of oral polio vaccine (OPV), 1 dose Measles-rubella, 1 dose of inactivated polio vaccine (IPV), 3 doses of Pneumococcal vaccine, 2 doses rotavirus)

Data quality assessment

DHIS2 data quality for the five variables was conducted on the health facility level data before aggregation based on methodology developed by World Health Organization (WHO) [37]. In brief, the WHO tool assesses completeness of reporting, outlier detection and an internal consistency check by comparison between indicators (e.g., ANC1 and Penta 1). To account for incomplete reporting. the number of service outputs (numerators) were adjusted at sub-county level with an assumption about the extent to which non-reporting health facilities are still providing services. Here, an adjustment factor of $K = 0.25$ was used assuming that non reporting facilities delivered services at 25% of reporting facilities for the missing months [20] therefore have minimal impact on the data quality.

Outlier detection was done to check for data entry errors at facility level and effects of changes in patterns of service delivery based on a modified Z-score, with extreme outliers identified as monthly values that were greater than the sub-county monthly mean value by at least three standard deviations. Any values flagged as outliers were adjusted using the median value of the indicator for the year. For consistency check, the ratio of ANC1 to Penta 1 and Penta 1 to Penta 3 were calculated. These two indicators were selected for comparison based on their predictable relationship [37] with the expectation that the number of pregnancies should always be greater than number of Penta 1 doses administered.

Modelling RMCH indicator estimates at sub-national level

A Bayesian hierarchical spatio-temporal model was fitted at sub-county level to estimate coverage across the five indicators adjusting for standardized physical and socio-economic determinants. This approach was selected to adjust for spatial and temporal structure in the data. Additionally, Bayesian approaches permit inclusion of expert/prior knowledge or prior distribution and quantify uncertainties associated with estimates. This includes the uncertainty in data and prior distributions. The model was implemented using the Integrated Nested Laplace Approximation (INLA) package in R software version 4.1.2 [38]. Spatial effects were incorporated using an adjacency matrix that defined geographical neighbours for each sub-county(SC) following [39] i.e. a sub-county is assigned 1 if a neighbor, or 0 if otherwise. This adjacency matrix was used to define the spatial structure.

The model was fitted with a temporal component although trends in the individual variables were not extensively examined in this study. The objective was to extract a contemporary estimate while adjusting for the temporal structure in routine data. Thus, let $Y(i,t) = Y_t(i)$ denote a temporally varying spatial model for each indicator where $i = 1......I$ represents the sub-counties and $t = 1......T$represent the time for which data was collected. The spatio-temporal model was defined as:

$$y_t(i) = \alpha_0 + \mathrm{X(i)}'\,\beta + \phi(\mathrm{i}) + \mathrm{y(t)}$$

where is α_0 an intercept, $X(i)'$ is a vector of covariates data associated with each sub-county, β represents the corresponding regression coefficients, $\gamma(t)$ is a temporal random effect following a random walk in time of first order (RW1) and $\phi(i)$ is a spatial random effect accounted for using Besag-Yorke-Model (BYM) [40] comprising of both the spatially structured ($\mathrm{U_i}$) and unstructured ($\mathrm{V_i}$) components. The unstructured component was modelled as an independent and identically distributed random error (iid) with a normal distribution expressed as $\mathrm{V_i}\left|\sigma_\mathrm{v} \sim \text{iid } \mathrm{N}\left(0, \sigma_\mathrm{v}^2\right)\right.$ [39]. The spatially structured component was modeled with a conditional auto-regressive (CAR) approach. CAR spatial models adjust for the spatial structure in data through a spatial prior distribution $U_i\middle|U_{i-1} \sim N\left(\overline{\mu}_i, \frac{\omega^2}{mi}\right)$ where m_i is the total number of neighbors for sub-county (i), $\overline{\mu}_i$ is the mean of the spatial random effects conditioned on neighbors ω^2 and represents a conditional variance and its magnitude determines the amount of spatial variation [41]. The model was scaled to make the precision parameter of models with different CAR priors comparable [42]. Bayesian specifications were completed by assessing flat prior distribution to the intercept and the regression parameters.

Three CAR models were fitted: model 1 did not adjust for spatial and temporal aspects in the raw data, model 2 adjusted for the temporal effect and included determinants (covariate effects), while model 3 adjusted for all the components (the spatial effects, temporal and covariate or drivers of RMCH at the unit of analysis). Model selection was done by comparing the performance of the three fitted models based on the deviance information criterion (DIC) [43]. A best fitting model was used to generate coverage estimates of the five indicators at sub-county level for each of the four years and these were subsequently used to compute the composite RMCH index.

For validation, a 20% subset of data at sub-county level was used for validation of the selected model. Firstly, sub county level coverage estimates were compared to raw coverages computed from the data through the Pearson's correlation co-efficient which measures association between predicted and observed values. Secondly, residuals were used to calculate the root mean square error (RMSE), which assesses the overall model performance and accuracy and mean square error (MSE) which gives a measure of the model bias.

Examining the effect of social, demographic and geographic determinants of reproductive, maternal and child health on RMCH coverage

Four physical and socio-demographic determinants of RMCH outcome indicators at population level based on previous studies [29, 44–47] and were used as determinants. These were: wealth index, women's education, health facility density and remoteness index (Supplementary Fig. 1). Two of these determinants, wealth index and women's education, which are collected at household level were extracted and summarized at subcounty level from the 2014 Kenya Demographic Health Survey (KDHS). The KDHS 2014 was conducted using a two-stage sampling design on a national sampling frame constituting of 1612 clusters with an average size of 40,300 households each [48]. All sub counties had at least one DHS cluster. The computation of these survey indicators was weighted and adjusted for DHS survey sampling and a mean was derived at subcounty level for each variable.

Health facility (HF) density was derived from the Kenya list of health facilities [49] with the capability of delivering services in each of these indicators. In computing mean HF density at sub-county level, facilities offering specialized services were excluded. A subcounty level index of remoteness (RI) was modelled from a set of geospatial data including roads, land cover and digital elevation model (DEM). Remoteness index was based on average travel times to urban centers [50] and was used to classify sub-counties as either rural or urban. Further details on the derivation and classification of the remoteness index adopted from previous studies [51] are presented in the supplementary information.

The estimation of reproductive maternal child health index (RI) composite index

A composite index on RMCH was derived to understand at a glance, the status of RMCH at county and subcounty level and enable comparison across these subnational levels to pick out gross inequalities. This would enable informed targeting of counties and sub counties for prioritisation of RMCH interventions or scale up of specific interventions in order to improve overall national performance.

Five indicators outlined in table one were used to generate the RMCH Index. The FP indicator measures service access and use, while ANC4, SBA and FIC are health service coverage indicators, and FMMR is a proxy estimate of quality of care [52]. Bayesian modelled mean estimates of the selected variables were combined in computation of the RMCH index (RI) as a weighted average estimate of overall performance of the indicators at the unit of analysis. The weights were assigned based on approaches recommended by Wehrmeister et al [53]. FP was weighted individually for reproductive health, and FIC for child health. ANC4, SBA and the FMMR index were combined for maternal health. The FMMR index was scaled by dividing the county specific FMMR by the maximum value nationally, and the inverse derived such that that the lowest estimate of FMMR reflected a higher FMMR Index representing better maternal health outcomes at the county level. The mean estimates of this variable (FMMR index) was then used to compute the RMCH index per county as below.

$$RI = \left[\frac{1}{3}\left(FP + \frac{ANC4 + SBA + FMMR^{Index}}{3} + FIC\right)\right]$$

The main difference between the RMCH index and the composite index in Wehrmeister et al. is the use of FMMR. Using FMMR in this study is novel as it measure outcomes related to maternal mortality. The Wehrmeister Index has since been revised to include more indicators.

Results

Quality of the selected DHIS2 RMCH indicators

The database contained data points representing 9803 health facilities as of December 2021. The mean national reporting rate for all the indicators over the 48-month period was 98.4%. However, these did not vary much by indicators as 98.9% for FP, ANC4 (98.9%), SBA (98.9%), FIC (98.9%) and FMMR (96.4%). Across all the indicators examined, there were 2.6% missing data values which were imputed by computing their predictive distribution from the monthly data. Specifically, the percentage of missing data was 0.0 l for FP, 0.02 for ANC4, 0.03 for SBA and FIC, and 2.46 for FMMR. The prevalence of outliers was highest in FMMR with 3%. Less than 1% of outliers were detected in the other four indicators. These outliers were adjusted using the median value of the year. There was a strong correlation between ANC1 and DPT1 $\left(R^2 = 0.91\right)$.

Model selection and validation

Based on Deviance Information Criterion and Marginal likelihood, the spatio-temporal model (Model 3) was selected as the best fitting model in comparison to the other two models (Supplementary Table 1), and (Supplementary Fig. 2). This suggested there was value in adjusting for spatial and temporal variation in data. Using FP variable, the statistical validation based on out of sample data (20%) for the fully adjusted model (model 3) had a mean square error (MSE) from residuals was 1%. the mean absolute error (MAE) was 8% and the Pearson correlation between observed raw coverage and modelled coverage was 68%. These validation statistics were similar for ANC4, SBA, FMMR and FIC (Table 1).

Indicator estimates

The average estimate for each indicator over the 4 years was derived. Full immunization coverage at 1 year had the highest estimate (79.3% BCI: 77.8—80.5%), followed by skilled birth attendance (60.1% 95% BCI: 58.9–60.7%) and fourth antenatal care attendance at (48.0% 95% BCI: 46.9–48.9%), while Family Planning (Women of reproductive age receiving FP commodities) had the lowest estimate (38.6% BCI: 38.2–38.9%). The quality-of-care indicator: Facility Maternal Mortality Ratio (FMMR) was estimated at 105.4 (BCI 67.3–177.1).

Sub-national variations in indicator estimates

Figure 1 shows the geographic variation in each of the five indicators within county and sub-county level in Kenya. Generally, the lowest FP estimates of less than 20% were recorded in West Pokot, Wajir, Turkana, Garissa and Mandera counties, which are in the northern regions of the country (Fig. 1A). However, the largest geographical inequalities in FP uptake within counties were observed in Vihiga and Baringo counties. In Vihiga, 2 sub-counties had FP uptake estimates of 2.5% and 8.6% respectively while the rest of the sub-counties had an average of 40.8%.

Figure 1B presents geographic inequalities in ANC4 at sub-county level. Across the counties, 19 had ANC 4 estimates of less than 40% (Table 2). Of these counties, West Pokot, Elgeyo Marakwet and Narok counties had estimates of less than 20%. However, Meru in the Eastern

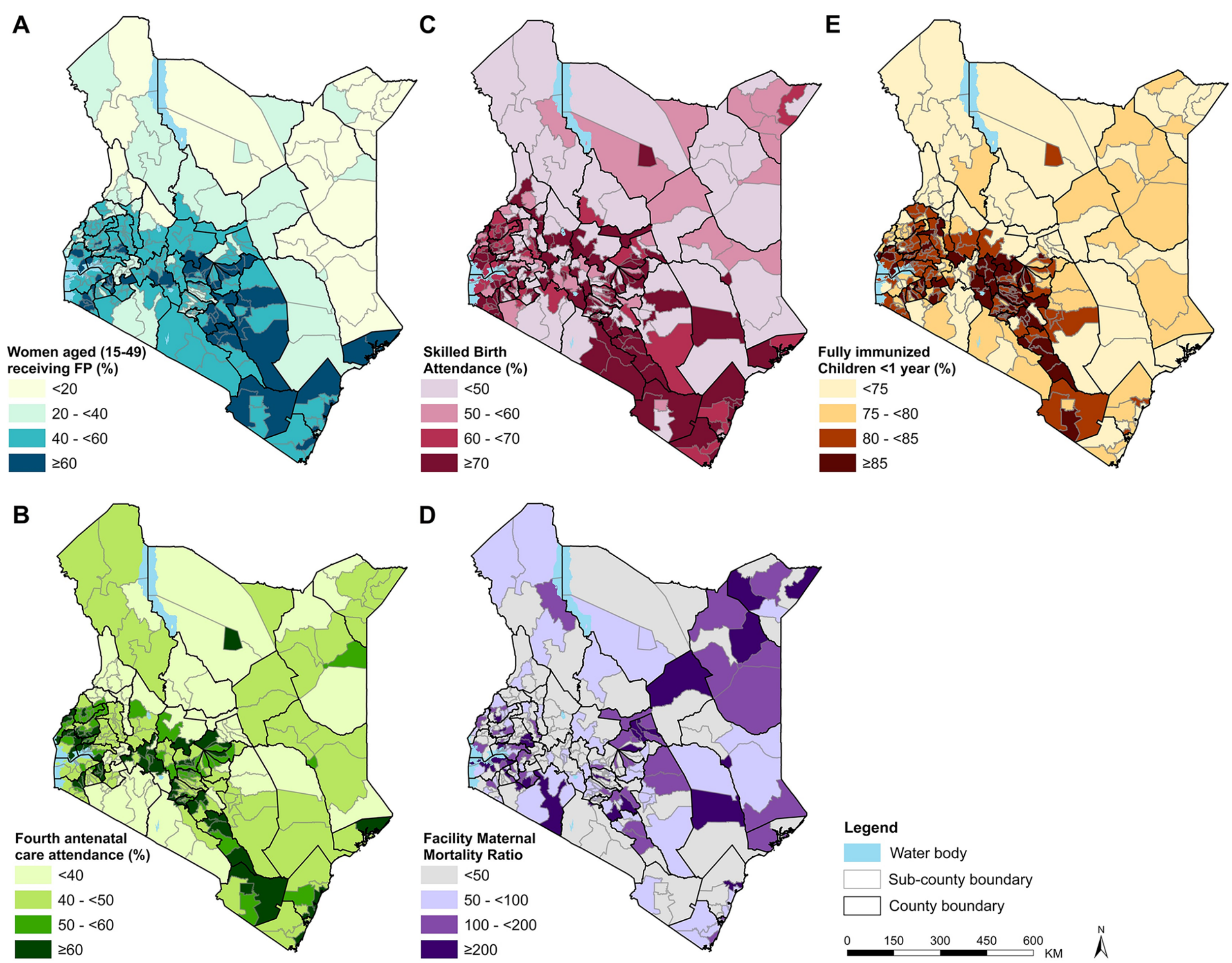


Fig. 1 Maps showing geographical variation in RMCH indicator estimates at sub-county level in 2021: **A** Percentage of women of reproductive age receiving family planning commodities, **B** Percentage of pregnant women attending fourth antenatal care visit, **C** Percentage of deliveries conducted by skilled birth attendants, **D** Facility maternal mortality rate and (**E**) Percentage of fully immunized children < 1 year. Maps produced in ArcGIS version 10, ESRI, Redlands

Table 2 RMCH indicator estimates (2018 to 2021 average) in 47 counties of Kenya with 95% Bayesian credible interval

County	Region	Family planning (%)	Fourth antenatal care attendance (%)	Skilled birth attendance (%)	Full immunization of children < 1 year (%)	FMMR	FMMR Index	RMCH Index
Tharaka Nithi	Eastern	60.1 (59.6–60.5)	56.1 (54.7–57.3)	58.9 (57.5–56.4)	79.1 (77.3–80.6)	46.1 (20.1–67.6)	45.7	64.2
Makueni	Eastern	52.6 (52.2–52.9)	59.6 (58.4–60.7)	75.2 (73.7–72.3)	86.8 (85.3–88.2)	97 (42.2–122.3)	21.7	63.8
Kirinyaga	Central	51.5 (51.0–51.8)	57.2 (55.8–58.4)	68.5 (67.1–68.4)	86.6 (84.8–88.2)	94.4 (41–115.8)	22.3	62.5
Migori	Nyanza	50.8 (50.3–51.2)	57.4 (56.4–58.3)	76.1 (74.9–71.6)	83.5 (82.2–84.6)	87.6 (38.1–107.4)	24.1	62.3
Nyamira	Nyanza	54.7 (54.2–55.1)	59.2 (57.9–60.2)	57.5 (56.4–57.6)	86.4 (84.9–87.7)	99.6 (43.3–106.1)	21.2	62.3
Siaya	Nyanza	43.3 (42.9–43.6)	62.1 (60.9–63.0)	73.3 (72.0–72.3)	86.9 (85.5–88.1)	61.5 (26.7–68.1)	34.3	62.2
Taita Taveta	Coast	48.9 (48.4–49.4)	50.4 (49.1–51.6)	65.2 (63.6–62.8)	83 (81.0–84.6)	47.2 (20.5–63.7)	44.6	61.8
Laikipia	Rift Valley	47.7 (47.3–48.0)	56.3 (55.2–57.2)	72.4 (71.3–73.6)	80.3 (79.0–81.5)	57.8 (25.1–62)	36.5	61.0
Machakos	Eastern	56.1 (55.6–56.4)	55 (53.8–56.1)	58.5 (57.3–63.8)	80.7 (79.3–82.0)	144.3 (62.7–174.6)	14.6	59.8
Embu	Eastern	51 (50.6–51.3)	53.2 (52.0–54.3)	64.6 (63.3–60.9)	80.9 (79.4–82.2)	94.7 (41.2–116.5)	22.2	59.5
Nyeri	Central	51.3 (50.9–51.7)	52.4 (51.0–53.8)	55.7 (54.3–54.3)	85.4 (83.3–87.3)	125.3 (54.5–148.2)	16.8	59.4
Lamu	Coast	54.4 (53.7–55.0)	57.9 (56.0–59.6)	72.3 (70.2–70.3)	72.3 (70.1–74.3)	88.9 (38.6–107.2)	23.7	59.3
Murang'a	Central	43.1 (42.7–43.4)	49.7 (48.5–50.8)	62.9 (61.6–62.3)	89.6 (87.8–91.1)	103.7 (45.1–128.3)	20.3	59.0
Kilifi	Coast	48.1 (47.8–48.4)	53.4 (52.5–54.2)	70.5 (69.4–70.9)	77.8 (76.6–78.7)	111.6 (48.5–135.3)	18.9	57.8
Kisumu	Nyanza	43.3 (43.0–43.7)	55.9 (54.8–56.7)	64.1 (63.0–60.4)	85.1 (83.8–86.3)	144.4 (62.8–180.5)	14.6	57.7
Nyandarua	Central	42.3 (41.9–42.6)	43.6 (42.4–44.5)	54.1 (52.9–55.6)	88.7 (86.9–90.2)	73.9 (32.1–84.3)	28.5	57.7
Kwale	Coast	47.3 (46.9–47.5)	55.2 (54.3–56.0)	70.5 (69.5–71.9)	76.2 (75.1–77.1)	106.3 (46.2–127.6)	19.8	57.3
Bungoma	Western	42.3 (42.0–42.6)	52.9 (52.0–53.8)	71.2 (70.1–69.1)	80.3 (79.1–81.4)	106.5 (46.3–129.7)	19.8	56.8
Uasin Gishu	Rift Valley	43.2 (42.9–43.5)	47.3 (46.4–48.0)	48.6 (47.8–50.2)	84.6 (83.3–85.7)	67.8 (29.5–84.3)	31.1	56.7
Kiambu	Central	36.7 (36.4–36.9)	61 (59.9–62.0)	65.5 (64.4–67.7)	86.5 (85.1–87.7)	153.6 (66.8–162.6)	13.7	56.6
Kakamega	Western	38.2 (37.8–38.4)	55.6 (54.5–56.5)	66.8 (65.6–64.8)	82.3 (80.9–83.5)	92.2 (40.1–116.8)	22.9	56.3
Bomet	Rift Valley	44.1 (43.8–44.4)	38.2 (37.4–38.9)	61.5 (60.5–64.9)	83.9 (82.5–85.0)	103.6 (45–128.1)	20.3	56.0
Nandi	Rift Valley	47.5 (47.2–47.9)	36.9 (36.0–37.6)	51.2 (50.1–50.0)	84 (82.5–85.3)	110.6 (48.1–128.8)	19.1	55.7

Table 2 (continued)

County	Region	Family planning (%)	Fourth antenatal care attendance (%)	Skilled birth attendance (%)	Full immunization of children < 1 year (%)	FMMR	FMMR Index	RMCH Index
Trans Nzoia	Rift Valley	33.8	34.7	45.5	83.5	30.8	68.4	55.6
		(33.5–34.0)	(34.0–35.3)	(44.0.7–49)	(82.2–84.6)	(30.5–99.6)		
Kitui	Eastern	50.8	37.8	46.5	80.9	110.7	19.0	55.4
		(50.4–51.2)	(37.0–38.6)	(45.6–53.6)	(79.4–82.3)	(48.1–126.3)		
Kajiado	Rift Valley	42.2	54.9	64.9	76.7	97.4	21.6	55.3
		(41.8–42.5)	(53.9–55.7)	(63.9–66.3)	(75.6–77.7)	(42.3–115.9)		
Nairobi	Nairobi	35.2	62.5	56.8	86.1	199.6	10.6	54.9
		(34.9–35.4)	(61.5–63.2)	(56.1–58.9)	(84.9–87.0)	(86.8–225.9)		
Baringo	Rift Valley	30.4	38.8	55.6	79.6	30.4	69.3	54.8
		(30.1–30.7)	(37.8–39.7)	(54.4–58.1)	(78.0–80.9)	(13.2–57.9)		
Kisii	Nyanza	37.8	44.3	63.6	83.5	117.4	17.9	54.4
		(37.5–38.1)	(43.3–45.2)	(62.4–64.7)	(81.9–84.7)	(51.1–130.9)		
Homa Bay	Nyanza	43.6	48.1	65.5	77.3	175.7	12.0	54.3
		(43.2–43.9)	(47.1–48.9)	(64.3–66.8)	(76.0–78.5)	(76.4–219.2)		
Vihiga	Western	33.9	50.6	51.8	85.3	83	25.4	53.9
		(33.5–34.2)	(49.5–51.6)	(50.7–51.1)	(83.6–86.7)	(36.1–130.8)		
Nakuru	Rift Valley	45.9	46.4	62	73.5	116.6	18.1	53.8
		(45.6–46.2)	(45.5–47.1)	(61.0–60.0)	(72.3–74.5)	(50.7–134.6)		
Busia	Western	32.1	54.8	59.6	79.6	114.7	18.4	52.0
		(31.7–32.4)	(53.6–55.8)	(58.4–61.6)	(78.1–80.9)	(49.9–134.6)		
Mombasa	Coast	35.8	54.1	55.4	75.8	130	16.2	51.2
		(35.5–36.0)	(53.2–55.0)	(54.5–58.2)	(74.6–76.8)	(56.5–141.6)		
Meru	Eastern	37.2	37.3	59.6	76.9	178	11.8	50.1
		(36.9–37.5)	(36.5–38.1)	(58.6–64.9)	(75.5–78.1)	(77.4–220.1)		
Elgeyo Marakwet	Rift Valley	32	27.8	62.9	77.8	70.3	30.0	50.0
		(31.7–32.3)	(27.0–28.5)	(61.7–64.4)	(76.3–79.1)	(30.5–99.6)		
Kericho	Rift Valley	28.6	35.1	55.6	81.8	105.4	20.0	49.1
		(28.3–28.9)	(34.3–35.8)	(54.5–59.1)	(80.3–83.0)	(45.8–116.1)		
Isiolo	Eastern	28.3	50.3	66.1	70.5	210.7	10.0	47.0
		(27.9–28.7)	(48.6–51.6)	(64.3–67.2)	(68.4–72.4)	(91.6–231.3)		
Marsabit	Eastern	18.2	51.5	65.2	69	52.7	40.0	46.5
		(17.9–18.4)	(50.2–52.5)	(63.8–64.9)	(67.6–70.3)	(22.9–72.3)		
Narok	Rift Valley	33.5	29.6	43.6	72	141.3	14.9	45.0
		(33.2–33.7)	(28.9–30.1)	(42.8–48.0)	(70.9–73.0)	(61.4–168.8)		
Turkana	Rift Valley	16.9	50.6	55.9	67.7	48.8	43.2	44.8
		(16.6–17.0)	(49.6–51.5)	(54.9–54.8)	(66.5–68.7)	(21.2–53.8)		
Samburu	Rift Valley	30.8	38.9	45.7	61	55.7	37.8	44.2
		(30.4–31.1)	(37.9–39.8)	(44.6–53.9)	(59.7–62.1)	(24.2–58.8)		
Tana River	Coast	23.7	42.9	51.5	68.1	124.7	16.9	43.0
		(23.4–23.9)	(41.9–43.8)	(50.4–54.4)	(66.8–69.2)	(54.2–148.3)		
Garissa	North Eastern	7.6	44.9	46.5	78.9	156.1	13.5	40.5
		(7.4–7.7)	(43.9–45.8)	(45.5–52.3)	(77.5–80.2)	(67.9–181.1)		
Mandera	North Eastern	9.8	34.3	59.9	74.5	153.8	13.7	40.1
		(9.7–10.0)	(33.4–35.0)	(58.8–62.4)	(73.1–75.6)	(66.9–187.6)		
Wajir	North Eastern	8.6	34.8	45.7	78.4	145.6	14.5	39.5
		(8.4–8.7)	(33.9–35.6)	(44.7–48.6)	(76.8–79.7)	(63.3–176.8)		

Table 2 (continued)

County	Region	Family planning (%)	Fourth antenatal care attendance (%)	Skilled birth attendance (%)	Full immunization of children < 1 year (%)	FMMR	FMMR Index	RMCH Index
West Pokot	Rift Valley	17.5	24.3	53.2	56.3	43.8	48.1	38.5
		(17.3–17.7)	(23.7–24.9)	(52.3–39.9)	(55.4–57.1)	(19–53.7)		
National average		38.6	48	60.1	79.3	105.4	20.0	53.5
		(38.2–38.9)	(46.9–48.9)	(58.9–60.7)	(77.8–80.5)	(67.3–177.1)		

Region and Nakuru in the Rift Valley Region the country revealed highest geographic inequalities at sub-county level. In Meru County, 2 sub-counties had ANC4 estimates of 17.7% and 24.1% respectively while three sub-counties had estimates of greater than 60%. In Nakuru county, 2 sub-counties had estimates of 17.7% and 27.7% while the remaining 9 sub-counties had an average estimate of 59.3%.

Figure 1C highlights heterogeneities in SBA at sub-county level. Estimates of SBA were less than 50% in 7 counties (Table 2). The greatest sub-county geographical inequalities were observed in Nairobi, Embu and Bomet counties. In Nairobi County, 3 sub-counties had SBA estimates less than 30% while 5 sub-counties had estimates of greater than 90%. In Embu County, 1 subcounty had an estimate of 18.7% while the remaining 3 sub-counties had an average estimate of 85.3%.

Facility maternal mortality rate, of all the indicators, exhibited the greatest disparity at county and sub-county level (Fig. 1D). More than 150 maternal deaths per 100,000 deliveries were recorded in 7 counties, that is, Isiolo, Nairobi, Meru, Homa Bay, Garissa, Mandera and Kiambu. Isiolo and Garissa counties in the north-eastern regions of the country presented the greatest subcounty inequalities. In Isiolo county, 1 sub-county had an estimate as low as 26 maternal deaths compared to 123 and 443 maternal deaths per 100,000 deliveries in 2 sub-counties. In Garissa County, while 4 sub-counties recorded an FMMR of less than 100, 2 sub-counties had 170 and 448 maternal deaths per 100,000 deliveries.

FIC estimates across the counties were high with coverage of more than 80% in 25 counties while only 5 counties (West Pokot, Samburu, Turkana, Tana River and Marsabit) in the North Eastern regions of the country had less than 70% (Fig. 1E). However, the largest geographic inequalities were observed in Nakuru, Machakos and Baringo counties. Nakuru county had 2 sub-county FIC estimates of 41.1% and 47.7% respectively, while 5 sub-counties had estimates of greater than 80%.

Determinants of reproductive, maternal and child health

Table 3 summarizes the posterior means and 95% Bayesian credible intervals of the spatio-temporal model parameters at the national level. Remoteness index was an important determinant in estimation of immunization suggesting FIC was likely lower in rural areas by 3.0%. Wealth index was an important determinant of FMMR only suggesting wealthier sub-counties were likely to have more maternal deaths compared to poorer ones by 11%. Women's education was an important determinant suggesting FIC coverage was likely higher by 5% in areas where mothers were more educated. In estimation of FP, ANC4, SBA, FMMR and FIC, health facility density, a proxy of access to health facilities was an important determinant. The availability of health facilities offering maternal services at sub-county level increased the likelihood of pregnant women attending fourth antenatal care visits by 5% and assisted deliveries by a skilled health worker by 10%. Higher facility density suggested that more women have access to health facilities for reception of family planning commodities by 8%, immunization of children

Table 3 Summary of posterior means and Bayesian credible intervals (BCI) of model 3 parameters

Parameter	FP	ANC4	SBA	FMMR	FIC
Remoteness index	0.94 (0.86–1.02)	0.94 (0.88–1.01)	0.93 (0.85–1.01)	0.98 (0.57–1.58)	0.97 (0.95–0.99) [a]
Wealth index	1.02 (0.91–1.12)	1.09 (0.99–1.19)	1.03 (0.90–1.17)	1.11 (1.05–1.33) [a]	0.98 (0.95–1.02)
Women's education	1.12 (0.99–1.25)	1.02 (0.92–1.14)	0.97 (0.84–1.11)	0.92 (0.42–1.78)	1.05 (1.01–1.08) [a]
Health facility density	1.08 (1.03–1.13) [a]	1.05 (1.01–1.10) [a]	1.10 (1.04–1.16) [a]	1.11 (1.06–1.39) [a]	1.01 (1.00–1.02) [a]

[a] Statistically significant model results

by 1% and increased the likelihood of maternal deaths at facilities during delivery by 11.%.

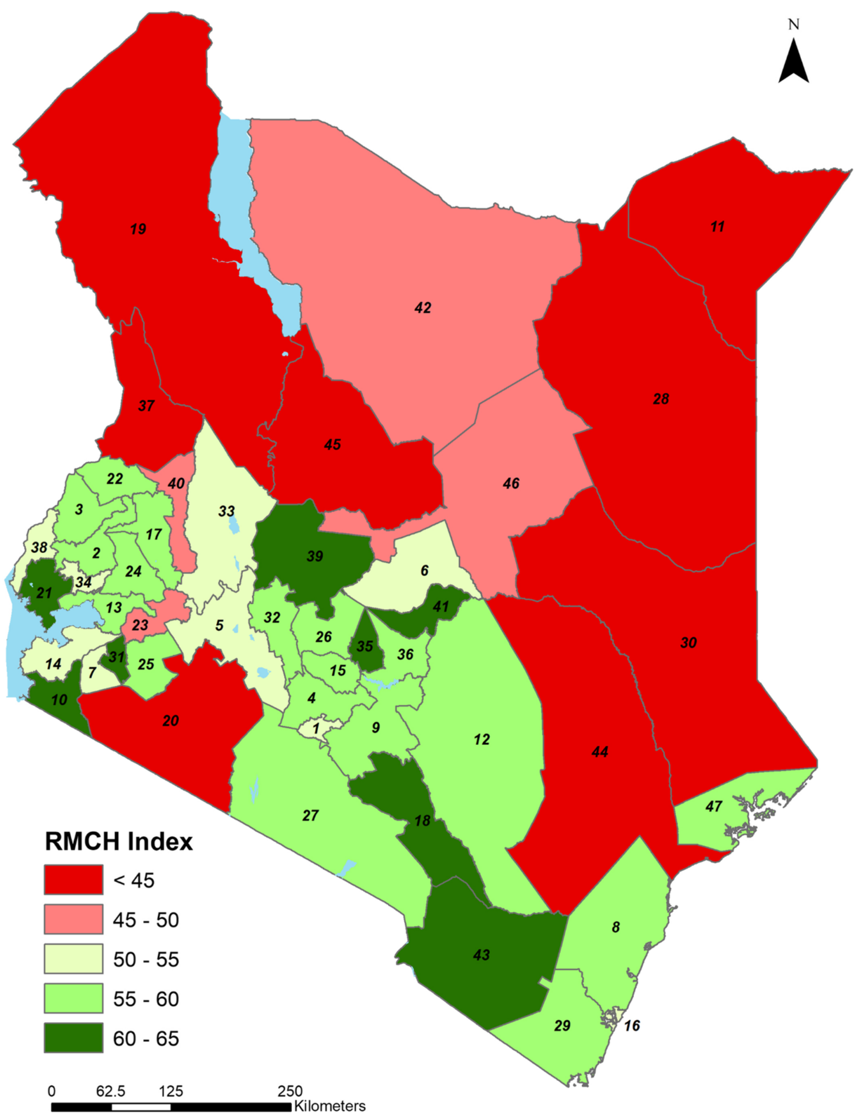
Reproductive maternal and child health index

Figure 2 shows geographic inequalities in overal indicator estimates across the counties in Kenya through the RMCH Index (RI). The national index across the years was 53.5% ranging from 38.5% in West Pokot to 64.2% % in Tharaka Nithi. Overall, 8 (17%) counties (Tharaka Nithi, Makueni, Kirinyaga, Migori, Nyamira, Siaya, Taita Taveta, and Laikipia) located in the Eastern and Nyanza regions of the country had RI estimates of greater than 60%. Estimates of the RI were less than 50% in 11 counties (Kericho, Isiolo, Marsabit, Narok, Turkana, Samburu, Tana River, Garissa, Mandera, Wajir, West Pokot) which are mostly in the North-Eastern region of Kenya. The RMCH index gave equal weight to FP, FIC but since 3 indicators were weighted jointly for maternal health(ANC4, SBA,FMMR), they individually had a lower weight.

Discussion

Data quality

In order to improve RMNCAH outcomes, performance of selected indicators must be monitored closely to be



County	ID
Nairobi	1
Kakamega	2
Bungoma	3
Kiambu	4
Nakuru	5
Meru	6
Kisii	7
Kilifi	8
Machakos	9
Migori	10
Mandera	11
Kitui	12
Kisumu	13
Homa Bay	14
Muranga	15
Mombasa	16
Uasin Gishu	17
Makueni	18
Turkana	19
Narok	20
Siaya	21
Trans Nzoia	22
Kericho	23
Nandi	24
Bomet	25
Nyeri	26
Kajiado	27
Wajir	28
Kwale	29
Garissa	30
Nyamira	31
Nyandarua	32
Baringo	33
Vihiga	34
Kirinyaga	35
Embu	36
West Pokot	37
Busia	38
Laikipia	39
Elgeyo Marakwet	40
Tharaka	41
Marsabit	42
Taita Taveta	43
Tana River	44
Samburu	45
Isiolo	46
Lamu	47

Fig. 2 Map showing the geographical distribution of the RMCH index at county level in Kenya. Maps produced in ArcGIS version 10, ESRI, Redlands

able to identify those with slow progress, geographical areas with the poorest performance, and contributory factors to design appropriate response strategies. The Kenya DHIS2 data reporting has been shown to be high with 97% reporting rate for RMCH indicators, with data quality being acceptable with detection of less than 3% outliers for the FMMR and less than 1% for the other indicators. Similar studies which measure health outcomes in Kenya showed that the DHIS2 provides an opportunity for more frequent, local monitoring of progress, in maternal and child health. A study by Maina et al. found that there was consistency of DHIS reporting with the 2014 DHS. It also found the completeness of data reporting was 80% in 2014 [21] showing improvement over time. Other studies and also emphasise the need for investment in routine systems to optimise the potential for timely data use for decision making [19–21].

The average estimate of WRA receiving FP commodities coverage across the 4 years was 38.6%. This estimate was seemingly low compared to the current population level modern contraceptive prevalence rate (mCPR) of 61% [54] among married women. This is because the use of the denominator of WRA is larger than the actual proportion with demand for FP. The WRA does not exclude the proportion of WRA who are not sexually active, or are pregnant or have post-partum amenorrhea, or those who do not want to use FP methods. The numerator might under-estimate FP use as those using long-acting methods are not counted in subsequent years or over-estimate due to double counting those who come back multiple times a year for short acting FP methods. There is therefore need to explore improvement of the FP data collection to minimize errors in the use of routine data to monitor FP to routinely monitor FP coverage. FMMR data was included to measure the outcomes of the reproductive and maternal health interventions. However, the FMMR is grossly under reported in African countries with the current study estimate of 105 being much lower than the national population level Maternal Mortality Ratio estimate of 362. This is because of under-reporting of maternal deaths due to non-reporting of deaths which occur at home during delivery or after being discharged [54]. Maternal deaths which occur during referral may also not be reported by either the recipient of referring facility. Misclassification of maternal deaths especially where they occur outside the maternity ward also results in unreported maternal deaths [55] Health facilities which have robust reporting for maternal deaths and correctly classify all maternal deaths will seemingly have higher FMMR compared to facilities with a similar number of maternal deaths who do not correctly classify and report the maternal deaths.

Inequalities

There were large inequalities in all the individual indicator estimates which was reflected in the composite RMCH Index. At county level, the counties in the North Eastern, Eastern region and Coast region had the lowest FP uptake, 4 ANC, SBA coverage with high FMMR. The use of composite indices has been used to assess subnational inequalities, emphasizing the need of doubling efforts in health service interventions marginalized areas [19–22]. The findings in Keats et. al [56] also shows low coverage especially in the former North Eastern Region of Kenya while Nairobi and Central region had high RMCH indicator performance. Our Study work has additionally shown inequalities still exist within non marginalized counties at the sub county level. The inequalities within the sub counties are often masked by aggregation of data at county level. The inequalities were related to some determinants of health as shown in our study. However, errors in the denominator estimates at sub county level may also contribute to the seeming inequalities. The denominator estimates do not take into account the community migratory patterns. Therefore, a sub county which hosts a higher-level health facility, for example a county referral hospital, will serve clients from neighboring sub counties who are not included in the denominator estimates and therefore this is interpreted as high coverage, while in the neighboring sub counties, lower coverages are achieved. For FMMR, the sub counties with higher level hospitals will also receive self-referrals and emergency referrals for delivery services and so they will also report higher coverage of SBA and higher facility maternal mortalities than sub counties at lower-level facilities.

Determinants

Large geographic inequalities were revealed in FMMR within counties and sub counties. National estimate of FMMR in Kenya across the four years was at an average of 105 maternal deaths per 100,000 deliveries. Wealthier counties and sub-counties, and those with a higher facility density were more likely to have more facility maternal deaths. This is because wealthier counties are more likely to have larger towns with higher populations and large referral facilities which conduct a higher number of deliveries with a major proportion being obstetric emergency referrals from other counties. This likely explains the case of Nairobi, Mombasa and Kisumu counties, the 3 major cities in Kenya which have very high FMMR despite having high coverages of 4 ANC, SBA and FIC. This finding correlates to other studies which show that availability of facilities and increased ANC and SBA coverage does not necessarily relate to improved maternal outcomes [57, 58]. Where there is increase in access to skilled delivery without improved health outcomes, the quality of delivery services offered has been found to poor [59–61]. This is among the causes of maternal death under the three-delay model. The third delay, that is, delay in getting timely and appropriate care at a health facility [62], accounts for most of the maternal deaths in Kenya and other developing countries [63].

Health facility density was positively correlated with increased coverage of for FP, ANC4, SBA and FIC. Similar studies have shown that better access to health facilities translated to improvement of these indicators [64–71]. It is therefore critical for each county to aim to reach the recommended health facility to population ratio in order to reduce barriers to accessing health services.

Women's education had a significant impact on full immunization of children which is consistent with other research showing a strong association between full immunization of children and mother's education status [72]. Women's education and wealth have been found to be positively associated with higher uptake of ANC, and SBA. However, in this study, women's education and wealth index did not significantly influence the estimates of FP, ANC. This could be attributed to the way in which they were assembled where a mean was derived at sub-county level. Some sub-counties had as few as 17 clusters which may not be a representative of the entire population and thus could have influenced the results.

Overall, the RMCH index was 53.5 across the 4 years (57.3–60.3). The usefulness of a composite index based on routine facility based DHIS2 is dependent on the individual data element reporting rates and accuracy of the denominator estimates in measuring the target population. This study demonstrates that the RMCAH composite indices can be generated and used where there DHIS2 uptake and use is robust with high reporting rates and data quality assurance mechanisms are in place. It also underscores the usefulness of RMNC index as a reliable and meaningful summary measure to assess performance of key indicators for maternal, newborn and child health against national targets. Estimates of RI at sub-national level are vital in highlighting marginalized populations and providing evidence for decision making and targeting of resources and RMCH interventions.

There were some limitations in the analyses undertaken in this study. Our computation of the RMNCAH index included only four service delivery indicators and one quality of care indicator. At least one indicator was selected from along the continuum of care from before pregnancy (FP), pregnancy (ANC4 and SBA), child health (FIC) and. Although these indicators were sufficient in generating a RMNC index, there is potential for integrating them with additional indicators from all levels of care including newborn and adolescent health to provide a comprehensive set of indicators across the continuum of care. The facility reporting of newborn facility mortality in DHIS2 is low, with poor data quality for other newborn, child and adolescent health indicators which limited their use in developing a complete RMCH index. The selection of only five RMCH indicators limits the scope of the RMCH index, potentially underrepresenting critical aspects of maternal, child, and reproductive health, and excluding new-born health which is part of the spectrum.

In addition, four physical and socio-economic determinants which were applicable as explanatory variables across the five indicators were selected. While the scope of this paper employed use of these determinants to improve indicator estimates at sub-county level. Future work could aim to explain causations of such patterns to potentially offer better insight into targeting of RMNCAH interventions.

The findings using DHIS2 systems may not be generalizable in areas where other data information systems are used, or more or less rigor is employed in ensuring the quality of data at the health facility.

Data verification at health facility at the point of data generation and entry into DHIS was not done and this may result in errors in external validity. Data quality assessment for outlier detection and internal consistency was done from data entered into DHIS at the health facility level. Completeness of data was assessed at subcounty level and adjusted for non-reporting facilities. The model assumptions used to adjust for outliers and account for non-reporting health facilities could affect the results reported.

Conclusion

Kenya has generally made substantial efforts in improving RMCH coverage. However, without targeted investment in RMNCAH interventions geographical inequalities will persist. There is value in investing in strengthening use of routine data to monitor RMNCAH and other health services in order to reveal the existing geographical inequalities, and enable implement timely and responsive interventions to address the gaps. Robust data systems will enable countries use data to develop policies, and focus resources and interventions targeting low service coverage and marginalized areas, enabling real time adjustments to emerging priorities in order to meet the 2030 SDG health targets. The counties also need to identify and address inequalities within the sub-counties to improve overall county performance hence contributing to the overall national performance.

Achieving national targets in RMNCAH coverage requires targeted actions to marginalized geographic areas which not only consists of health system strengthening but also addressing the social determinants of health. The counties in the north-eastern region which mainly are in the arid and semiarid lands with nomadic populations which have the poorest health outcomes across all the indicators. The health system strengthening aspects should aim to not only ensure availability and access to health services, but also improved quality of care to ensure Kenyans receive high quality services to improve health outcomes resulting in reduced maternal and child mortality. A focus on preventive care through strengthened and primary health systems tailored to the community needs and dynamics. Strengthening of Community units, provision of mobile health units at community level and equipping existing primary health facilities and improved linkage and referral in marginalized, hard to reach areas will help to bridge the gap in coverage.

Abbreviations

DHIS2	District Health Information Software version 2
LMICs	Low- and middle-income countries
RMCH	Reproductive, maternal, and child health
RI	RMCH index
FP	Family planning
ANC	Antenatal care
SBA	Skilled birth attendance
FMMR	Facility maternal mortality rate
FIC	Full immunization coverage
KDHS	Kenya Demographic Health Survey
HF	Health facility
WHO	World Health Organization
RMNCAH	Reproductive maternal, newborn, child and adolescent health
RMSE	Root mean square error
MSE	Mean square error
MAE	Mean absolute error
WRA	Women of reproductive age
CAR	Conditional auto-regressive

Supplementary Information

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Supplementary material 1.

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Authors' contributions
JK, VA, AC, HK, and conceptualized the paper. Data curation was done by AC and RM. The data analysis and methodology were done by VA, AC, JK and MM. JK, AC and VA wrote the original draft. The discussion was written by JK, AC and VA. MT, PG and HK gave guidance in the discussion and overview. All authors read, edited and approved the final manuscript.

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Data availability
Aggregated DHIS2 data is available online with access provided by Ministry of Health through https://hiskenya.org/dhis-web-commons/security/login.action. The datasets used and/or analyzed during the current study are also available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study involved the assembly of aggregated secondary data from DHIS2 and did not require additional IRB approval or ethical clearance. Relevant authorization to analyze DHIS2 data was received from the Ministry of Health Kenya.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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