Spatial accessibility of continuous maternal and perinatal healthcare services in Mozambique

Qin Li  
Sichuan University

Elsa Kanduma  
Comité para a Saúde de Moçambique (CSM)

Isaías Ramiro  
Comité para a Saúde de Moçambique (CSM)

Dong Xu  
Southern Medical University

Rosa Marlene  
The Ministry of Health of Mozambique (MoH)

Eusebio Chaquisse  
The Ministry of Health of Mozambique (MoH)

Yili Yang  
Sichuan University

Xiuli Wang  
Sichuan University

Jay Pan (✉️ panjie.jay@scu.edu.cn)  
Sichuan University  https://orcid.org/0000-0001-9501-1535

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Abstract

Maternal and perinatal healthcare remain insufficient in impoverished regions such as sub-Saharan Africa (SSA), and removing geographic barriers to access continuous maternal and perinatal healthcare services (CMPHS) has been addressed as a critical strategy. Based on the framework of maternal, neonatal, and child health (MNCH) proposed by WHO, access to CMPHS in Mozambique was assessed as the integration of three independent service packages, namely antenatal care (ANC), institutional delivery (ID), and postnatal care (PNC). We perform a spatial overlap analysis to identify eight types of multi-level healthcare access zones and reveal the geographic barriers for women of reproductive age (WoRA) reaching CMPHS. We find that access to reaching ANC, ID, and PNC varied significantly, with access to ANC being the best and PNC being the worst. More than 51% of the WoRA were not able to access any service package as part of CMPHS, while only about 21% could access CMPHS in a timely manner. Similar research should be carried out in SSA countries to identify resource shortage area and successful experiences should be learned to broad CMPHS coverage with particular focus.

Introduction

Maternal and perinatal healthcare services serve as the cornerstone of human health and are listed as important indicators for monitoring the progress of maternal and neonatal outcomes. Despite remarkable milestones achieved towards the global reduction of maternal and neonatal mortality over the past decades, the unfavorable situation among impoverished regions has posed huge obstacles in achieving Sustainable Development Goals (SDGs) from a holistic perspective, especially in Sub-Saharan Africa (SSA) where the globally highest maternal and neonatal mortality persists as a critical issue, as reflected by an estimation of 533 maternal deaths per 100,000 live births (compare with 211/100,000 globally), and 27 neonatal deaths per 1,000 live births (compare with 18/1,000 globally), respectively. Infectious diseases and complications during pregnancy and childbirths have been identified as the leading causes of maternal and neonatal deaths. However, most of these deaths can be prevented via timely provision of quality obstetric and neonatology services. Mothers, newborns, and children have been recognized as a sequence of inseparable elements that affect each other throughout lifecycles. However, it was not until the year of 2005 that policy makers became aware of the necessity that both maternal and newborn health should be addressed at different stages of the whole lifecycle via consecutive provision of health services. Striving to bridge such gap embedded in healthcare policies, the continuum of care (CoC) towards maternal, newborn, and child health (MNCH) has been proposed by World Health Organization (WHO) as an essential strategy to reduce worldwide burden of maternal, neonatal and children deaths via the integration of different health service packages throughout lifecycles. The framework of CoC established in accordance with the specific needs of women and neonates via continuous provision of maternal and perinatal healthcare services (CMPHS) throughout lifecycles involves the integration of three service delivery packages, including antenatal care (ANC), institutional delivery (ID), and postnatal care (PNC). ANC plays a pivotal role in protecting the
health of women and their unborn children at an early stage. This form of preventive healthcare enables pregnant women to acquire essential knowledge about healthy behaviors during pregnancy, as well as to facilitate prompt detection and management of complications that potentially occur throughout maternal and perinatal healthcare process via timely interventions, such as micronutrient supplementation, treatment for hypertension, HIV testing and medications, immunization against tetanus, and finally going to a district hospital for specialized care at the time of delivery. It is noteworthy that even a 7% increase in ANC coverage might save 160,000 newborn lives annually in Africa, which significantly contributes to improved neonatal health outcomes. ID has great potential to increase survival prospects for both mothers and neonates through the provision of access to appropriate equipment and supplies that are available on site or through immediate referral to a higher-level facility if necessary. Monitoring deliveries inside healthcare facilities is essential to ensuring that women receive quality care and delivery-related services in an environment that is well-prepared for an emergency. As suggested by the literature, perinatal mortality is 21% lower for facility-based deliveries compared to home. Under the best settings, up to 14 perinatal deaths might be averted per 1,000 births if the obstetric deliveries occurred at facilities instead of at homes. PNC delivered for the neonates provides great opportunities to check for dangerous signs and symptoms associated with poor health outcomes of babies, such as insufficient feeding, fast breathing, fever and abnormally low body temperature. Quality skilled care delivered immediately at the time of birth would ensure that the neonates receive essential newborn care including thermal and cord care, and immediate breastfeeding. It would also increase access to emergency care in the event of life-threatening complications. The importance of PNC has been documented with an estimation that if PNC rates were to reach 90% in SSA, then 10-27% of all neonatal deaths could be averted. The three service packages are delivered in the sequence of pregnancy, childbirth and postpartum stages corresponding to the lifecycle to ensure a set of comprehensive healthcare experiences for each woman and newborn. Moreover, the effectiveness of health services delivered at each single stage would be largely affected by healthcare outcomes achieved in the previous stage. As such, it is not surprising to find that well-established linkages between maternal and perinatal healthcare services contributes to 17% reduction in the risk of combined neonatal, perinatal and maternal mortality. The maintenance and effective utilization of CMPHS could save an estimated 860,000 additional lives for mothers and neonates each year.

Despite the critical role that the three service packages play throughout lifecycles, access to CMPHS remains insufficient, which has been recognized as a predominant contributor to high maternal and neonatal mortality rates worldwide. With the penetration of various MNCH programs implemented in the worldwide range, increased investments have been made to facilitate the delivery of maternal and perinatal services, especially among low-resource settings. However, geographic proximity, also known as spatial access to health facilities, which is a crucial aspect of accessibility, utilization, and the provision of health services to the population in need, has become one of the primary barriers preventing women from obtaining timely health services.
Mozambique is located on the southeast coast of Africa and one of the poorest and most underdeveloped countries in the world \((\text{United Nations Human Development Index}=0.446, \text{in 2021})\). The country covers an area of 799,380 square kilometers with a coastline of 2,630 kilometers and is divided into eleven provinces. According to the data of the General Population and Housing Census 2017 in Mozambique, the estimated total population was 30.07 million, with each single province having sparsely and unevenly distributed residents. The north-central provinces of Zambezia and Nampula are the most densely populated areas, with approximately 40% of the entire population residing among these regions. While the national population density is 37.6/km\(^2\), Maputo city presents to be the most densely populated city with a population density of 3750/km\(^2\). Niassa located in the northern region and Gaza located in the southern region are the two most sparsely populated provinces with a population density of 15/km\(^2\) and 19/km\(^2\), respectively. The country’s overall economy remains extremely underdeveloped (<\$1.0/person/day), while the economic disparities within the country are also large. For example, the highest average consumption level in Maputo city is 6.9 times higher than the lowest Zambezia province. In terms of the daily income of residents, a huge gap persists in the nation with other developed countries such as the United States (\$107/person/day) and European Union (\$44.90/person/day), and even with China (\$10.88/person/day)\(^\text{19}\) (Fig. 1a, b, c). Mozambique is confronted with daunting stress in the implementation of SDGs concerning maternal and perinatal health, the health indicators of Mozambicans remain below the average of SSA\(^\text{18}\). Under extreme poverty, maternal mortality rate in the nation was found to be as high as 451 deaths per 100,000 live births, while the infant mortality rate was 67.4 deaths per 1,000 live births. Long travel distances from residential locations to healthcare facilities, lack of transport available, and poorly-constructed transportation networks all result in significant service delays for pregnant and postpartum women accessing CMPHS\(^\text{20}\). For example, postponed provision of ANC directly leads to delayed HIV diagnostic outcomes for pregnant women. As the consequence, the diagnosis of high-risk pregnancies as well as the assessments of potential obstetric complications were also delayed\(^\text{21}\).

As an attempt to bridge the gap embedded in the current literature, in this study, we identified a set of essential indicators representing three service packages of CMPHS, based on the framework of maternal, neonatal, and child health (MNCH) programs and guidelines of pregnancy, childbirth, postpartum and newborn care (PCPNC) proposed by WHO, the current states of CMPHS delivery in Mozambique. The selection of indicators was based on two main principles. One is evidence-based indicators retrieved from the global guidelines of MNCH and PCPNC proposed by WHO and relevant references, and the other is the region-specific situation of Mozambique’s healthcare market reflected as the prevalence of particular diseases, such as infectious diseases including malaria, diarrhoea and HIV/AIDS. For example, the ANC package consists of seven indicators, and a provider is counted as having provided ANC only when all of the service indicators are met. ID and PNC are also calculated in the same way. We applied geographic information system (GIS) to explore access to healthcare services. A geo-database containing suppliers (three service packages provided by healthcare facilities), demanders (population density expressed as raster pixels), and the administrative boundary
was established\textsuperscript{22}. The Nearest-Neighbor Method (NMM) was utilized to calculate the spatial accessibility of population points of WoRA (e.g., demand location). For each population point, only the nearest health facility (e.g., supply location) was considered when using the nearest-neighbor method\textsuperscript{23}. The shortest travel time spent to reach ANC, ID, and PNC was calculated in each province, respectively. We used the a spatial overlap analysis to identify multi-level healthcare access zones. Accessibility coverage of the network of healthcare facilities was calculated at the 2h maximum travel time standard. This standard was deemed appropriate to capture the extent of safe access\textsuperscript{24}. For WoRA, an average walking speed of 4km/h by foot was used in the model. Accessibility coverage (i.e., coverage rate) was defined as the percentage of WoRA covered for CMPHS. The disparities identified both between and within regions were used to provide policy implications at the government level.

\section*{Results}

\subsection*{Identification and coverage of essential indicators representing CMPHS}

We identified the essential indicators of three service packages representing CMPHS (Table 1, 2). ANC was comprised of seven independent indicators for WoRA during pregnancy, while ID consisted of eight indicators reflective of different service items needed to assist the delivery of childbirth inside healthcare facilities. PNC contained another ten service items delivered for mothers and neonates within two days of delivery.

Combined with the results of the National Survey on Infrastructure, Equipment, Human Resources and Health Services 2018 in Mozambique, the current states of 1,542 healthcare facilities across the study area were described in terms of the coverage of different service items that each single service package contained. As suggested by the findings, most healthcare facilities across the study area managed to cover all service items listed in each single service package, with some indicators having fairly good penetration among most healthcare institutes, such as the provision of IPT for malaria in pregnancy as part of the ANC service package which could be found in 1,408 (91.3\%) of healthcare facilities investigated. There were also other indicators showing unfavorable coverage, such as the provision of emergency obstetric care as part of the ID service package which could only be found in 504 (32.7\%) healthcare facilities. Likewise, the provision of injectable antibiotics intended for neonatal sepsis which is an essential healthcare intervention at PNC stage but could only be found among 766 (49.7\%) healthcare facilities investigated (Table 2).

\begin{table}[h]
\centering
\caption{The selected process of indicators representing three service packages of CMPHS}
\begin{tabular}{|c|c|}
\hline
\textbf{ANC} & \textbf{ID} \tabularnewline
\hline
\hline
Provision of IPT & Provision of emergency obstetric care \tabularnewline
\hline
For malaria in pregnancy & \tabularnewline
\hline
Provision of injectable & Provision of injectable antibiotics \tabularnewline
antibiotics & for neonatal sepsis \tabularnewline
\hline
\end{tabular}
\end{table}
<table>
<thead>
<tr>
<th>Three service packages</th>
<th>The global guidelines of MNCH and PCPNC proposed by WHO&lt;sup&gt;5,25&lt;/sup&gt;</th>
<th>Existing literatures&lt;sup&gt;7,9,13,14,29,31,32,35,40&lt;/sup&gt;</th>
<th>Selected indicators in Mozambique</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANC</td>
<td>Folic acid supplementation; Iron supplementation; IPTp and ITN for malaria; Tetanus toxoid vaccination; Measure blood pressure; Pre-eclampsia and eclampsia prevention; Prevention and management of STIs including HIV PMTCT services including anti–retroviral therapy for pregnant women; Detection and treatment of bacteriuria; Detection and management of fetal growth restriction; Detection and management of diabetes in pregnancy; Counselling and preparation for newborn care and breastfeeding; Prevention and management of TB; Prevention and management of maternal anaemia;</td>
<td>Folic acid supplementation; Iron supplementation; IPTp and ITN for malaria; Tetanus injection; Blood pressure measured; Prevention and management of infectious diseases (malaria, HIV, tuberculosis); Antenatal visits; Weight and height measured; Prevention and management of maternal anaemia; Informed about pregnancy complication; Given malaria prophylaxi;</td>
<td>Folic acid supplementation; Iron supplementation; IPTp for malaria; Tetanus toxoid vaccination; Monitoring for hypertensive disorder of pregnancy; HIV counseling and testing to HIV+ pregnant women; Antiviral treatment to HIV+ pregnant women;</td>
</tr>
<tr>
<td>ID</td>
<td>Skilled obstetric at birth/Skilled birth attendant; Clean birth practices; Birth and emergency preparedness; Monitoring of labour with partograph; Magnesium sulfate for eclampsia; Antibiotics for preterm rupture of membranes; Corticosteroids for preterm labour; Antenatal corticosteroids for preterm labor; Caesarean section and prophylactic antibiotics; Emergency obstetric care to manage complications;</td>
<td>Using skilled and institutional birth-care services; Emergency obstetric care; Training for traditional birth attendants on safe deliveries; Delivery at the health facility; Utilization of caesarean section services;</td>
<td>Monitoring of labour with partograph; Parenteral administration of oxytocic; Assisted vaginal delivery; Manual removal of placenta; Antibiotics for preterm rupture of membranes; Blank partograph; Parenteral administration of magnesium sulphate; Emergency obstetric care;</td>
</tr>
<tr>
<td>PNC (mother/newborn)</td>
<td>Immediate initiation of exclusive breastfeeding;</td>
<td>Breastfeeding within 1h of birth newborn;</td>
<td>Immediate and exclusive breastfeeding;</td>
</tr>
</tbody>
</table>
Immediate thermal care;
Resuscitation of newborn baby;
Emergency newborn care for sepsis;
LBW babies given kangaroo mother care;
Hygienic cord care and skin care;  
Detect and manage sepsis;
Screen/initiate/continue ARVs for HIV;
Case management of infections;
Case management for pneumonia;
Delay in bathing;
Immunization services;

Thermal protection;
Neonatal resuscitation;
LBW babies given kangaroo mother care;
BCG and polio vaccination;
Care of children with HIV;
Early detection and referral of complications;
PMTCT services including appropriate feeding;
Immediate emergency care for newborn babies;

Thermal protection;
Neonatal resuscitation;
Staff trained newborn resuscitation;
Kangaroo mother care;
Injectable antibiotics for neonatal sepsis;
HIV counseling and testing to infants born to HIV+ women;
ARV prophylaxis to newborns of HIV+ pregnant women;
HIV+ infant and young child feeding counseling;
BCG vaccination;

IPTp (intermittent preventive treatment in pregnancy); ITN (insecticide–treated bednet); STIs (sexually transmitted diseases); TB (tuberculosis); PMTCT (prevention of mother to child transmission); LBW (low-birth-weight); KMC (kangaroo mother care); ARV (AIDS related virus); BCG (bacille calmette-guerin)

Table 2: Percentage of healthcare facilities providing essential indicators
<table>
<thead>
<tr>
<th>Phases</th>
<th>Key indicators</th>
<th>Evidences</th>
<th>Percent(Yes)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANC (seven indicators; 784 healthcare facilities)</strong></td>
<td>Iron supplementation</td>
<td>Global guidelines &amp; Existing literatures</td>
<td>1070 (69.4%)</td>
</tr>
<tr>
<td></td>
<td>Folic acid supplementation</td>
<td></td>
<td>1035 (67.1%)</td>
</tr>
<tr>
<td></td>
<td>Tetanus toxoid vaccination</td>
<td></td>
<td>1364 (88.5%)</td>
</tr>
<tr>
<td></td>
<td>Monitoring for the hypertensive disorder of pregnancy</td>
<td></td>
<td>1198 (77.7%)</td>
</tr>
<tr>
<td></td>
<td>IPTp for malaria*</td>
<td>Global guidelines &amp; Existing literatures &amp; Epidemic of disease</td>
<td>1408 (91.3%)</td>
</tr>
<tr>
<td></td>
<td>HIV counseling and testing for HIV+ pregnant women*</td>
<td></td>
<td>1369 (88.8%)</td>
</tr>
<tr>
<td></td>
<td>Antiviral treatment for HIV+ pregnant women*</td>
<td></td>
<td>1347 (87.4%)</td>
</tr>
<tr>
<td><strong>ID (eight indicators; 365 healthcare facilities)</strong></td>
<td>Monitoring of labour with partograph</td>
<td>Global guidelines</td>
<td>1273 (82.6%)</td>
</tr>
<tr>
<td></td>
<td>Parenteral administration of oxytocic</td>
<td></td>
<td>1243 (80.6%)</td>
</tr>
<tr>
<td></td>
<td>Assisted vaginal delivery</td>
<td></td>
<td>1125 (73.0%)</td>
</tr>
<tr>
<td></td>
<td>Manual removal of placenta</td>
<td></td>
<td>1103 (71.5%)</td>
</tr>
<tr>
<td></td>
<td>Antibiotics for preterm</td>
<td></td>
<td>849 (55.1%)</td>
</tr>
<tr>
<td></td>
<td>Blank partograph</td>
<td></td>
<td>1204 (78.1%)</td>
</tr>
<tr>
<td></td>
<td>Parenteral administration of magnesium sulphate</td>
<td></td>
<td>1079 (70.0%)</td>
</tr>
<tr>
<td></td>
<td>Emergency obstetric care</td>
<td>Global guidelines &amp; Existing literatures</td>
<td>504 (32.7%)</td>
</tr>
<tr>
<td><strong>PNC (ten indicators; 299 healthcare facilities)</strong></td>
<td>Immediate and exclusive breastfeeding</td>
<td>Global guidelines &amp; Existing literatures</td>
<td>1313 (85.1%)</td>
</tr>
<tr>
<td></td>
<td>Thermal protection</td>
<td></td>
<td>1293 (83.9%)</td>
</tr>
<tr>
<td></td>
<td>Hygenic cord care</td>
<td></td>
<td>1307 (84.8%)</td>
</tr>
<tr>
<td></td>
<td>Neonatal resuscitation</td>
<td></td>
<td>1122</td>
</tr>
<tr>
<td>Healthcare Service</td>
<td>Coverage (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------</td>
<td>--------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kangaroo mother care</td>
<td>1094 (70.9%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injectable antibiotics for neonatal sepsis</td>
<td>766 (49.7%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIV counseling and testing to infants born to HIV+ women*</td>
<td>1351 (87.6%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARV prophylaxis to newborns of HIV+ pregnant women*</td>
<td>1345 (87.2%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIV+ infant and young child feeding counseling*</td>
<td>1367 (88.7%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCG vaccine</td>
<td>886 (57.5%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) IPTp (intermittent preventive treatment in pregnancy); ARV (AIDS related virus); BCG (bacille calmette-guerin); (2)* Malaria is endemic country-wide and HIV was with an overall prevalence of 12.6% among adults (aged 15–49)\(^2\)⁶.

**Distribution of healthcare facilities providing CMPHS**

In 2017, there were 1,542 healthcare facilities in total across the study region, among which 1,490 were primary-level facilities (urban and rural health centers, community health posts), 43 secondary-level facilities (rural, district and general hospitals), and 9 belonged to tertiary level (central and provincial hospitals, specialized and military hospitals). Among all the healthcare facilities, 784 provided ANC, 365 provided ID, and 299 provided PNC (Table 1). The primary healthcare facilities delivering ANC, ID, and PNC were 51.48% (767/1490), 21.34% (318/1490) and 18.46% (275/1490), respectively. The secondary healthcare facilities delivering ANC, ID, and PNC were 37.21% (16/43), 90.70% (39/43) and 23.29% (17/43), respectively. The tertiary healthcare facilities delivering ANC, ID, and PNC were 11.11% (1/9), 88.89% (8/9) and 77.78% (7/9), respectively.

From the perspective of spatial distribution, the healthcare facilities that delivered three service packages tended to be clustered around areas with relatively high population density in Mozambique. In contrast, sparsely populated areas also have fewer healthcare facilities (Fig. 2a, b). The primary healthcare facilities were mainly clustered among densely populated central and northern regions, where both secondary and tertiary healthcare facilities were rarely found. At the provincial level, the three provinces with the lowest population density including Niassa, Gaza, and Inhambane, had fewer healthcare facilities to delivery the three service packages. Particularly, Niassa with the lowest population density among all provinces even had no secondary or tertiary healthcare facilities to provide ID-related service items (Fig. 3a,b,c).

**Spatial access to three service packages of CMPHS**
Statistical outcome produced via the adoption of NNM suggested that the average shortest travel time spent to access ANC, ID, and PNC were 2.38h, 3.69h, and 4.16h, respectively. On the one hand, the shortest travel time needed to access each single type of service package demonstrated large variations among different regions. To the nearest ANC healthcare facilities, the shortest travel time spent ranged from 0.46h in Maputo City to 4.95h in Manica province. To the nearest ID healthcare facilities, the shortest travel time spent ranged from 0.74h located in Maputo City to 18.20h located in Niassa province. To the nearest PNC healthcare facilities, the shortest travel time needed ranged from 1.34h located in Maputo City to 10.76h located in Inhambane. On the other hand, according to the standard of 2-hour security service range, Maputo city was found to be the only region that can guarantee the accessibility of CMPHS. Except for Manica province, the shortest travel time spent to access ID was beyond ANC in all other provinces. The shortest travel time spent to access ID was found to be distinctly longer than that for PNC among three provinces, namely Gaza, Maputo and Niassa, with Niassa demonstrating relatively minor differences in this aspect (Table 3). According to the coverage of different service packages, multiple provinces with lower population density were recognized as underserved areas, including Niassa, Cabo Delgado, Gaza and Inhambane, especially for the provision of ID and PNC (Fig. 4a,b,c).

Table 3: Shortest travel time to maternity care services for women aged 15-49 years in different region

<table>
<thead>
<tr>
<th>Region</th>
<th>The shortest travel time access to ANC(h)</th>
<th>The shortest travel time access to ID(h)</th>
<th>The shortest travel time access to PNC(h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Med</td>
<td>Max</td>
<td>IQR</td>
</tr>
<tr>
<td>Mozambique</td>
<td>2.38</td>
<td>30.38</td>
<td>3.84</td>
</tr>
<tr>
<td>Cabo Delgado</td>
<td>4.01</td>
<td>25.71</td>
<td>5.11</td>
</tr>
<tr>
<td>Gaza</td>
<td>2.90</td>
<td>20.40</td>
<td>3.43</td>
</tr>
<tr>
<td>Inhambane</td>
<td>2.69</td>
<td>16.95</td>
<td>3.39</td>
</tr>
<tr>
<td>Manica</td>
<td>4.95</td>
<td>27.48</td>
<td>7.36</td>
</tr>
<tr>
<td>Maputo</td>
<td>1.94</td>
<td>18.92</td>
<td>3.22</td>
</tr>
<tr>
<td>Maputo City</td>
<td>0.46</td>
<td>2.19</td>
<td>0.50</td>
</tr>
<tr>
<td>Nampula</td>
<td>2.13</td>
<td>10.61</td>
<td>2.86</td>
</tr>
<tr>
<td>Niassa</td>
<td>4.07</td>
<td>30.38</td>
<td>4.97</td>
</tr>
<tr>
<td>Sofala</td>
<td>2.11</td>
<td>18.16</td>
<td>3.59</td>
</tr>
<tr>
<td>Tete</td>
<td>3.87</td>
<td>18.06</td>
<td>4.45</td>
</tr>
<tr>
<td>Zambezia</td>
<td>2.47</td>
<td>12.83</td>
<td>2.97</td>
</tr>
</tbody>
</table>

Descriptive measures (medians[Med], maximum[Max], and interquartile ranges[IQR]).
Classification and identification of CMPHS underserved area

Our map illustrated spatial access to CMPHS in Mozambique (Fig. 5). For WoRA in Mozambique, more than 21% residents (living in about 2.69% of Mozambique's) lived in Type I: multi-level healthcare access zones on CMPHS (i.e., able to receive all services contained in three service packages in a timely manner), more than 51% (living in 83.25% of Mozambique's) lived in Type ~: failed to get timely access to any service packages from CMPHS. Only 27.5% (living in about 14.07 % of Mozambique's) lived in Type ~: able to access one or two levels of CMPHS. The second highest percentage of the population fell within Type , meaning approximately 10% residents (living in about 7.42 % of Mozambique's) were not able to obtain ID and PNC services in a timely manner. The third highest percentage of the population fell within Type , meaning more than 9% residents (living in about 2.19 % of Mozambique's) cannot timely reach PNC (Table 4). Under-served populations were mostly located in the central of Mozambique (Maputo province and Maputo city).

Table 4: Percentage of population covered within the eight types of under-served areas in terms of travel time in Mozambique

<table>
<thead>
<tr>
<th>Type</th>
<th>Multilevel healthcare access zones</th>
<th>Area (%)</th>
<th>Population (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Able to get timely CMPHS including ANC, ID and PNC</td>
<td>2.69</td>
<td>21.10</td>
<td></td>
</tr>
<tr>
<td>Fail to get timely ANC</td>
<td>0.95</td>
<td>1.63</td>
<td></td>
</tr>
<tr>
<td>Fail to get timely ID</td>
<td>1.61</td>
<td>3.79</td>
<td></td>
</tr>
<tr>
<td>Fail to get timely PNC</td>
<td>2.19</td>
<td>9.70</td>
<td></td>
</tr>
<tr>
<td>Fail to get timely ID and PNC</td>
<td>7.42</td>
<td>9.96</td>
<td></td>
</tr>
<tr>
<td>Fail to get timely ANC and PNC</td>
<td>1.03</td>
<td>1.47</td>
<td></td>
</tr>
<tr>
<td>Fail to get timely ANC and ID</td>
<td>0.87</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td>Fail to get timely CMPHS including ANC, ID and PNC</td>
<td>83.25</td>
<td>51.40</td>
<td></td>
</tr>
</tbody>
</table>

Discussion

Despite great efforts made to improve access to essential health services, Mozambique is still confronted with major challenges in its long-term battle towards reduced maternal and neonatal mortality rates\(^{18, 27}\). A couple of recently published studies conducted investigations to explore the geographical accessibility of maternal, neonatal, and child health services under Mozambique's context, including emergency obstetric care and children services, the integration of health indicators and continuity of service deliveries failed to be considered\(^{28, 29, 30}\). Our study further explored the potential of improving accessibility of CMPHS as a meaningful approach to achieve better maternal and neonatal healthcare outcomes.
Overall, spatial access to CMPHS for WoRA remains limited over the study area. As suggested by previous findings, 49.8% WoRA in Mozambique lived outside 2h travel distance from the nearest hospital to utilize emergency hospital services. 67.3% of the Mozambican population lived outside 1h travel distance from primary healthcare centers. Another similar study showed that in Mozambique, about 50% of the population lived more than 20 km away from the nearest health facility available. As of 2020, the average travel distance needed to access a health facility for people living in more distant places was found to be 12.3 km in Mozambique. In addition to poor spatial accessibility of CMPHS, the continuum of health services was also found to be unfavorable in Mozambique, as reflected by dramatically decreased coverage of service deliveries both during ID and PNC stages, which coincides with the fact that mothers and neonates are at the highest risk during the first critical hours after childbirth. This highlights the necessity of enhancing the accessibility of CMPHS as a critical solution to maternal and neonatal health promotion in underdeveloped regions.

From the perspective of equity, large disparities in the access to CMPHS was found to be a critical issue among regions. Inequities in maternal and neonatal health services always exist at the national, provincial and district levels presenting fundamental barriers to progress, particularly among the most disadvantaged population groups. This has been validated by our findings that both the provinces of Niassa and Cabo Delgado (northern regions of the country) with lower population density tended to be more underserved, especially in the aspect of accessing ID and PNC service packages. However, healthcare service disparities within the same region was found to be exacerbated in the southern region compared with the northern region. This was mainly induced by the fact that the capital city of Maputo, as the economic and social development center located in the southern region, far exceeded all the other areas. In our study, Maputo City was found to be the only city located in the southern region that provided effective access to three service packages investigated, which was consistent with previous findings from other studies that 46% of pregnant women residing in southern Mozambique were able to access the nearest primary healthcare institute within 1-hour walking distance, while the other 64% of women living in the region were able to receive life-saving service delivery within 2 hours. In addition, the frequent occurrence of natural disasters that posed huge hinderance to healthcare service delivery procedures further added to health inequity between southern and northern regions, leading to lower rates of both ANC and ID visits in the southern region, corresponding to 74 additional maternal deaths and 726 additional deaths of children under the age of 1 month by the end of 2021. Under such circumstances, effective activities to address such inequity issue should include the implementation of decentralized allocation strategies, which has been recognized as an effective measure to facilitate the promotion of both accessibility and coverage of maternal health resources, thus contributing to higher hospital delivery rates as well as the reduction of both maternal and newborn mortality.

Under Mozambique’s context of poor accessibility and equity, learning from the successful experiences of other countries in maternal and perinatal healthcare services can quickly and efficiently improve maternal and neonatal health outcomes and contribute to the achievement of the SDGs. China, as the developing country with the largest population coverage, has made remarkable achievements milestones in the
survival development goals through improving accessibility and equality of healthcare. The maternal mortality ratio has lowered from around 1500 maternal deaths per 100,000 live births in 1949 to 17.8 maternal deaths per 100,000 live births in 2019, and the infant mortality rate has lowered from around 200 neonatal deaths per 1000 live births in 1949 to 5.6 neonatal deaths per 1000 live births in 2019. China's successful experience provides valuable lessons for other nations confronted with similar challenges. Such remarkable achievements can be largely attributed to constant efforts made by the Chinese government on the promotion of primary health care (PHC), along with the implementation of other strategies towards the optimization of the hierarchical healthcare delivery system intended for maternal and child healthcare. For example, integrated service packages delivered via collaborative efforts of tertiary hospitals and primary maternal care institutions proved to be an effective solution to strengthening the capacity of local healthcare facilities as well as their corresponding referral systems, which resulted in increased in-hospital births and significantly reduced maternal mortality. In addition to the provision of training programs to cultivate highly-skilled healthcare professionals among local healthcare facilities, strategies to address the accessibility and inequity issue should also consider the adoption of information technologies for those living in remote areas, such as mobile clinics, mobile emergency services or telemedicine applications for routine check-ups. Such technology-facilitated interventions have become even more indispensable during the COVID-19 pandemic to mitigate the risk of infection during face-to-face visits, as well as to overcome restrictions put on cross-regional travels.

Several limitations of this study should be noted. Firstly, the adoption of the geographic information system (GIS) enabled us to determine the distance and time, through simple estimation of straight-line distances along walking paths between two points (i.e., health facility and WoRA). However, such estimation ignored the fact that in practice, travel time spent to access health services would be typically affected by additional geographic barriers or bypassing on the road, which would likely produce biased estimations. The selection of appropriate indicators posed another great challenge to our study, in that the set of indicators selected from CMPHS should be comprehensive enough to meet the needs of all women and neonates throughout pregnancy and puerperium cycles. As such, the omission of essential indicators might be inevitable, which should be addressed as a major shortcoming for future studies to overcome down the road.

In summary, using Mozambique represented SSA as a case, this study assesses the accessibility of CMPHS in low-resource settings and proposes policy recommendations for achieving SDGs based on the successful experience of China. Further investigations could be conducted under similar contexts to inform resource allocation related decision-making procedures for SSA countries confronted with similar challenges, which can have a huge contribution to the improvement of global maternal and neonatal health and the realization of SDGs.

Methods

Data sources
This study aims to explore the spatial accessibility of CMPHS, and two perspectives of data were utilized, namely data for identifying indicators reflective of the delivery of three service packages in Mozambique, and data for spatial accessibility calculation. Following the existing literature, three categories of data were needed to facilitate the analysis of spatial accessibility, including supply side data, demand side data, and environmental data\textsuperscript{45, 46, 47}. The data sources are shown in detail in Supplementary Table 1.

**Data pretreatment**

For supply side data, healthcare facilities of all levels were included in the model. The health system in Mozambique has three levels of progressively complex care: the primary level (urban and rural health centers, community health posts) provides primary care including basic maternal and perinatal healthcare services, the secondary level (rural, district and general hospitals) may offer surgical services and serves as referral hospitals for the first level hospitals, while the tertiary level (central and provincial hospitals, specialized and military hospitals) serves as the regional referral level.

The inclusion and exclusion of indicators reflective of three service packages as well as the continuum of CMPHS throughout lifecycles were performed via a two-step approach. The first step aimed to identify three groups of indicators that respectively represent three service packages under the region-specific context of Mozambique’s healthcare market, while the second step aimed to evaluate the continuum of healthcare from a holistic perspective based on indicators identified from the previous step. As the selection of indicators should be tailored for the actual situation of maternal and neonatal health in Mozambique, not only the global guidelines proposed by WHO, but also the indicators listed in the questionnaire of the National Survey on Infrastructure, Equipment, Human Resources and Health Services 2018 (Supplementary Table 2) were considered and compared. It should be noted that in practice, it is difficult for indicators to scale up one by one due to the fact that in addition to some essential indicators that are necessary and applicable everywhere, others might be situational in endemic regions, and there are also indicators which have a small marginal effect to produce enough cost-effectiveness\textsuperscript{5}. Through the adoption of the two-step approach, a group of separate indicators were identified from each single service package, and further integrated to avoid fragmented services and ensure the quality of CoC.

For demand side data, the WoRA was used in the modelling to establish proportions of the population's access to three health service packages. The pregnancy population was adjusted based on the actual values of WoRA in 2017 and was allocated to 1*1 km\textsuperscript{2} grids according to the value per cell of the WorldPop dataset, with the following formula\textsuperscript{48}.

\[
P_{ij} = G_{ij} \times \left( \frac{T_j}{G_j} \right)
\]
Where $P_{ij}$ is the corrected population density value of grid $i$ in the province/provincial capitals $j$, $G_{ij}$ is the corresponding WorldPop value of population density. $G_j$ is the sum of the grid values for WorldPop in a province/provincial capitals $j$, and $T_j$ is the actual population size in the province/ provincial capitals $j$ based on the Statistical Yearbook 2020 in Mozambique.$^{34}$

**Declarations**

Data availability

All data are available in the main text or supplementary materials

Code availability

All the relevant code used to generate the results in this paper and the Supplementary Information is available upon request.

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Author information

Authors and Affiliations

**HEOA Group, West China School of Public Health and West China Fourth Hospital, Sichuan University, No.17 People’s South Road, Chengdu, 610041, China**

Institute for Healthy Cities and West China Research Center for Rural Health Development, Sichuan University, No.17 People’s South Road, Chengdu, 610041, China

Qin Li, Yili Yang, Xiuli Wang&Jay Pan

**Comité para a Saúde de Moçambique (CSM), Praceta Caetano Viegas, 67 Maputo City, Mozambique**

Elsa Kanduma&Isaías Ramiro
Dong Roman Xu

The Ministry of Health of Mozambique (MoH), 2HJP+972, Avenida Eduardo Mondlane, Maputo, Mozambique

Rosa Marlene&Eusebio Chaquisse

Contributions

Q. L. and XL.W. designed the study. Q.L., XL.W, and J.P. designed had fully accessed and verified the underlying data reported in the study. Q.L. performed the data analysis and wrote the first draft with supervision from XL.W. and J.P. E.K., I.R., R.M., and E.C. provided suggestions on the data processing. D.X. and Y.Y. helped revising the draft. All authors contributed to interpretation of data, revised the article critically for important intellectual content, and approved the final version of the manuscript.

Corresponding authors

Correspondence to Xiuli Wang or Jay Pan

Competing interests

The authors declare no competing interests

Additional information

Supplementary material

References


Figures
Figure 1

Study Area

a. Administrative region (the data was extracted from OpenStreetMap)

b. Population density (the data was extracted from WorldPop 2015)

c. Average consumption levels (the data was extracted from Ministry of Economics and Finance of Mozambique, 2016)
Figure 2

Population density of WoRA and spatial distribution of all healthcare facilities

a. Density of women of reproductive (WoRA)

b. Distribution of all healthcare facilities
Figure 3

Spatial distribution of healthcare facilities delivering ANC, ID, and PNC

a. Distribution of healthcare facilities delivering ANC (Antenatal care)

b. Distribution of healthcare facilities delivering ID (Institutional delivery)

Distribution of healthcare facilities delivering PNC (Postnatal care)

Figure 4
The coverage of three service packages in terms of 2h travel time

a. The coverage area of ANC in terms of 2h travel time (ANC: Antenatal care)

b. The coverage area of ANC in terms of 2h travel time (ID: Institutional delivery)

c. The coverage area of PNC in terms of 2h travel time (PNC: Postnatal care)

Figure 5

Overlay analysis for WoRA to access CMPHS

Type : Able to get timely CMPHS including ANC, ID and PNC; Type : Fail to get timely ANC; Type : Fail to get timely ID; Type : Fail to get timely PNC; Type : Fail to get timely ID and PNC; Type : Fail to get timely ANC and PNC; Type : Fail to get timely ANC and ID.
Supplementary Files

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- SupplementaryMaterials.docx