

Optimising scale and deployment of community health workers in Sierra Leone: a geospatial analysis

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ABSTRACT

Background Little is known about strategies for optimising the scale and deployment of community health workers (CHWs) to maximise geographic accessibility of primary healthcare services.

Methods We used data from a national georeferenced census of CHWs and other spatial datasets in Sierra Leone to undertake a geospatial analysis exploring optimisation of the scale and deployment of CHWs, with the aim of informing implementation of current CHW policy and future plans of the Ministry of Health and Sanitation.

Results The per cent of the population within 30 min walking to the nearest CHW with preservice training increased from 16.1% to 80.4% between 2000 and 2015. Contrary to current national policy, most of this increase occurred in areas within 3 km of a health facility where nearly two-thirds (64.5%) of CHWs were deployed. Ministry of Health and Sanitation-defined 'easy-to-reach' and 'hard-to-reach' areas, geographic areas that should be targeted for CHW deployment, were less well covered, with 19.2% and 34.6% of the population in 2015 beyond a 30 min walk to a CHW, respectively. Optimised CHW networks in these areas were more efficiently deployed than existing networks by 22.4%–71.9%, depending on targeting metric.

Interpretations Our analysis supports the Ministry of Health and Sanitation plan to rightsize and retarget the CHW workforce. Other countries in sub-Saharan Africa interested in optimising the scale and deployment of their CHW workforce in the context of broader human resources for health and health sector planning may look to Sierra Leone as an exemplar model from which to learn.

BACKGROUND

Countries committed to achieving Universal Health Coverage (UHC) as part of the Sustainable Development Goals set in 2015 and reaffirmed that commitment at the United Nations General Assembly High Level Meeting on UHC in 2019.¹ Achieving UHC and ensuring effective pandemic preparedness and response will require strengthening health systems by investing in primary

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Previous studies in Sierra Leone have explored geographical accessibility to antenatal care and childbirth services at health facilities but not community-based primary healthcare (PHC) services provided by community health workers (CHWs).

WHAT THIS STUDY ADDS

⇒ Our analysis provides new insight on the contribution of CHWs to increasing geographical accessibility of community-based PHC services in Sierra Leone between 2000 and 2015, as well as policy relevant variation across subnational areas, gender of the CHW and training of the CHW on specific interventions.

⇒ Our analysis identifies important misalignment between the scale and geographic distribution of the existing CHW workforce and current national policy, and points to opportunities for optimising scale and efficiency of CHW deployment.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE AND/OR POLICY

⇒ Our analysis supports Ministry of Health and Sanitation (MOHS) plans to rightsize and retarget the CHW workforce.

⇒ The MOHS could use our analysis and future iterations to fine-tune planning and implementation of CHW policy in the context of broader HRH and health sector planning.

⇒ MOHS and partners could consider re-investing cost-savings from rightsizing and retargeting towards the professionalisation of CHWs and strengthening the systems components needed to optimise CHW performance.

healthcare (PHC), particularly frontline health workers at the primary healthcare level and in communities.^{2–5} CHWs are foundational to the PHC approach as frontline human resources for health (HRH), essential members of PHC teams providing community-based PHC services and a trusted

bridge between the health system and communities.⁶⁻⁹ Research has shown CHWs can be a cost-effective and equity-promoting investment, particularly when they are well-supported by the health system and communities they serve.¹⁰⁻¹⁵ Investment in CHWs can also promote the economic development and the empowerment of women through paid work.^{10 16} Globally, there is a severe HRH shortage, including for CHWs, compounded by a maldistribution of HRH, with the most severe affects in Africa, particularly in rural, remote and underserved geographic areas.^{17 18} Globally, financing of HRH is inadequate, including for CHWs with an estimated funding gap of US\$5.4 billion annually.¹⁹

In Sierra Leone, CHWs are essential frontline HRH critical to the country's vision of a resilient national health system and prosperous socioeconomic development.²⁰⁻²² Under the leadership of the Ministry of Health and Sanitation (MOHS), there was a large scale-up of CHWs employed by non-governmental organisations between 2000 and 2020, including during the Ebola crisis.²³ As of 2020, there were >17 000 CHWs deployed in Sierra Leone.²³ An assessment of the national CHW programme incorporated findings from earlier iterations of our analysis, and informed the new MOHS CHW policy for the period 2021–2025.²³ The new policy included three key policy shifts: harmonisation and integration of all CHW cadres into the national CHW programme, rightsizing the scale of the CHW network and retargeting CHW deployment to areas of greatest need.²⁴

ries strive to increase financing for HRH, including for CHWs, concurrent efforts are needed to optimise impact and efficiency of available funding through rightsizing scale and improving the equitable distribution of HRH, including CHWs. Geospatial analysis using geographic information systems can be a powerful tool in the HRH toolkit for optimising scale and deployment of HRH. However, few countries leverage the potential of geospatial analysis, contributing to inefficiencies and inequities in the distribution of HRH and geographical accessibility of health services.^{17 18}

We used data from a national georeferenced census of CHWs and other spatial datasets in Sierra Leone to undertake a geospatial analysis exploring optimisation of the scale and deployment of CHWs with the aim of informing implementation of the new CHW policy and future MOHS planning.

DATA AND METHODS

We provide a detailed description of the data and methods in online supplemental appendix 1, including a simplified analysis flow (online supplemental appendix 1 figure 1). Methods were adapted from previous work in the region by Oliphant *et al.*²⁵

Study setting

During our period of focus, 2000–2016, Sierra Leone had four political administrative levels (chiefdoms, districts,

provinces and national).²⁶ The health system included a public and private sector organised in a decentralised, pyramidal structure with three administrative levels—tertiary, secondary and primary—overseen by the MOHS.²⁷ Our analysis focuses on CHWs situated at the base of the primary level. The primary level comprised public health facilities, collectively known as peripheral health units (PHUs) providing PHC services and referral services to the secondary level (district hospitals). PHUs—in descending order according to size and availability of skilled healthcare workers—included community health centres, community health posts and maternal and child health posts. The primary level also included private sector clinics focused on primary healthcare services.

At the base of the primary level were CHWs. National CHW policy evolved over time, including the development of the first national CHW policy in 2012 (covering 2012–2015)²⁸ and subsequent updates in 2016 (covering 2016–2020)²¹ and 2021 (covering 2021–2025).²⁴ According to the national CHW policy of 2012–2015, a CHW was defined as a community member selected by the community and trained to provide basic essential health services and information at community level.²⁸ Following a standardised 10-day preservice training designed by the MOHS, CHWs were allowed to provide a standard package of community-based PHC services, including prevention, promotion and curative services, as well as surveillance activities, through household visits. The national CHW policy of 2012–2015 did not include geographic criteria for guiding the deployment of CHWs (ie, the CHW could be selected from and work in communities regardless of proximity to health facilities). The national CHW policy of 2021–2025 sought to rightsize and retarget the CHW network and was informed, in part, by early iterations of our analysis.^{23 24} Additional details on the evolution of CHW policy, including the definition of CHWs, package of services, selection, training, certification, deployment, CHW per population ratios and supervision are provided in online supplemental appendix 1.

Data

We obtained the following spatial datasets to inform our models of travel time to CHWs and health facilities: administrative boundaries (levels 0–3),²⁹ a 2016 national georeferenced master facility list (Ministry of Health and Sanitation, the Republic of Sierra Leone, UNICEF, 2016), a 2016 national georeferenced CHW master list (CHWML) (Ministry of Health and Sanitation, the Republic of Sierra Leone, UNICEF, 2016), digital elevation model,³⁰ land cover,³¹ roads,³² waterbodies³³ (treated as barriers to movement where roads did not cross) and travel scenarios (online supplemental appendix 1 figures 27–37). As of 2016, there were 14 632 working CHWs of which 14 579 CHWs (99.6%) had geographic coordinates for the main settlement in which they worked and 14 494 CHWs (99.1%) reported they received the standard 10-day preservice training of the MOHS (online supplemental appendix 1 figure 38). Data on training

and year of deployment were self-reported by CHWs in the CHWML. For our analysis of accessibility coverage, geographic coverage and efficiency of deployment, we obtained modelled estimates for population counts for 2000–2015.^{34 35} Community-based PHC services provided by CHWs are intended to address under-five (U5) mortality and malaria was a main cause for curative consultations among children U5 in Sierra Leone.²⁷ For this reason, we obtained modelled estimates of the annual mean U5 mortality rate in 2015³⁶ and modelled estimates of the annual mean incidence of *Plasmodium falciparum* (*Pf*) malaria among all ages (0–99 years) in 2015³⁷ to inform our efficiency analysis. We prepared the input datasets in the projected coordinate reference system EPSG:2161—Sierra Leone 1968/UTM zone 28N for Sierra Leone at 100 m×100 m resolution for our analysis of accessibility coverage and 1 km×1 km for our analysis of geographic coverage and efficiency of deployment.

We prepared a travel speed table for the travel scenario walking in dry conditions (online supplemental appendix 1). We adapted travel speeds for each land cover class and road class from previous studies.^{25 38 39} Travel speeds refer to the population walking in dry conditions in the direction of the CHW. Travel speeds and analysis for other travel scenarios (eg, travel in wet conditions, motorised travel) that were not our main focus are provided in online supplemental appendix 1.

Geographic areas relevant to CHW policy

The current CHW policy for 2021–2025 included two policy-relevant geographic areas: easy-to-reach (ETR) and hard-to-reach (HTR) areas.²⁴ The MOHS defined ETR areas as areas 3–5 km from a health facility and not in difficult terrain. The MOHS did not define ‘not in difficult terrain’. Hills, mountains and water bodies can increase the travel time needed to traverse an area or impede travel altogether, depending on the mode of transport. We accounted for the effect of such geographic features on travel time in our analysis and defined ‘not in difficult terrain’ as areas within 60 min walking of a health facility. The MOHS-defined HTR areas as areas beyond 5 km from a health facility or between 3 and 5 km of a health facility and in an area with difficult terrain. The MOHS did not define ‘difficult terrain’. We defined ‘difficult terrain’ as beyond 60 min walking of a health facility. This is a change from previous definitions of ETR and HTR areas in Sierra Leone. In the CHW policy for 2016–2020, the MOHS defined ETR areas as areas within 3 km of a health facility and HTR areas as areas beyond 3 km from a health facility.²¹ The MOHS definitions of ETR and HTR areas in the 2016–2020 policy did not mention ‘difficult terrain’. The CHW policy of 2012, covering the period 2012–2015, did not provide definitions for HTR and did not mention ETR.²⁸

We conducted our analysis for three geographic areas relevant to the current CHW policy for 2021–2025: areas within 3 km of a health facility, which are not prioritised for CHW deployment in the 2021–2025 CHW policy, ETR

areas and HTR areas. Populated areas within 3 km of a health facility covered a total of 12 990 km² with an estimated population of 5.5 million in 2015 (77.2% of the total population). Populated ETR areas covered a total of 3 345 km² with an estimated population of 167 000 in 2015 (2.4% of the total population). Populated HTR areas covered a total of 14 878 km² with an estimated population of 1.4 million in 2015 (20.2% of the total population). Further details on the data and methods used to derive these geographic areas are in online supplemental appendix 1 1.

Assessing accessibility coverage

We defined accessibility coverage as the estimated percentage of people within a given travel time to the nearest health service delivery location, accounting for travel speeds of different modes of transportation over different land cover classes.³⁹ The slope of the terrain is accounted for by correcting for walking speeds,⁴⁰ and by considering a direction of travel towards the health service delivery location.³⁹

We estimated accessibility coverage at 100 m×100 m resolution for the health facility and CHW networks in 2015. We also did this for the CHW networks in ETR and HTR areas, gender of the CHW, year of deployment (2000–2015), preservice training and training on specific interventions. We used 10 min, 30 min and 60 min cut-offs as previous analyses have shown care seeking decays as a function of travel time after these cutoffs⁴¹ and they are clinically relevant (eg, for prompt treatment of severe illness).⁴² The analysis was constrained to national borders but allowed for travel across subnational administrative boundaries. We used the ‘accessibility’ module within AccessMod 5 (V.5.6.56)⁴¹ to calculate travel time layers and the ‘zonal statistics’ module to calculate zonal statistics for each travel time layer by administrative level.

Assessing efficiency of deployment in ETR and HTR areas

We assessed the efficiency of deployment of the existing CHW networks and compared them with hypothetical networks designed to optimise efficiency of CHW deployment. We defined efficiency of deployment as the geographic coverage of the estimated population achieved by a given number of CHWs, based on an adaptation of the definition of technical efficiency by Palmer and Torgerson.⁴³ A CHW network designed to optimise efficiency of CHW deployment is one that maximises geographic coverage of the population with the fewest number of CHWs. This requires deploying CHWs such that each CHW maximises the gain in geographic coverage of the population. We assessed efficiency of deployment by comparing the gain/loss in geographic coverage achieved by optimised CHW networks compared with the existing CHW networks, given the same number of CHWs. We defined geographic coverage as the estimated population within a theoretical catchment area of the CHW networks, given a 30 min maximum travel time (walking scenario) and the maximum population capacity of the

CHWs.³⁹ We assessed geographic coverage of (a) the estimated population in 2015, (b) the estimated U5 deaths in 2015 and (c) the estimated *Pf*malaria cases in 2015 by the existing CHW networks in 2016 at 1 km×1 km resolution using the ‘geographic coverage’ module of AccessMod 5 (V.5.6.56).³⁹ We then assessed geographic coverage of a–c using the hypothetical CHW networks in 2016 designed to optimise metrics a–c, and compared these results with the results from the existing networks. The maximum population capacity for CHWs was based on the MOHS norms for the ratio of CHWs per population from the 2021 CHW policy.²⁴ We used the lower bound of the MOHS range for the ratio of CHW per population to be conservative in our estimates: 500 for CHWs in ETR areas and 300 for CHWs in HTR areas. The maximum extent of a catchment was therefore delimited by the maximum travel time of 30 min except in cases where the estimated population in the catchment exceeded the maximum population capacity. In this case, the extent of the catchment was defined by the area containing the estimated population, up to the maximum population capacity.

For (a) we compared the efficiency of deployment of the existing CHW networks with hypothetical networks of the same number of CHWs (n=1521 in ETR areas and n=3650 in HTR areas). We used the MOHS norms for CHWs to population stated above. There is no MOHS norm for the ratio of CHW per U5 deaths or *Pf*malaria cases. Assuming one CHW could cover all estimated U5 deaths or *Pf*malaria cases within their catchment regardless of population size would be unrealistic. For metrics (b) and (c), we based the number of CHW required for the existing CHW networks and the hypothetical CHW networks on the estimated number of CHW needed to cover the estimated population in each catchment using the MOHS norms above. We then compared the estimated geographic coverage attained in ETR areas by the first 1521 CHW of the existing CHW network with the first 1521 CHW of the hypothetical CHW network designed to optimise metrics b–c. We did the same comparison for HTR areas, using the first 3650 CHW of the existing CHW network and first 3650 CHW of the hypothetical CHW network designed to optimise metrics b–c. We assessed the potential effect of uncertainty of the estimates for U5 deaths and *Pf*malaria cases among all ages on interpretation of our efficiency results (see online supplemental appendix 1 and 4).

Patient and public involvement statement

We did not involve patients or the public in this study.

RESULTS

Accessibility coverage

Three-quarters (76.1%) of the estimated population in 2015 had walking access to a health facility within 60 min (table 1). Accessibility coverage within a 30 min walk to a CHW increased from 16.0% to 80.4% between 2000 and 2015 (table 1). Contrary to current national policy,

most of the increase in accessibility coverage of CHWs occurred within 3 km of a health facility where nearly two-thirds (64.5%) of CHWs were deployed. Increases in accessibility coverage were least pronounced in ETR and HTR areas, where only 10.4% and 25.0% of CHWs were deployed, respectively (table 1, online supplemental appendix 1 figure 35). Accessibility coverage of the estimated population in ETR and HTR areas within a 30 min walk to a CHW was 80.9% and 65.4%, respectively, covering an estimated 135 000 and 801 000 people (table 1). Online supplemental video shows the evolution of travel time (walking) to a CHW between 2000 and 2015, indicating a relatively slower scale-up between 2000 and 2010 and a rapid scale-up thereafter—continuing during the Ebola outbreak of 2015–2016. Accessibility coverage within a 30 min walk to a CHW was higher for male CHWs compared with female CHWs, with the disparity most pronounced in ETR and HTR areas (table 1). Accessibility coverage within a 30 min walk varied by training on specific interventions, with the highest accessibility coverage (near 74%) for community case management (CCM) for malaria, prevention and promotion interventions, and CCM index (CCM for malaria plus identification and referral for severe malnutrition) and lower accessibility coverage for reproductive, maternal and newborn health (RMNH) interventions (65.5%) Ebola virus disease signal functions (60.2%) and all packages (48.3%) (table 1). Accessibility coverage also varied by travel scenario, with higher accessibility coverage for dry scenarios versus wet scenarios and walking plus motorised transportation scenarios versus walking scenarios. We provide additional maps in online supplemental appendix 1 figures 2–19 and detailed results at national and subnational levels (chiefdoms) by travel scenario in online supplemental appendix 2, tab ‘Detailed_Results’.

Efficiency of deployment

ETR areas

The hypothetical CHW network in ETR areas was 43.2% more efficient than the existing network in terms of geographic coverage of the estimated population within a 30 min catchment (97.0% vs 67.7%) (figures 1 and 2A and online supplemental appendix 3, tab ‘Comparison_Pop_ETR’). A majority (53%) of the existing CHW network realised <30% of their maximum population capacity (500), indicating redundancy from inefficient deployment. Additionally, 80% of the estimated population not covered by the existing CHW network in 2015 was concentrated in just 36.6% (56/153) of communes (online supplemental appendix 1 figures 20–22 and 26). The hypothetical CHW network in ETR areas was 27.2% more efficient than the existing network in terms of geographic coverage of the estimated U5 deaths within a 30 min catchment (95.1% vs 74.8%) (figure 2B, online supplemental appendix 3, tab ‘Comparison_U5d_ETR’). The hypothetical CHW network in ETR areas was 26.1% more efficient than the existing network in terms of geographic coverage of the estimated *Pf*malaria

Table 1 Accessibility coverage of the estimated population in 2015 by the health facility and CHW networks, walking scenario

Network*	Among population within 3 km of a health facility, % within travel time				Among estimated population in ETR areas, % within travel time				Among estimated population in HTR areas, % within travel time				Among total estimated population in 2015, % within travel time					
	10 min	30 min	60 min	10 min	30 min	60 min	10 min	30 min	60 min	10 min	30 min	60 min	10 min	30 min	60 min	10 min	30 min	60 min
Health facility	54.8	84.5	95.8	0.0	0.0	92.2	0.0	0.0	0.0	0.0	42.3	65.2	76.1					
CHW	68.0	84.4	96.3	69.5	80.9	97.0	56.1	65.4	75.3	65.6	80.4	92.0						
CHW in 2000 with preservice training	5.3	20.6	31.0	0.9	2.1	3.8	0.4	0.5	0.9	4.2	16.1	24.2						
CHW with preservice training	67.9	84.4	96.3	69.5	80.8	97.0	56.1	65.4	75.3	65.5	80.4	92.0						
Female CHW with preservice training	47.9	63.0	79.8	27.3	39.5	63.4	20.1	26.8	41.0	41.7	55.0	71.4						
Male CHW with preservice training	60.7	80.6	95.6	62.0	77.4	94.7	49.1	59.3	71.8	58.4	76.1	90.6						
CHW with preservice training and training on prevention and promotion interventions	60.6	79.3	92.7	61.3	72.6	91.2	47.7	56.5	67.3	57.9	74.4	87.4						
CHW with preservice training and training on RMNH interventions	53.5	71.5	87.0	41.7	52.3	76.1	36.2	44.5	57.0	49.7	65.5	80.5						
CHW with preservice training and training on CCM for malaria	61.9	79.5	91.5	63.7	71.7	86.6	48.9	56.9	66.9	59.2	74.7	86.3						
CHW with preservice training and training on CCM index	60.9	78.7	90.8	62.6	70.4	84.8	48.3	56.3	66.4	58.4	73.9	85.6						
CHW with preservice training and training on EVD signal functions	48.9	67.7	84.0	33.3	44.0	70.4	26.9	34.0	47.6	44.0	60.2	76.2						
CHW with preservice training and training on all packages	38.3	56.3	71.5	20.9	25.6	50.0	16.4	20.7	31.2	33.4	48.3	62.8						

*Results for the health facility network are as of May 2016. Results for the CHW networks are as of February 2016, except where noted (row three is for CHWs in the year 2000 that had preservice training). CCM, community case management; CHW, community health worker; ETR, easy-to-reach area; EVD, Ebola virus disease; RMNH, reproductive, maternal, newborn health.

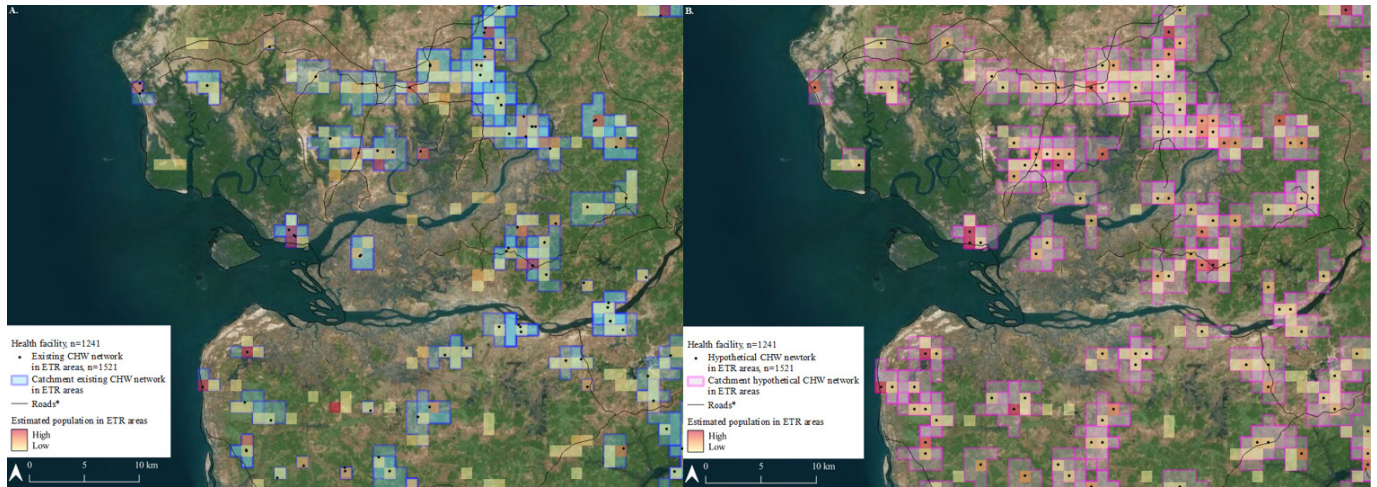


Figure 1 Modelled catchment areas of the existing CHW network in ETR areas, and hypothetical optimised CHW network in ETR areas in 2016 at 1 km×1 km resolution. (A) Modelled 30 min catchment areas of the existing CHW network (blue) in ETR areas in 2016; (B) modelled 30 min catchment areas of the hypothetical optimised CHW network (pink) in ETR areas in 2016. All analyses at 1 km×1 km resolution based on a walking scenario and maximum population capacity of the given network. Images depict chiefdoms within Kambia and Port Loko districts in Northern province. *For visualisation purposes, road classes limited to motorway, trunk, primary, secondary and tertiary. CHW, community health worker; ETR, easy-to-reach area.

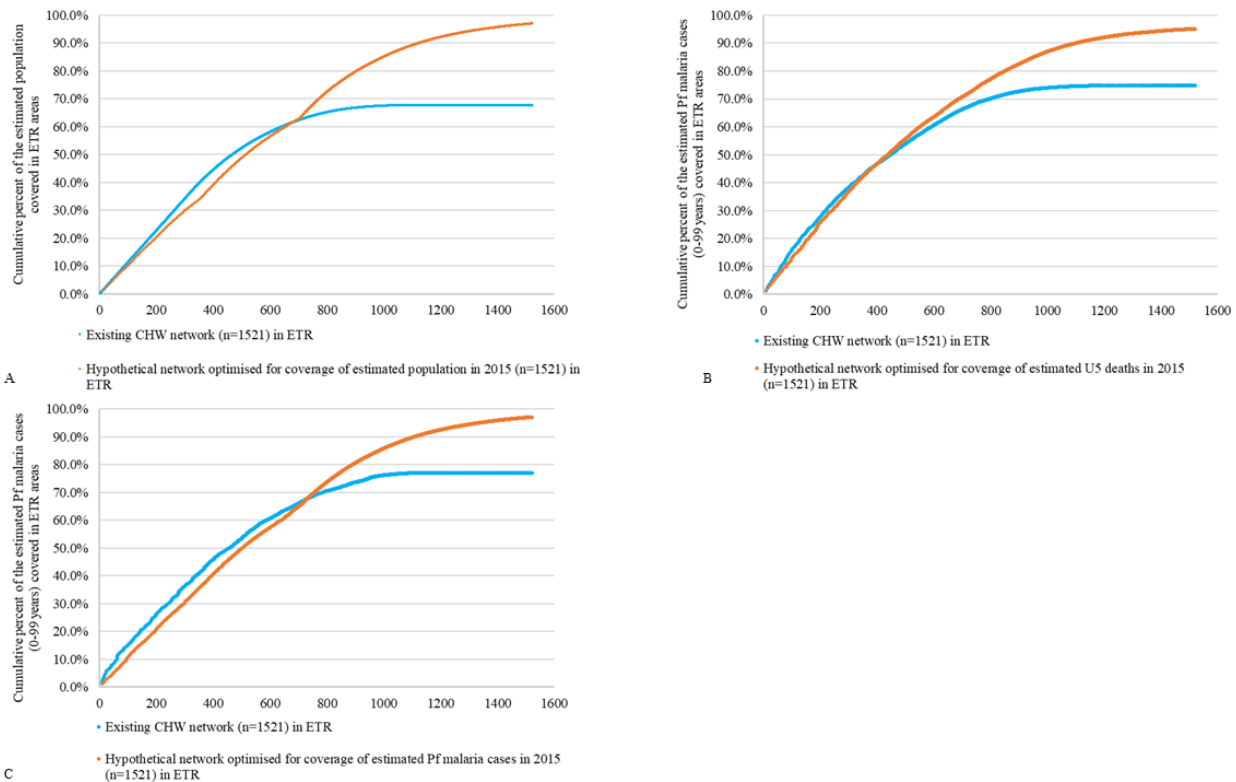


Figure 2 Efficiency of deployment of the existing CHW network compared with hypothetical optimised CHW networks in ETR areas at 1 km×1 km resolution. (A) Comparison of the per cent of the estimated population in ETR areas covered within a 30 min catchment area (walking) by the existing CHW network compared with a hypothetical CHW network deployed to optimise geographic coverage of the estimated population in ETR areas; (B) comparison of the per cent of the estimated U5 deaths in ETR areas covered within a 30 min catchment area (walking) by the existing CHW network compared with a hypothetical CHW network deployed to optimise geographic coverage of the estimated U5 deaths in ETR areas; (C) comparison of the per cent of the estimated Pf malaria cases among all ages (0–99 years) in ETR areas that was covered within a 30 min catchment area (walking) by the existing CHW network compared with a hypothetical CHW network deployed to optimise geographic coverage of the estimated Pf malaria cases among all ages (0–99 years) in ETR areas. All analyses at 1 km×1 km resolution. CHW, community health worker; ETR, easy-to-reach area; Pf, *Plasmodium falciparum*; U5, under-five.

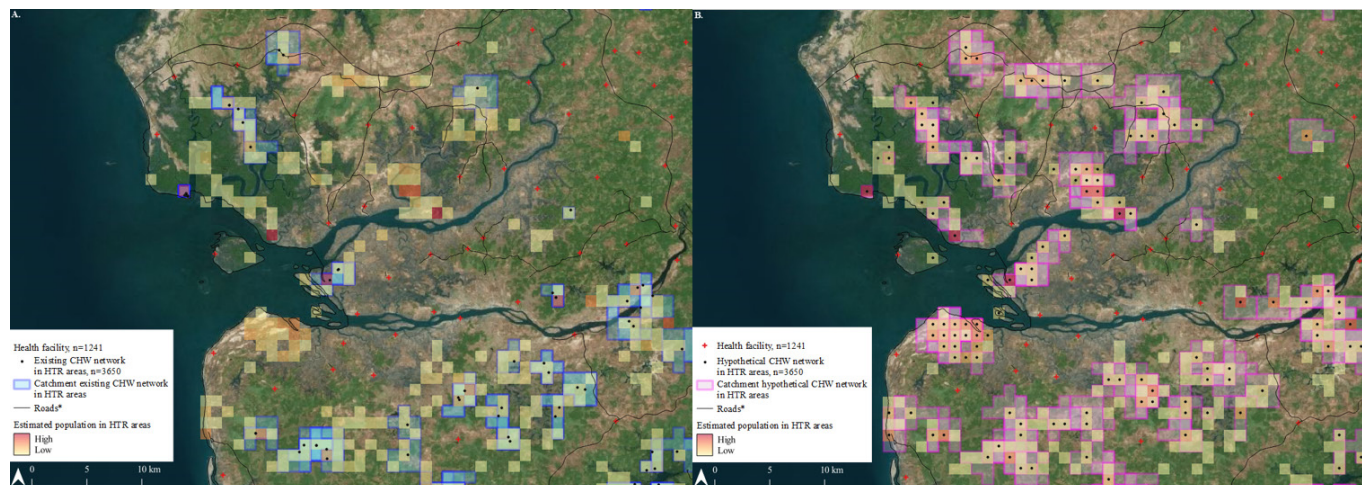


Figure 3 Modelled catchment areas of the existing CHW network in HTR areas, and hypothetical optimised CHW network in HTR areas in 2016 at 1 km×1 km resolution. (A) Modelled 30 min catchment areas of the existing CHW network (blue) in HTR areas in 2016; (B) modelled 30 min catchment areas of the hypothetical optimised CHW network (pink) in HTR areas in 2016. All analyses at 1 km×1 km resolution based on a walking scenario and maximum population capacity of the given network. Images depict chiefdoms within Kambia and Port Loko districts in Northern province. *For visualisation purposes, road classes limited to motorway, trunk, primary, secondary and tertiary. CHW, community health worker; HTR, hard-to-reach area.

cases (all ages) within a 30 min catchment (97.1% vs 77.0%) (figure 2C, online supplemental appendix 3, tab ‘Comparison_Cases_ETR’).

HTR areas

The hypothetical CHW network in HTR areas was 71.9% more efficient than the existing network in terms of geographic coverage of the estimated population within a 30 min catchment (78.3% vs 45.5%) (figures 3 and 4A and online supplemental appendix 3, tab ‘Comparison_Pop_HTR’). Nearly half (47%) of the existing CHW network in HTR realised <30% of their maximum population capacity (300), indicating redundancy from inefficient deployment. Additionally, 80% of the estimated population not covered by the existing CHW network in 2015 was concentrated in just 37.2% (57/153) of communes (online supplemental appendix 1 figures 23–25). The hypothetical CHW network in HTR areas was 38.9% more efficient than the existing network in terms of geographic coverage of the estimated U5 deaths within a 30 min catchment (90.1% vs 64.9%) (figure 4B, online supplemental appendix 3, tab ‘Comparison_U5d_HTR’). The hypothetical CHW network in HTR areas was 22.4% more efficient than the existing network in terms of geographic coverage of the estimated *Pf*malaria cases (all ages) within a 30 min catchment (79.7% vs 65.1%) (figure 4C, online supplemental appendix 3, tab ‘Comparison_Cases_HTR’).

DISCUSSION

This was the first study to assess geographical accessibility and efficiency of deployment of CHWs at national scale in Sierra Leone. Accessibility coverage of CHWs increased between 2000 and 2015 but most of the increase occurred within 3 km of a health facility, contrary to

current national policy. ETR and HTR areas were less well covered by CHWs. There was substantial variation in access to a CHW across subnational geographies. Access to female CHWs was lower than male CHWs. Access to CHWs trained on RMNH interventions was lower than access to CHWs trained on prevention and promotion interventions or community case management for malaria. Optimised CHW networks in ETR and HTR areas were more efficiently deployed than existing networks by 26.1%–43.2% and 22.4%–71.9%, respectively, depending on targeting metric.

Implications for policy

Planning for the scale-up and efficient deployment of the CHW workforce, like with broader HRH and health sector planning, cannot be addressed purely through modelling. The political economy of such planning is complex, involving multiple factors that are difficult to capture in models.^{44 45} That said, modelling can be a useful tool among others, for policy makers and planners. Below we outline the implications of our analysis for policy makers and planners in Sierra Leone, as well as other countries in sub-Saharan Africa with similar contexts and interest in optimising PHC at community level.

First, scale-up of CHWs improved geographical accessibility of PHC at community level between 2000 and 2015 but most of the increase occurred within 3 km of a health facility, where a majority of CHWs were deployed. This pattern broadly reflects the population distribution—77.2% of the population in 2015 were within 3 km of a health facility—this is similar to the urban skew of the broader HRH workforce²⁰ and reflects early CHW policy (prior to 2016, CHW could be selected from and work in communities regardless of proximity to health facilities). But it does not align with current national policy and

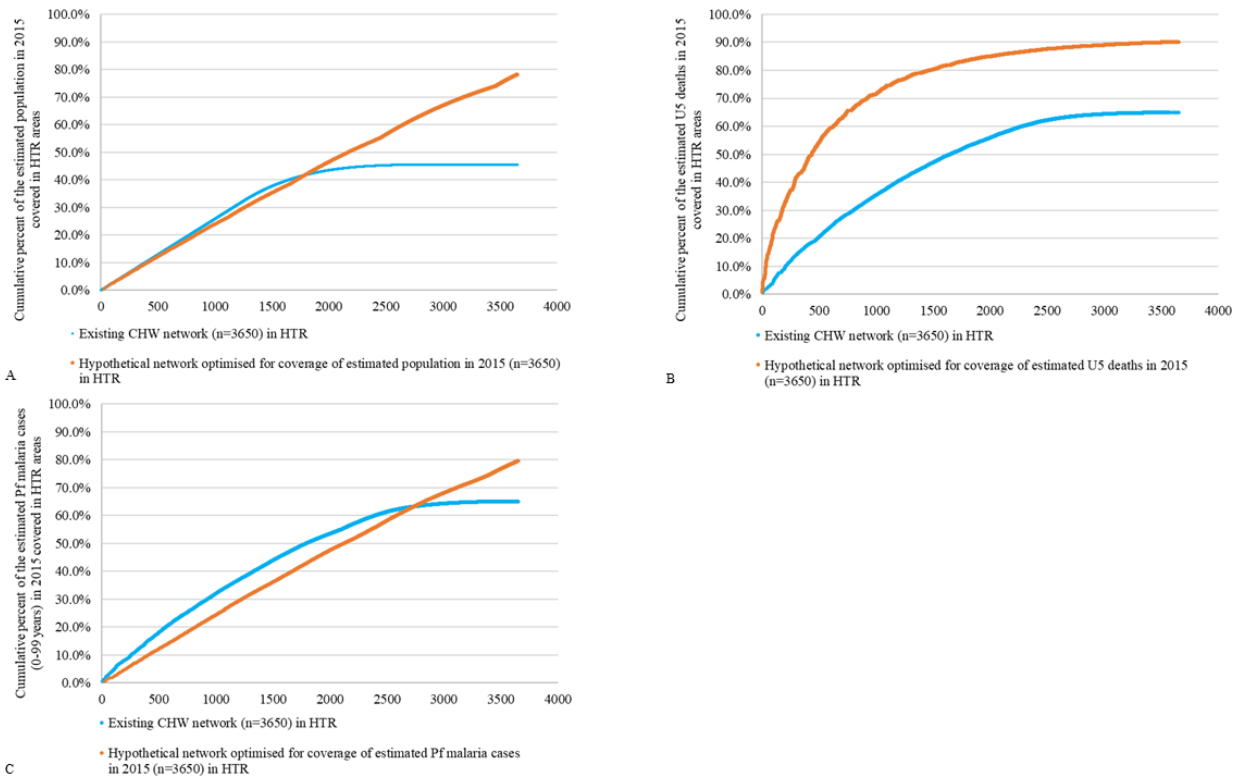


Figure 4 Efficiency of deployment of the existing CHW network compared with hypothetical optimised CHW networks in HTR areas at 1 km×1 km resolution. (A) Comparison of the per cent of the estimated population in HTR areas covered within a 30 min catchment area (walking) by the existing CHW network compared with a hypothetical CHW network deployed to optimise geographic coverage of the estimated population in HTR areas; (B) comparison of the per cent of the estimated U5 deaths in HTR areas covered within a 30 min catchment area (walking) by the existing CHW network compared with a hypothetical CHW network deployed to optimise geographic coverage of the estimated U5 deaths in HTR areas; (C) comparison of the per cent of the estimated Pf malaria cases among all ages (0–99 years) in HTR areas that was covered within a 30 min catchment area (walking) by the existing CHW network compared with a hypothetical CHW network deployed to optimise geographic coverage of the estimated Pf malaria cases among all ages (0–99 years) in HTR areas. All analyses at 1 km×1 km resolution. CHW, community health worker; HTR, hard-to-reach area; Pf, *Plasmodium falciparum*; U5, under-five.

therefore warrants rethinking. With the 2021–2025 CHW policy, the MOHS plans to rightsize and retarget the CHW workforce (including CHW peer supervisors) by reducing it by 40% and retargeting CHW recruitment and deployment towards ETR and HTR areas. This is a bold move to optimise scale and deployment of CHWs in the context of broader efforts to optimise HRH deployment.²² This key shift was informed by an earlier iteration of our current analysis, which was included in an assessment of the National CHW Programme by JSI²³ and broader CHW policy discussions. Our current analysis supports this important policy decision by the MOHS. However, optimising scale and deployment of CHWs comes with operational challenges. For example, employers will need to end the employment of CHWs and CHW peer supervisors located within 3 km of a health facility. Affected workers should be compensated fairly for early termination of their employment. Planners should anticipate the need to engage affected communities to regain their trust. Similarly, new CHWs and CHW peer supervisors will need to be recruited from communities in ETR and HTR areas not already adequately covered. They will need to be trained, paid, supervised and supported. This

will require effective planning, coordination, logistics and resources. But on balance, the positives outweigh the negatives. We estimate the cost-savings from the planned rightsizing and retargeting of the CHW workforce to be approximately US\$3.8 million annually (40% of the current annual cost of US\$9.5 million).²³ Cost-savings could be re-directed towards professionalising the CHW workforce and strengthening the health system and community enablers needed to optimise CHW performance,^{12 9} which have been well described to have major shortfalls in Sierra Leone^{46–48} and most national CHW programmes.^{14 49–52}

Second, our analysis highlighted an important gender disparity in CHW deployment (35% of CHWs were female and 65% were male). This gender disparity may negatively impact the use of specific services (eg, interventions for sexual health, RMNH).¹⁵ The MOHS intends to address this gender disparity in implementation of the 2021–2025 CHW policy, shifting the gender distribution to 60% female and 40% male. This would be an important shift from an HRH gender equity lens. It could improve the use of interventions such as those noted above. Lastly, it would contribute to greater gender

equity in socioeconomic development by employing and empowering more women.^{10 15} However, addressing the gender disparity in ETR and HTR areas may prove to be challenging, given gender disparities in education levels in rural communities. The MOHS may need to consider a range of gender responsive actions along the HRH cycle (eg, planning, recruitment, performance management and retention) to adequately and sustainably address the gender disparities identified.

Third, our analysis highlighted important variation in CHW training. Nearly all CHWs self-reported that they received preservice training but there was large variation in terms of training on specific services, indicating that the standard MOHS preservice training may not have been systematically implemented. The MOHS may need to strengthen coordination and oversight of the implementation of the standard MOHS preservice training as well as in-service training. This could be aided by updating and maintaining the national georeferenced CHWML hosted within or linked to the national human resources for health information system—iHRIS—and using the CHWML as the basis for tracking, planning and coordinating training.⁵³

Fourth, the current focus of the MOHS on rightsizing and retargeting the CHW workforce could enable future discussions on a sustainable financing pathway for CHWs,^{10 19 54 55} inclusive of increasing government financing for CHWs and a pathway for integration of CHWs within the civil service.¹⁶

Limitations

There are several important limitations of our study. First, our analysis is limited by the completeness and quality of the publicly available road and river network data. We acknowledge that more complete and/or higher quality data on roads and rivers may be available outside the public domain. We acknowledge that not all rivers may be perennial barriers to movement, particularly where bridges exist. We attempted to mitigate this limitation by allowing major road classes to cross rivers. Second, our analysis does not account for uncertainty of the estimates of population counts, limiting our ability to account for this source of uncertainty in measures of physical accessibility to services. Estimates of the uncertainty of the estimated population counts in Sierra Leone for the years 2000–2015 were not available, but we acknowledge that availability of this kind of data will be important for improving future modelling efforts. Third, the estimated population counts for 2000–2014 use the 2015 population settlement footprint from 2015,³⁴ which may not accurately reflect the population settlement footprint for the period 2000–2014. Fourth, our analysis is based on estimated travel speeds from other studies in sub-Saharan Africa, not empirical data from Sierra Leone or local expert knowledge, although research indicates these speeds may be appropriate in the Sierra Leone context.⁵⁶ Our analysis does not account for uncertainty of travel speed estimates.

Additionally, our analysis does not account for variation in walking speeds or common modes of transportation used across population groups. For example, pregnant women, people with illness, caregivers of ill children, the elderly population, people with disabilities may walk slower than the general population, modes of transport may differ by socioeconomic status and boat travel may be important in certain geographic areas. A planned update to this analysis in 2021–2022 will attempt to address the limitations above regarding travel speeds and modes of transportation by incorporating information derived from subnational level workshops with local experts. Fifth, our analysis used CHW self-reported data on receipt of training and year of deployment, which may be subject to recall bias. Sixth, our analysis did not account for the possibility of accessing health services across national boundaries, an important consideration for border communities and migrant populations.

We acknowledge that there are many factors beyond physical accessibility that affect access to and use of health services, such as social and economic barriers to care seeking.⁵⁷ Such factors may impact access to and use of health services independently of physical accessibility or through interactions with physical accessibility.⁵⁸ It is also important to consider quality of services, including population perceptions of the quality of services, and the potential for bypassing.^{59 60}

We also acknowledge that this kind of modelling can be challenging. Integration into national processes and policy takes time and requires strengthening national institutional capacity. Additionally, operationalising the optimised deployment poses many challenges as noted above. But despite these challenges, this kind of modelling can be very useful as we have demonstrated in the case of Sierra Leone. At the time of writing, coauthors—including those from the MOHS—were updating this analysis with datasets from 2021, with a view of fine-tuning implementation of the 2021–2025 CHW policy and informing updates to broader HRH and health sector development plans and strategies.

CONCLUSION

Geographical accessibility of PHC services at community level improved in Sierra Leone between 2000 and 2015 through the scale-up of CHWs. However, the scale and deployment of the CHW network no longer aligns with current national policy. The new CHW policy for 2021–2025 calls for a rightsizing and retargeting of the CHW network and our analysis supports this policy decision by identifying important inefficiencies of scale and deployment. Countries in sub-Saharan Africa with similar interest in optimising scale and deployment of their CHW workforce in the context of broader HRH and health sector planning may look to Sierra Leone as an exemplar model from which to learn.

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REFERENCES

- World Health Organization. Universal health coverage (UHC), 2021. Available: [https://www.who.int/news-room/fact-sheets/detail/universal-health-coverage-\(uhc\)](https://www.who.int/news-room/fact-sheets/detail/universal-health-coverage-(uhc)) [Accessed 15 Sep 2021].
- World Health Organization. Declaration of astana. Global conference on primary health care, 2018. Available: <https://www.who.int/publications/i/item/WHO-HIS-SDS-2018.61> [Accessed 15 Sep 2021].
- BBC News. Coronavirus: what the world can learn from Ebola fight, 2020. Available: <https://www.bbc.com/news/world-africa-52061547> [Accessed 15 Sep 2021].
- Boyce MR, Katz R. Community health workers and pandemic preparedness: current and prospective roles. *Front Public Health* 2019;7:62.
- Ballard M, Bancroft E, Nesbit J, et al. Prioritising the role of community health workers in the COVID-19 response. *BMJ Glob Health* 2020;5:e002550.
- World Health Organization. WHO guideline on health policy and system support to optimize community health worker programmes, 2018. Available: <https://www.who.int/publications-detail-redirect/9789241550369> [Accessed 15 Sep 2021].
- World Health Organization. Health policy and system support to optimize community health worker programmes for HIV, TB and malaria services: an evidence guide, 2020. Available: <https://apps.who.int/iris/bitstream/handle/10665/340078/9789240018082-eng.pdf?sequence=1> [Accessed 15 Sep 2021].
- Kok MC, Broerse JEW, Theobald S, et al. Performance of community health workers: situating their intermediary position within complex adaptive health systems. *Hum Resour Health* 2017;15:59.
- Sacks E, Morrow M, Story WT, et al. Beyond the building blocks: integrating community roles into health systems frameworks to achieve health for all. *BMJ Glob Health* 2018;3:e001384.
- Dahn B, Woldemariam AT, Pery H. Strengthening primary health care through community health workers: investment case and financing recommendations, 2015. Available: <https://www.who.int/hrh/news/2015/CHW-Financing-FINAL-July-15-2015.pdf> [Accessed 15 Sep 2021].
- Vaughan K, Kok MC, Witter S, et al. Costs and cost-effectiveness of community health workers: evidence from a literature review. *Hum Resour Health* 2015;13:71.
- Nkonki L, Tugendhaft A, Hofman K. A systematic review of economic evaluations of CHW interventions aimed at improving child health outcomes. *Hum Resour Health* 2017;15:19.
- Scott K, Beckham SW, Gross M, et al. What do we know about community-based health worker programs? A systematic review of existing reviews on community health workers. *Hum Resour Health* 2018;16:39.
- McCollum R, Gomez W, Theobald S, et al. How equitable are community health worker programmes and which programme features influence equity of community health worker services? A systematic review. *BMC Public Health* 2016;16:419.
- Kok MC, Dieleman M, Taegtmeier M, et al. Which intervention design factors influence performance of community health workers

- in low- and middle-income countries? A systematic review. *Health Policy Plan* 2015;30:1207–27.
- 16 Ballard M, Westgate C, Alban R, *et al.* Compensation models for community health workers: comparison of legal frameworks across five countries. *J Glob Health* 2021;11:04010.
 - 17 World Health Organization. Global strategy on human resources for health: workforce 2030, 2016. Available: <https://www.who.int/publications/i/item/9789241511131> [Accessed 15 Sep 2021].
 - 18 Asamani JA, Akogun OB, Nyoni J, *et al.* Towards a regional strategy for resolving the human resources for health challenges in Africa. *BMJ Glob Health* 2019;4:e001533.
 - 19 Gichaga A, Masis L, Chandra A, *et al.* Mind the global community health funding gap. *Glob Health Sci Pract* 2021;9:S9–17.
 - 20 Ministry of Health and Sanitation, the Republic of Sierra Leone. National health sector strategic plan 2017–2021, 2017. Available: https://extranet.who.int/countryplanningcycles/sites/default/files/planning_cycle_repository/sierra_leone/sierra_leone_nhssp_2017-21_final_sept2017.pdf [Accessed 15 Sep 2021].
 - 21 Ministry of Health and Sanitation, the Republic of Sierra Leone. National community health worker policy 2016–2020, 2016. Available: <https://portal.mohs.gov.sl/wp-content/uploads/2021/04/national-chw-policy-2016-2020-final.pdf> [Accessed 15 Sep 2021].
 - 22 Ministry of Health and Sanitation, Government of Sierra Leone. Human resources for health strategy 2017–2021, 2017. Available: <https://platform.who.int/docs/default-source/mca-documents/policy-documents/plan-strategy/sle-ch-14-01-plan-strategy-2017-eng-hrh-strategy-2017.pdf> [Accessed 15 Sep 2021].
 - 23 JSI Research & Training Institute, Inc 2020 Arlington JSI Research & Training Institute, Inc
 - 24 Ministry of Health and Sanitation, the Republic of Sierra Leone. National Community Health Workers' (CHW) Policy 2021–2025. Freetown Ministry of Health and Sanitation, the Republic of Sierra Leone; 2020.
 - 25 Oliphant NP, Ray N, Bensaid K, *et al.* Optimising geographical accessibility to primary health care: a geospatial analysis of community health posts and community health workers in Niger. *BMJ Glob Health* 2021;6:e005238.
 - 26 Subdivisions of Sierra Leone, 2021. Available: https://en.wikipedia.org/w/index.php?title=Subdivisions_of_Sierra_Leone&oldid=1007674628 [Accessed 15 Sep 2021].
 - 27 Ministry of Health and Sanitation, Government of Sierra Leone. Annual health sector performance report 2016, 2017. Available: <https://www.afro.who.int/sites/default/files/2017-08/Sierra%20Leone%20Health%20Sector%20%20Performance%20Report%202016.pdf>
 - 28 Ministry of Health and Sanitation, Government of Sierra Leone. Policy for community health workers in Sierra Leone, 2012. Available: <https://chwcentral.org/wp-content/uploads/2015/01/CHW-Policy-Sierra-Leone.pdf>
 - 29 GADM. Data from: gadm36_SLE_shp, zenodo, 3.6.
 - 30 NASA JPL. Data from: NASA shuttle radar topography mission global 1 Arc second. *Zenodo*;v:003.
 - 31 Buchhorn M, Smets B, Bertels L, *et al.* Data from: Copernicus global land service: Land Cover 100M: collection 3:epoch 2015: Globe 2020. zenodo 2018.
 - 32 Humanitarian OpenStreetMap Team (HOTOSM). Data from: HOTOSM Sierra Leone roads, zenodo 2018.
 - 33 Humanitarian OpenStreetMap Team (HOTOSM). Data from: HOTOSM Sierra Leone waterways, zenodo 2018.
 - 34 WorldPop and Statistics Sierra Leone. Data from: census disaggregated gridded population estimates for Sierra Leone (2015), zenodo, 2.0.
 - 35 WorldPop. School of geography and environmental science, University of Southampton; Department of Geography and Geosciences, University of Louisville; Departement de Geographie, Universite de Namur and Center for International Earth Science Information Network (CIESIN), Columbia University. Data from: Population Counts / Unconstrained individual countries 2000–2020 UN adjusted (100m resolution) / Sierra Leone 100m. Population. zenodo 2021 www.worldpop.org
 - 36 Institute for Health Metrics and Evaluation (IHME). Data from: low- and middle-income country neonatal, infant, and under-5 mortality geospatial estimates 2000–2017. zenodo 2020.
 - 37 Weiss DJ, Lucas TCD, Nguyen M. Data from: mapping the global prevalence, incidence, and mortality of Plasmodium falciparum, 2000–2017: a spatial and temporal modelling study. zenodo 2020.
 - 38 Huerta Munoz U, Källestål C. Geographical accessibility and spatial coverage modeling of the primary health care network in the Western Province of Rwanda. *Int J Health Geogr* 2012;11:40.
 - 39 Ray N, Ebener S. AccessMod 3.0: computing geographic coverage and accessibility to health care services using anisotropic movement of patients. *Int J Health Geogr* 2008;7:63.
 - 40 Tobler W. Three presentations on geographical analysis and modelling, 1993. Available: <https://core.ac.uk/display/224570984> [Accessed 14 Nov 2021].
 - 41 Alegana VA, Maina J, Ouma PO, *et al.* National and sub-national variation in patterns of febrile case management in sub-Saharan Africa. *Nat Commun* 2018;9:4994.
 - 42 World Health Organization. *Management of severe malaria: a practical handbook*. 3rd edn. Geneva, 2012. https://apps.who.int/iris/bitstream/handle/10665/79317/9789241548526_eng.pdf
 - 43 Palmer S, Torgerson DJ. Economic notes: definitions of efficiency. *BMJ* 1999;318:1136.
 - 44 Dalgligh SL, Surkan PJ, Diarra A, *et al.* Power and pro-poor policies: the case of iCCM in Niger. *Health Policy Plan* 2015;30:i184–94.
 - 45 Croke K. The origins of Ethiopia's primary health care expansion: the politics of state building and health system strengthening. *Health Policy Plan* 2021;35:1318–27.
 - 46 Koroma O, Chen Y, Wang P, *et al.* Community health workers' job satisfaction in Ebola-stricken areas of Sierra Leone and its implication for COVID-19 containment: a cross-sectional mixed-methods study. *BMJ Open* 2021;11:e051645.
 - 47 Miller NP, Milsom P, Johnson G, *et al.* Community health workers during the Ebola outbreak in Guinea, Liberia, and Sierra Leone. *J Glob Health* 2018;8:020601.
 - 48 Simen-Kapeu A, Reserva ME, Ekpini RE. Galvanizing action on primary health care: analyzing bottlenecks and strategies to strengthen community health systems in West and central Africa. *Glob Health Sci Pract* 2021;9:S47–64.
 - 49 Pery H, Crigler L. Developing and strengthening community health worker programs at scale: a reference guide and case studies for program managers and policymakers, 2014. Available: http://www.mchip.net/sites/default/files/mchipfiles/MCHIP_CHW%20Ref%20Guide.pdf [Accessed 15 Sep 2021].
 - 50 Hodgins S, Kok M, Musoke D, *et al.* Community health workers at the dawn of a new era: 1. Introduction: tensions confronting large-scale CHW programmes. *Health Res Policy Syst* 2021;19:109.
 - 51 Olaniran A, Briggs J, Pradhan A. Stock-outs of essential medicines among community health workers (CHWs) in low- and middle-income countries (LMICs): a systematic literature review of the extent, reasons, and consequences. *Human Res Health*;2021.
 - 52 Nepomnyashchiy L, Westgate C, Wang A. Protecting community health workers. PPE needs and recommendations for policy action, 2020. Available: <https://www.cgdev.org/sites/default/files/protecting-community-health-workers-ppe-needs-and-recommendations-policy-action.pdf> [Accessed 15 Sep 2021].
 - 53 Liu A, Ballard M, Oliphant N. Implementation support guide: development of a national georeferenced community health worker master list hosted in a registry, 2021. Available: <https://www.unicef.org/documents/implementation-support-guide-development-national-georeferenced-community-health-worker> [Accessed 15 Sep 2021].
 - 54 Masis L, Gichaga A, Zerayacob T, *et al.* Community health workers at the dawn of a new era: 4. programme financing. *Health Res Policy Syst* 2021;19:107.
 - 55 Taylor C, Griffiths F, Lilford R. Affordability of comprehensive community health worker programmes in rural sub-Saharan Africa. *BMJ Glob Health* 2017;2:e000391.
 - 56 van Duinen AJ, Adde HA, Fredin O, *et al.* Travel time and perinatal mortality after emergency caesarean sections: an evaluation of the 2-hour proximity indicator in Sierra Leone. *BMJ Glob Health* 2020;5:e003943.
 - 57 Bedford KJA, Sharkey AB. Local barriers and solutions to improve care-seeking for childhood pneumonia, diarrhoea and malaria in Kenya, Nigeria and Niger: a qualitative study. *PLoS One* 2014;9:e100038.
 - 58 Treacy L, Bolkan HA, Sagbakken M. Distance, accessibility and costs. Decision-making during childbirth in rural Sierra Leone: a qualitative study. *PLoS One* 2018;13:e0188280.
 - 59 Ocholla IA, Agutu NO, Ouma PO, *et al.* Geographical accessibility in assessing bypassing behaviour for inpatient neonatal care, Bungoma County-Kenya. *BMC Pregnancy Childbirth* 2020;20:287.
 - 60 Kruk ME, Chukwuma A, Mbaruku G, *et al.* Variation in quality of primary-care services in Kenya, Malawi, Namibia, Rwanda, Senegal, Uganda and the United Republic of Tanzania. *Bull World Health Organ* 2017;95:408–18.