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Modelling geographical accessibility to support disaster response and rehabilitation of a health care system: An impact analysis of Cyclones Idai and Kenneth in Mozambique

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Modelling geographical accessibility to support disaster response and rehabilitation of a health care system:

An impact analysis of Cyclones Idai and Kenneth in Mozambique

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KEYWORDS:

International health services, organisation of health services, geographical mapping, risk management

32 **Conclusion**

33 Post-disaster accessibility modelling can increase understanding of spatial differences in
34 geographic access to care in the direct aftermath of a disaster and can inform targeting and
35 prioritization of limited resources. Our results reflect opportunities for integrating
36 accessibility modelling in early disaster response, and to inform discussions on health
37 system recovery, mitigation and preparedness.

38

39 **STRENGTHS AND LIMITATIONS OF THIS STUDY**

40

- 41 • This is the first study presenting the applicability of post-disaster geographical
42 accessibility modelling.
- 43 • The approach enables quantification of disaster impacts on geographical health care
44 accessibility to prioritize post-disaster interventions and to build resilience for future
45 disasters.
- 46 • To account for uncertainty of the assumed travel speeds, we considered multiple
47 possible scenarios.
- 48 • Data from various sources were combined to represent the post-cyclone situation as
49 realistically as possible, but since data gathering was ongoing, it was expected that
50 some data were incomplete or not fully processed at the time of usage.
- 51 • Our accessibility modelling assumes that patients always travel to the nearest health
52 facility. However, literature has shown that patients sometimes bypass health
53 facilities in search of higher quality care in Mozambique

54

1. INTRODUCTION

Geographical proximity to health facilities is a crucial aspect of accessibility, utilization and the provision of health services to populations in need¹. Road networks and natural barriers (such as rivers, water bodies, and flooded areas) are important factors that determine the geographical (i.e. physical) accessibility of a population to the network of functional health facilities. During natural disasters, roads and health facilities are often damaged, yet health care demand rises substantially at the same time due to injuries and increased communicable disease risks^{2,3}. The interplay between the disruption of health infrastructure, transport network, and the rise in health care demand, is expected to disable a large portion of the population's access to care they need in the aftermath of a disaster^{3,4}. This is especially the case in already medically underserved regions, where the event can lead to new health disparities or exacerbate existing ones².

In March and April 2019, two cyclones made landfall in Mozambique. This was the first time in history that two strong cyclones hit Mozambique consecutively in the same season⁵. On 14 March 2019 Tropical Cyclone Idai made landfall in Beira, followed by a week of heavy rains and winds, the storm ended on 21 March 2019⁶. In the middle of the humanitarian emergency response for Cyclone Idai, a second cyclone hit Northern Mozambique. Cyclone Kenneth, a category 4 cyclone and the strongest recorded cyclone on the African continent, made landfall in Pemba, Cabo Delgado on 25 April 2019^{7,8}. The two cyclones combined had a death toll of 648 (603 fatalities due to Idai and 45 deaths caused by Kenneth) and left over 2.2 million people in need of humanitarian assistance⁵. The cyclone's destruction left entire communities isolated for weeks due to flood waters, destroyed telecommunication networks, and extensive road damage^{9,10}. In addition, stagnant waters, inaccessibility to safe water and sanitation, and overcrowding in temporary accommodation led to a cholera outbreak and a significant increase in malaria cases^{5,8,11,12}. Major damage to 113 health facilities were reported after both cyclones, causing severe disruption in health service provision and restricting the population's access to adequate health care^{13,14}.

Cyclones impact entire populations, however the burden disproportionately affects children and women¹⁵. It is estimated that for cyclones Idai and Kenneth more than 50% of the affected population were children, and with flood waters rising above 6 meters, their

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3 87 movements to safety and health care were particularly limited ⁵. Geographic inaccessibility
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5 88 to health facilities can interrupt childhood immunization, or prevent receipt of treatment for
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7 89 injuries ^{16,17}.
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9 90

10 91 Although many humanitarian actors have estimated substantial losses in health care
11
12 92 accessibility and availability ^{5,9,10,13,18}, the quantitative impact of Cyclone Idai and Kenneth
13
14 93 on geographical accessibility to health care for children under the age of 5 across the most
15
16 94 affected districts in Mozambique remains unknown. Modelling physical accessibility and
17
18 95 population coverage by means of travel time to health facilities, can give important insights
19
20 96 for targeting humanitarian action and preparing for future disasters in a coordinated
21
22 97 manner ¹⁹. International efforts to support humanitarian responses on the ground have
23
24 98 accelerated data gathering in the country, enabling post-disaster accessibility modelling by
25
26 99 means of health facility damages, loss of road access, and barriers to movement such as
27 100 flood waters ²⁰.
28
29 101

30 102 Currently, quantitative post-disaster accessibility assessments are not a part of standardized
31
32 103 response guidelines, preventing coordinated and centralized decision making on temporary
33
34 104 facility location to serve beneficiaries in the most optimal way ¹⁹. Since humanitarian actors
35
36 105 often have to deal with limited resources, informed decision making on temporary facility
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38 106 locations and prioritization of health facility rehabilitation can prevent duplicated action and
39
40 107 therefore enhances both financial and operational efficiency ^{21,22}.
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42 108

43 109 This study presents a data processing and spatial accessibility modelling method to assess
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45 110 post-disaster accessibility to health facilities and analyze population coverage losses as a
46
47 111 result of the disaster. The approach enables quantification of disaster impacts on
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49 112 geographical health care accessibility to prioritize post-disaster interventions and to build
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51 113 resilience for future disasters. This is the first study presenting the applicability of post-
52
53 114 disaster geographical accessibility modelling.
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117 2. METHODS

118 2.1 Overall methodology

119 In this study, accessibility is measured as the travel time to health facilities and coverage is
 120 defined as the number or percentage of people covered or located within a travel time
 121 catchment area²³. To model accessibility to health facilities, we consider topography, road
 122 networks, constraints to movement (e.g. rivers, lakes and flood extent), target population
 123 distribution, and the locations of functional health facilities. We accessed and prepared
 124 multiple data layers (Table 1) assembled in the aftermath of Cyclone Idai and Kenneth,
 125 between April 2019 and September 2019. A total of three scenarios were prepared,
 126 representing 1) pre-Idai and pre-Kenneth, 2) post-Idai, and 3) post-Kenneth situations. We
 127 modeled population travel time to the nearest health facility and population coverage, for
 128 two cyclone-affected regions.

130 **Table 1** – Overview of data layers and data sources

Layer name	Source ^a	Source date ^b	Download date	Type	Original resolution
Administrative boundaries	INE & UN-OCHA ROSEA (HDX)	02.04.19	31.07.19	Polygon	-
Land cover	Copernicus	15.11.18	31.07.19	Raster	100 meters
Elevation	SRTM CGIAR	25.11.18	20.09.19	Raster	30 meters
Rivers and lakes	DNGRH	12.8.19	19.9.19	Polygon	-
Flood extent Idai	Sentinel 1 (HDX)	19.03.19	31.07.19	Polygon	-
Flood extent Kenneth	Copernicus EMSR354 (INGC Geonode)	02.05.19	31.07.19	Polygon	-
Roads	OpenStreetMap (INGC Geonode)	25.11.18	07.08.19	Lines	-
Road damages (Idai/Kenneth)	LOG-WFP	19.03.19/ 03.05.19	23.09.19	PDF file	-
Health facilities	SIS-MA (HDX)	31.12.17	08.08.19	Points	-
Health facilities damages	Provided by WHO-Mozambique	48h – 1 week post cyclone	17.09.19	Points	-
Population density	Facebook/CIESIN population density	01.10.18	06.08.19	Raster	30 meters

131 ^a Abbreviations: CIESN = Center for International Earth Science Information Network, HDX = Humanitarian Data Exchange,
 132 INE = National Institute for Statistics Mozambique, INGC = National Institute for Disaster Management Mozambique, SIS-
 133 MA = Ministry of Health Mozambique, SRTM = Shuttle Radar Topography Mission, UN-OCHA ROSEA = United Nations
 134 Office for the Coordination of Humanitarian Affairs Southern and Eastern Africa, LOG-WFP = Logistics Cluster World Food
 135 Program

136 ^b Source date represents the imagery acquisition date for the flood extents and the release date for all other data

137

138 2.2 Data sources and preparation

139 The projection, resolution and alignment of geospatial data was processed using Quantum
140 Geographical Information System (QGIS) (version 3.4)²⁴ and, to a limited extent, R (version
141 3.5.2)²⁵. As indicated in Table 1, most data layers were retrieved from open data platforms.
142 All raster- and shapefiles were saved in the projection system of Mozambique, i.e. UTM-37S
143 [EPSG:32737]. The data preparation process is briefly described below, and fully detailed in
144 Supplementary 1.

146 Elevation data were obtained from the Shuttle Radar Topography Mission (SRTM) in tiles at
147 a resolution of 30 meters²⁶. Slopes were derived from it and accounted for when modelling
148 walking movements.

150 Land cover data was downloaded for the whole African continent at 100 meter resolution
151 from Copernicus Global Land Service²⁷ and was clipped to the extent of Mozambique. As
152 analyses were carried out at 30-meter resolution the land cover raster was resampled at a
153 resolution of 30 meters, using nearest neighbor interpolation.

155 The pre-cyclone road network dataset was retrieved from Open Street Map (OSM) through
156 the Geonode Platform of the National Institute for Disaster Management Mozambique
157 (INGC), and linked to the road damage information as indicated by the Logistics Cluster of
158 the World Food Program (LOG-WFP)^{28,29}. Historical post-cyclone status of roads and road
159 segments were manually digitized from pdf maps provided by LOG-WFP. The maps were
160 cross-referenced with the OSM road network layer, to include post-cyclone road damage
161 status, i.e. 1) open 2) restricted 3) closed. Road damages as a consequence of cyclones Idai
162 and Kenneth were taken from maps dated March 19 and May 3 2019, respectively (Table 1)
163 ^{28,29}. Information on road type and damage were combined in order to obtain unique road
164 type-damage combinations.

166 Information on rivers and lake layout were obtained as shapefiles from the National
167 Directorate for Water Resource Management (DNGRH). Only primary rivers and lakes were
168 considered as barriers to movement, under the assumption that smaller rivers and streams
169 were passable by the population. Flood extents for Idai (on 19 March 2019) and Kenneth (on

1
2
3 170 2 May 2019) were sourced as shapefiles from Sentinel-1 and Copernicus EMSR354,
4
5 171 respectively. The flood extents were visually inspected and found to be largest on those two
6
7 172 dates, and thus represent the biggest constraints for health care access. All flooded areas
8
9 173 were treated under two scenarios: 1) as being impassable, under the assumption that
10
11 174 people avoid traversing flood water to prevent further injury, 2) as being passable by foot at
12
13 175 an average walking speed of 1.5 km/h. In the first scenario, health facilities located on flood
14
15 176 extents were always treated as inaccessible since they are located on barriers.

16 177

17
18 178 High-resolution population density estimates for children under five were obtained from the
19
20 179 Facebook Connectivity Lab and Center for International Earth Science Information network³⁰
21
22 180 with a 30-meter resolution.

23 181

24
25 182 Additionally, geographic coordinates of all villages (i.e. communities) in Idai-affected
26
27 183 districts were obtained from UNICEF Mozambique, which had gathered this information
28
29 184 through a community mapping initiative conducted by health officials, 6 to 8 months before
30
31 185 Cyclone Idai made landfall. These community locations were used to extract pre- and post-
32
33 186 cyclone travel time for each community to the nearest functional health center.

34 187

35
36 188 The geographic coordinates of all health facilities were sourced from the health
37
38 189 management information system, Ministry of Health in Mozambique (SIS-MA). Data
39
40 190 cleaning was undertaken in cases where the geographic coordinates for health facilities
41
42 191 were located outside the international border of Mozambique or for coordinates falling on
43
44 192 barriers to movement (Supplementary 1). Information on damaged health facilities was
45
46 193 provided in tabular format by the World Health Organization (WHO). The health system in
47
48 194 Mozambique comprises four levels; the primary level consists of urban and rural health
49
50 195 centers, the secondary level consists of general, rural and district hospitals, the tertiary level
51
52 196 comprises provincial capital hospitals, and quaternary facilities comprise the central and
53
54 197 specialized hospitals³¹. Health facilities of all levels were included in the model.

54 198

55
56 199 Districts that were most affected by Cyclones Idai and Kenneth ("cyclone-affected districts",
57
58 200 thereafter) were identified in close collaboration with UNICEF and humanitarian responders.

1
2
3 201 All statistics presented below were calculated for these identified districts, with 26 such
4
5 202 districts in the Idai-affected region and 11 districts in the Kenneth-affected region (Figure 1).
6

7 203

8 204 **2.3 Geographical accessibility modelling**

9
10 205 To model travel times and population coverages, we used AccessMod 5 (version 5.6.30)^{23,32}.

11 206 AccessMod models geographic accessibility using terrain-based least-cost path distance
12
13 207 calculation. This open-source software has been successfully applied in many different
14
15 208 settings, among which accessibility and referral assessments of health facility networks,
16
17 209 optimization modelling of health programs in obstetric and neonatal care (EmONC)³³,
18
19 210 primary health care³⁴, emergency care³⁵, referral times³⁶, and treatment of fever cases³⁷.
20
21 211

22
23 212 Using the data preparation modules in AccessMod, we overlaid the roads, rivers, lakes,
24
25 213 flood extent, and landcover datasets to obtain a single 30-m resolution raster data set, to
26
27 214 which different travel scenarios were applied.
28

29 215

30 216 The travel scenarios (presented in Supplementary 2) were derived using local information as
31
32 217 model inputs on pre-cyclone and post-cyclone travel speeds and travel modes. Both
33
34 218 scenarios were developed in close collaboration with UNICEF Mozambique, with focus on
35
36 219 geographic accessibility to functional health facilities for the target population of children
37
38 220 under 5. Post-cyclone travel speeds were adjusted for wet weather conditions as heavy
39
40 221 rains persisted in the direct aftermath of both cyclones. During the post-cyclone situation,
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42 222 restricted and closed roads were assumed to be unpassable by any vehicle; but where flood
43
44 223 waters were not inundating roads, they were perceived to be accessible by foot. All
45
46 224 landcover classes outside of the road network and the barriers were considered as passable.
47
48 225 We assumed a functional bridge where a road segment crossed a river.
49

50 226

51 227 To account for uncertainty of the assumed travel speeds, we also considered both pre- and
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53 228 post-cyclone motorized travel speeds with a 20% slower and 20% faster speed, as adapted
54
55 229 from Ouma et al. (2018)³⁵. Population coverage of the network of health centers was
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57 230 calculated at the 2-hour maximum travel time limit. This limit was deemed appropriate to
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59 231 capture the extent of effective access, and is often used in health accessibility studies,
60
232 notably in maternal health (Ebener et al., 2019). A paired T-test was used to check for

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3 233 statistically significant difference between pre-cyclone and post-cyclone population
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5 234 coverage (R version 3.5.2).
6

7 235

8
9 236 **FIGURE 1**
10

11 237

12 238 **2.4 Patients and the public involvement**

13
14 239 There was no patient or public involvement in this study. Health facility functionality status
15
16 240 was shared in tabular format by WHO. All other geospatial data were publicly available.
17

18 241

19
20 242 **3. RESULTS**

21
22 243 **3.1 Pre-cyclone accessibility**

23 244 Pre-cyclone coverage in Idai-affected districts (Figure 3a) was highest in Cidade De Chimoio
24
25 245 and Cidade Da Beira, with 99.8% and 99.5% of all children under 5 covered within the 2
26
27 246 hours catchment limit, respectively (Supplementary 3). However, this coverage ranged from
28
29 247 35.8-99.8% in all Idai-affected districts (Supplementary 3). Absolute pre-cyclone coverage
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31 248 was also highest in Cidade De Chimoio and Cidade Da Beira, where 57,476, and 66,135
32
33 249 children were within 2 hours travel time from a health facility (Figure 2). In Kenneth-
34
35 250 affected districts (Figure 1b), pre-cyclone coverage was highest in Cidade De Pemba, where
36
37 251 100% of the children under 5 were expected to be able to reach a health facility within 2
38
39 252 hours travel time (Supplementary 4). The lowest pre-cyclone coverage was seen in Mazeze,
40
41 253 where only 52.6% of children under 5 were within 2 hours travel time from a health facility
42
43 254 (Supplementary 4). Absolute pre-cyclone coverage in Kenneth-affected districts was highest
44
45 255 in Cidade De Pemba (n = 35,467 children) and Chiure (n= 18,257 children) (Figure 2). Figure
46
47 256 3a and Figure 4a present the pre-cyclone travel time rasters for the cyclone-affected areas.
48

49 257

50
51 258 **FIGURE 2**
52

53 259

54 260 **3.2 Accessibility losses in affected districts**

55 261 Geographical accessibility to health care significantly decreased in the cyclone affected
56
57 262 districts, as a result of reduced travel speeds, road constraints and non-functional health
58
59 263 facilities (Figure 3B and Figure 4B). In Figure 3C, ratios of pre-cyclone and post-cyclone
60
264 travel time rasters are mapped for Idai-affected districts, with ratios close to 1 indicating

265 similar travel times pre- and post-cyclone, and ratios closer to 0 indicating large pre- and
 266 post-cyclone accessibility differences. Figure 4C presents the same results for Kenneth-
 267 affected districts. Regions shown in red indicate localities with relatively large differences
 268 between pre- and post-cyclone travel times (Figure 3C). In the Idai-affected region,
 269 especially in the districts surrounding the flood water and closed roads, accessibility is
 270 severely impacted. In Idai affected districts, the percentage of children under 5 covered
 271 within 2 hours travel time, generally decreased from 78.8% to 52.5%, implying that 136,941
 272 previously covered children under 5, lost timely access to health care (Table 2).

273

274 **Table 2-** Overview of pre- and post-cyclone population coverage in Idai and Kenneth
 275 affected districts.

Cyclone	Travel time	P-value*	Pre-cyclone		Post-cyclone			
			Children <5 covered (nr.)	Children <5 covered (%)	Children <5 covered (nr.)	Children <5 covered (%)	Children <5 coverage loss (nr.)	Children <5 coverage loss (%)
Idai	30 minutes	0.009	298432	57.3	153842	29.5	144591	27.7
	1 hour	0.002	346409	66.5	206610	39.6	139799	26.8
	2 hours	< 0.001	410696	78.8	273755	52.5	136941	26.3
Kenneth	30 minutes	0.001	131120	72.0	63953	48.8	30415	23.2
	1 hour	0.010	99056	73.8	86997	64.8	12060	9.0
	2 hours	0.039	110348	82.2	96019	71.5	14330	10.7

276 *P-values were obtained through a paired T-test.

277

278 The largest relative population coverage decline, within 2 hours travel time, was observed in
 279 Machanga, where 77.6% of the previously covered population was no longer able to access
 280 a facility under 2 hours in the aftermath of Idai (Figure 2). In terms of absolute coverage,
 281 Nhamatanda was the heaviest affected district, with a coverage loss of 25,121 children
 282 under 5, followed by Morrumbala (n = 19,554 children), Cidade Da Beira (n = 17,355
 283 children), and Buzi (n= 9,949 children) (Figure 2). Uncertainty modelling, by accounting for
 284 20% slower and 20% faster motorized travel speeds, indicated localities with travel time
 285 differences up to 3-hours comparing slower and faster travel speeds (Figure 3D). This
 286 information indicates where accessibility and coverage losses may be either under- or
 287 overestimated, which can help guide resource allocation for decreasing this uncertainty.

288

289 Relative population coverage in all Kenneth-affected districts decreased from 82.2% to
 290 71.5%, corresponding to 14,330 children having lost access to the nearest facility within 2

1
2
3 291 hours travel time (Table 2). The most affected district in terms of relative coverage loss was
4
5 292 Macomia, where 88.9% of previously covered children lost access (Supplementary 3-
6
7 293 Supplementary 4). Mazeze was the heaviest affected district in terms of absolute coverage
8
9 294 loss, as 5,496 children lost access in the aftermath of cyclone Kenneth, followed by
10
11 295 Macomia (n= 3,727 children), Chiure (n= 2,307 children), Quissanga (n= 1,270 children) and
12
13 296 Mueda (n= 750 children) (Figure 2). Pre-cyclone population coverage significantly ($p < 0.05$)
14
15 297 differed from post-cyclone population coverage under all travel time limits (30 minutes, 1
16
17 298 hour, 2 hours) and for both cyclones (Table 2). Since flood waters slowly receded in the
18
19 299 days/weeks after the cyclones, we ran an additional scenario where flood waters were
20
21 300 passable at a 1.5km/h walking speed. Considering this scenario, absolute coverage losses for
22
23 301 Idai-affected districts within 2 hours travel time were highest in Morrumbala (n= 29,566
24
25 302 children), Nhamatanda (n= 25,758 children), Dacata (n= 8,914 children), and Bùzi (n= 8,757
26
27 303 children). In Kenneth-affected districts, Mazeze (n= 6,167 children), Chiure (n= 4,684
28
29 304 children) and Macomia (n= 3,727 children) had the highest coverage losses in 2 hours
30
31 305 catchments under the passable scenario.
32
33 306

307 **3.3 Travel time in affected communities**

34 308 The most affected villages in Idai-affected districts, in terms of reduced accessibility to the
35
36 309 nearest health facility were communities located in the district Bùzi and Muanza in Sofala
37
38 310 province. The community Mucinemo in Bùzi was found to have a pre-cyclone travel time of
39
40 311 1.3 hours to the nearest health facility. However, this travel time upsurged to 63.6 hours in
41
42 312 the direct aftermath of cyclone Idai (Supplementary 5-Supplementary 6). Generally, the 6
43
44 313 most affected communities in terms of accessibility in Idai affected districts all had a pre-
45
46 314 cyclone travel time between 1 hour and 3 hours, while all post-cyclone travel times
47
48 315 increased to over 55 hours (Supplementary 6). Overall, post-cyclone accessibility ranged
49
50 316 from some minutes up to 78 hours, with the highest travel time for the community of
51
52 317 Chipota, Muanza.

54 319 FIGURE 3 & 4

3.4 Health facility closures

The sole effect of non-functionality of health facilities was isolated by comparing two separate scenarios; 1) a post-cyclone scenario where all health facilities were considered functional, and 2) a post-cyclone scenario where functionality status was considered. By comparing these scenarios to the pre-cyclone accessibility, the coverage losses caused by the disruption to transportation only (i.e. adjusted travel speeds and road constraints) could be isolated from the reduction in coverage due to the damage to health facilities (i.e. non-functional health facilities), providing a way to assess the likely impact of future programs aimed at reinforcing health facilities for disasters. In order to make these comparisons, both scenarios were run under the assumption that flood waters were fully passable. In case all health facilities remained functional in Idai-affected districts (i.e. disruption was due to transportation only), the overall coverage within 2 hours travel time would decrease from 79.3% to 57.7%, a difference of 21.6% (n = 112,538 children). Damage to health facilities caused an additional coverage decline of 5.3% (n = 27,840 children) in Idai-affected districts. However, hospital closures did not evenly affect all districts. In 17 out of 26 Idai-affected districts, hospital closures had no additional effect on accessibility, implying that coverage losses were only caused by disruption to transportation networks. However, in the remaining 9 Idai-affected districts, hospital closures were responsible for an additional 1.9-59.7% coverage loss within 2 hours catchment. Health facility closures in Machanga affected the relative coverage the most, with 59.7% coverage loss (n= 3,642 children) caused by non-functionality of 3 out of 6 health facilities. Absolute coverage losses as an effect of non-functional health facilities, were highest in Nhamatanda, where 12,946 (31.0%) children under 5 years old lost access due to health facility closures. In Nhamatanda, 9 out of 16 health facilities became unfunctional as a consequence of Cyclone Idai. Health facility closures did not have an additional effect on post-cyclone accessibility in Kenneth affected districts.

349 4. DISCUSSION

350 Population coverage significantly decreased ($p < 0.05$) and travel times substantially
351 increased in the direct aftermath of the cyclones. Damage to transport networks and
352 reduced travel speeds resulted in the most substantial population coverage losses in both
353 Idai- and Kenneth-affected districts.

354
355 In a post-disaster setting, access to health care is essential for effective response and
356 recovery³⁸. The results of our study can be implemented beyond the response phase of the
357 cyclones. Although the emphasis of the results is on identification of population coverage
358 losses on district level directly post-cyclone, the information presented here also provides a
359 platform for discussing health system recovery, mitigation and preparedness³⁹.

360
361 Early identification of underserved districts in the response phase can help reduce the
362 impacts caused by health service interruption, through targeted deployment of medical
363 services in districts with largest coverage losses and lowest baseline accessibility⁴⁰.
364 Information on population coverage losses per cyclone affected district can support
365 decision-making in the prioritization and planning of these medical services, by targeting
366 where the deployment of medical services reaches the highest number of people. Growing
367 access to open data and post-disaster information enables prompt accessibility modelling in
368 the aftermath of a natural disaster and the growing ability to quickly assemble this data
369 provides an opportunity to integrate accessibility modelling in the early response phase of a
370 natural disaster, so resources can be allocated in an informed way and health impacts can
371 be reduced.

372
373 Although flood waters receded in the weeks after the disasters, there were still 94 unsafe
374 and non-functional health facilities in June 2019 as a consequence of substantial damages
375 from the 2 cyclones^{14,41}. While it is critical to restore access to essential health services as
376 soon as possible, the WHO reported that the reconstruction of all destroyed and damaged
377 facilities may take up to 5 years¹⁴.

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379 Furthermore, the extensive damages to the road network will continue to limit movements
380 of the population, further complicating physical accessibility⁵. Our results have clearly

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3 381 pointed that road damages are responsible for a relatively larger loss of accessibility
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5 382 compared to the non-functionality of facilities. This calls for a concerted effort between
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7 383 road and health authorities when prioritizing reconstruction efforts. It was estimated by
8
9 384 WHO that damages to (health) infrastructure translated into 200,000 people living more
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11 385 than 5 kilometers from a functioning health facility ⁴¹. However, our results, which provide a
12
13 386 more realistic representation of accessibility, by accounting for topography, barriers to
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15 387 movement, and population distribution suggest this is an underestimate. We estimated that
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17 388 as a result of the damage to infrastructure and barriers to movement, 314,591 children
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19 389 under 5 live further than 1 hour travelling from a functioning health facility.
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391 Fourteen percent of all health facilities in cyclone-affected districts have been damaged or
392 fully destroyed. Rebuilding more resilient facilities and infrastructure, both in terms of
393 physical structure and in coping capacity, are needed to prevent similar impacts in future
394 disasters ⁴¹. The results presented here show the importance of joint efforts to reduce both
395 impacts on health facilities and the existing road network. However, resources are limited,
396 and efficient financial planning is needed to outline health system investment plans ^{5,11}. The
397 results of our accessibility modelling can be used to prioritize health facility reconstruction
398 for facilities with highest population coverages. Cyclone Idai for instance, caused the
399 destruction of the only tertiary hospital in four affected provinces that serves an estimated
400 12 million people ³⁸. Targeting hospitals with coverage numbers like these, to be
401 strengthened for future disaster impacts and to support them in providing continuity of care
402 in the aftermath of future disasters can help reduce coverage losses and health impacts
403 subsequently ⁴².

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405 Due to the persisting health system disruption, humanitarian responders have identified the
406 need to deploy community health workers (CHWs) and mobile outreach services to cover
407 accessibility losses caused by the cyclones and to extend the reach of existing functional
408 services ^{38,43}. These study findings can assist policymakers in identifying and prioritizing
409 severely impacted districts and communities and regions where CHWs deployment can
410 make a difference. Supplementary material 3 to 6 present the most affected communities in
411 terms of increased travel time and coverage losses, directly post-cyclone. These analyses
412 can be routinely updated to assess the effect of health system recovery on accessibility.

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3 413 The districts that were most affected by Cyclone Idai and Kenneth were historically and are
4 414 in the future also prone to disasters^{38,41}. Ideally, accessibility modelling could be applied to
5 415 simulate the effects of historical disasters on accessibility, as indicated in Supplementary 5
6 416 and Supplementary 6, so targeted preventive measures can be taken for future disasters.
7 417 Post-disaster accessibility modelling can help identify weak spots in the geographical
8 418 accessibility to the health system and helps to distinguish pre-existing accessibility gaps
9 419 (Figure 3A and 4A) from coverage losses as a result of disasters (Figure 3B and 4B). This
10 420 information is essential in health system recovery, strengthening and preparing for future
11 421 disasters.

12 422
13 423 Limitations and uncertainties of this study were primarily linked to the data. The
14 424 unfortunate event of natural disaster generally accelerates data availability in affected
15 425 countries, but with the challenges of data quality, consistency, and format⁴⁴. In this study,
16 426 data from various sources were combined to represent the post-cyclone situation as
17 427 realistically as possible, but since data gathering was ongoing, it was expected that some
18 428 data were incomplete or not fully processed at the time of usage. Health facility coordinates
19 429 for instance had duplicate occurrences in the database and health facility damages were
20 430 solely indicated by name, which resulted in manual spatial merging. Co-occurrences of rivers
21 431 that were indicated as floods were seen in the flood extent layer, minimally overestimating
22 432 actual flood extents in some parts of the affected regions. Besides post-disaster data
23 433 uncertainty, pre-disaster spatial data were also checked against background satellite
24 434 imagery. The hydrography of primary rivers stored in the data was found not to be fully
25 435 representative for actual hydrography in some regions, this could be a consequence of
26 436 digitizing against a less granular spatial resolution⁴⁵. In some cases, passages and bridges
27 437 were detected on satellite background imagery where the OpenStreetMap road layer did
28 438 not present presence of roads. The absence of roads in places where hydrography is
29 439 potentially overestimated, results in isolated land pockets, where accessibility cannot be
30 440 modelled, and the population is assumed to be fully isolated.

31 441
32 442 Next to data uncertainties, travel scenarios present a source of uncertainty as assumptions
33 443 on travel speeds and modes are uniformly generalized across regions. In addition, we
34 444 assumed that roads indicated as being restricted or closed, were considered only passable

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3 445 by foot if they were not inundated. However, some of the restricted roads were in fact
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5 446 passable by 4x4 vehicles. Since car ownership and access to motorized transport by the
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7 447 target population was expected to be very low, especially post-cyclone, it was decided to
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9 448 run the accessibility model for restricted and closed roads only by means of walking.

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11 449
12 450 Our accessibility modelling assumes that patients always travel to the nearest health facility.
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14 451 However, literature has shown that patients sometimes bypass health facilities in search of
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16 452 higher quality care in Mozambique ^{46,47}. Previous research, has shown that 30.8% of
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18 453 pregnant women bypassed the nearest health facility in search of better prenatal care ⁴⁶.
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20 454 Our results can therefore present slight underestimations of actual travel times.

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23 456 Despite some of the limitations, the results presented here provide important initial
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25 457 information for post-cyclone health system recovery which can be expanded through future
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27 458 research. Since post-disaster needs continuously change based on the nature of the event
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29 459 (e.g. receding flood waters, reconstruction efforts, and deployment of temporary medical
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31 460 services), following studies should also be focused on the ability to dynamically model
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33 461 accessibility based on these changes, so accessibility can be continuously monitored.
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35 462 Additionally, it would be interesting to assess the effect of CHW deployment and mobile
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37 463 outreach communities on improved accessibility and population coverage statistics, to
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39 464 quantify the effect of these interventions.

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41 466 Post-disaster accessibility modelling can increase our understanding of spatial differences in
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43 467 health care needs in the direct aftermath of a disaster and can help target limited resources
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45 468 efficiently. Currently, there is no standardized approach among humanitarian agencies to
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47 469 assess post-disaster accessibility losses, potentially resulting in uncoordinated decision
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49 470 making for temporary health facility locations which could result in duplicated efforts by
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51 471 humanitarian actors on the ground. The results in this paper not only reflect the importance
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53 472 of incorporating accessibility modelling in early disaster response, but also provide a
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55 473 platform for discussing health system recovery, mitigation and preparedness.

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3 476 **AUTHOR CONTRIBUTION**
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5 477 **Fleur Hierink**: conceptualization, methodology, formal analysis, writing, editing,
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8 478 visualization, supervision. **Nelson Rodrigues**: data sharing, methodology, writing, editing,
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10 479 validation. **Maria Muñiz**: writing, editing. **Rocco Panciera**: methodology, writing, editing.
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13 480 **Nicolas Ray**: conceptualization, methodology, writing, editing, validation, supervision.
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17 482 **DATA SHARING STATEMENT**
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20 483 Data available upon request.
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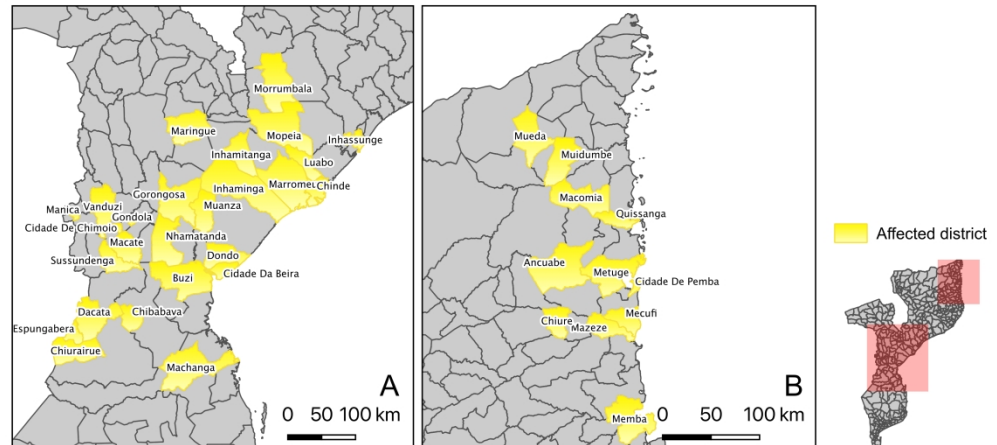


Figure 1 - Cyclone affected districts. (A) Idai affected districts. (B) Kenneth affected districts.

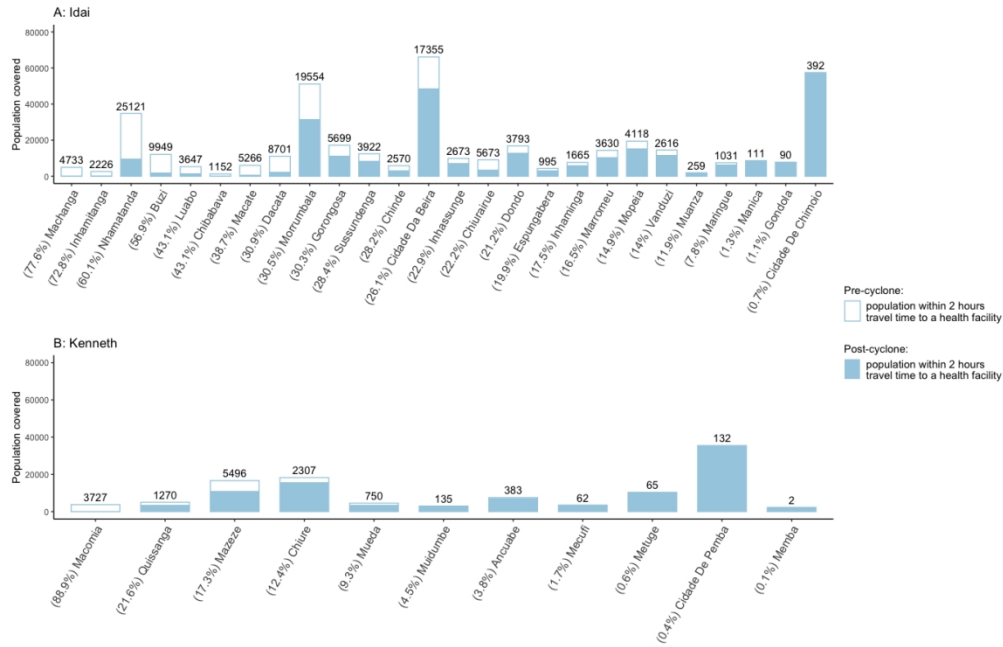
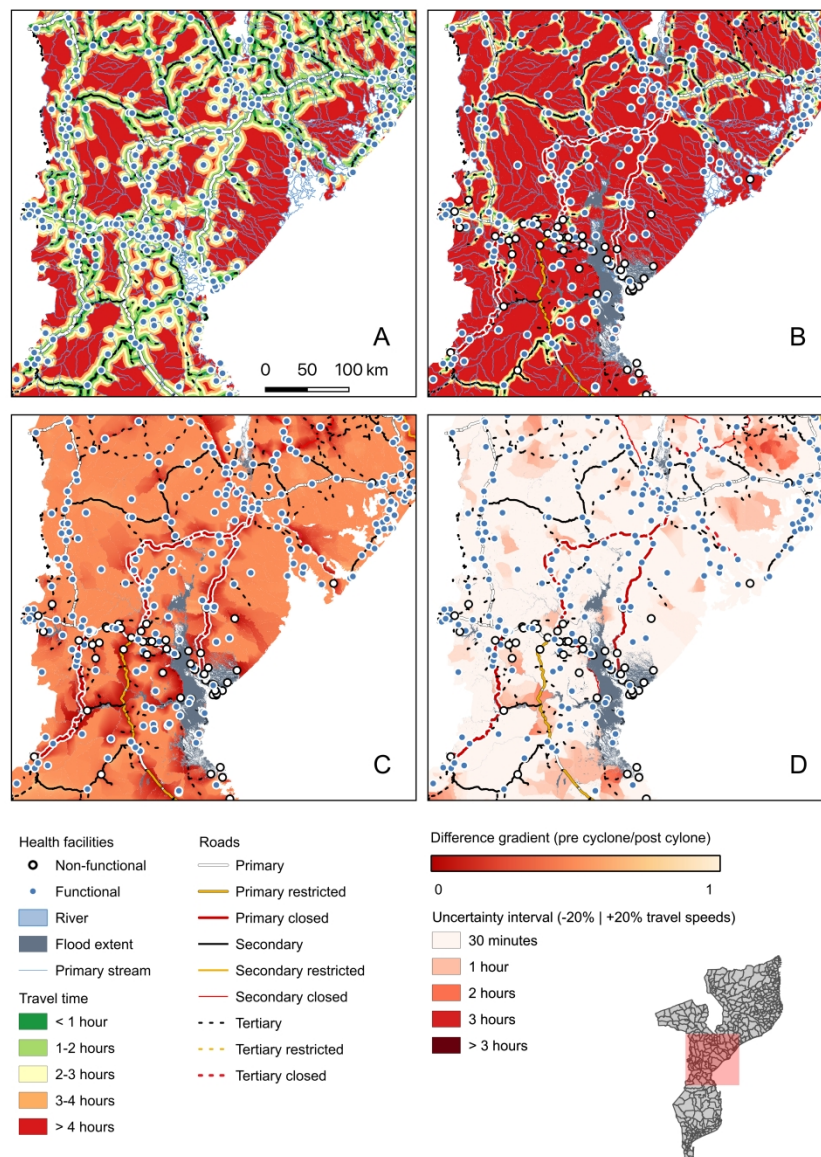


Figure 2- Absolute and relative reduction in population coverage pre- and post-cyclone Idai (A) and Kenneth (B). Labels on top of bars indicate absolute reduction in population coverage of children under 5. Labels under districts indicate relative reduction in population coverage. Maximum limits of the bars indicate the absolute pre-cyclone coverage within 2 hours travel time. Limits of the blue filled bar indicate the absolute post-cyclone coverage. The x-axis is ordered according to relative reduction in population coverage.

482x318mm (72 x 72 DPI)



45 Figure 3 – Accessibility modelling results for Idai districts. Pre-cyclone travel time raster (A). Post-cyclone
 46 travel time raster (B). Difference ratio raster between pre- and post-cyclone travel time (C). Uncertainty
 47 raster, as a result of the difference between -20% and +20% travel speed accessibility (D).
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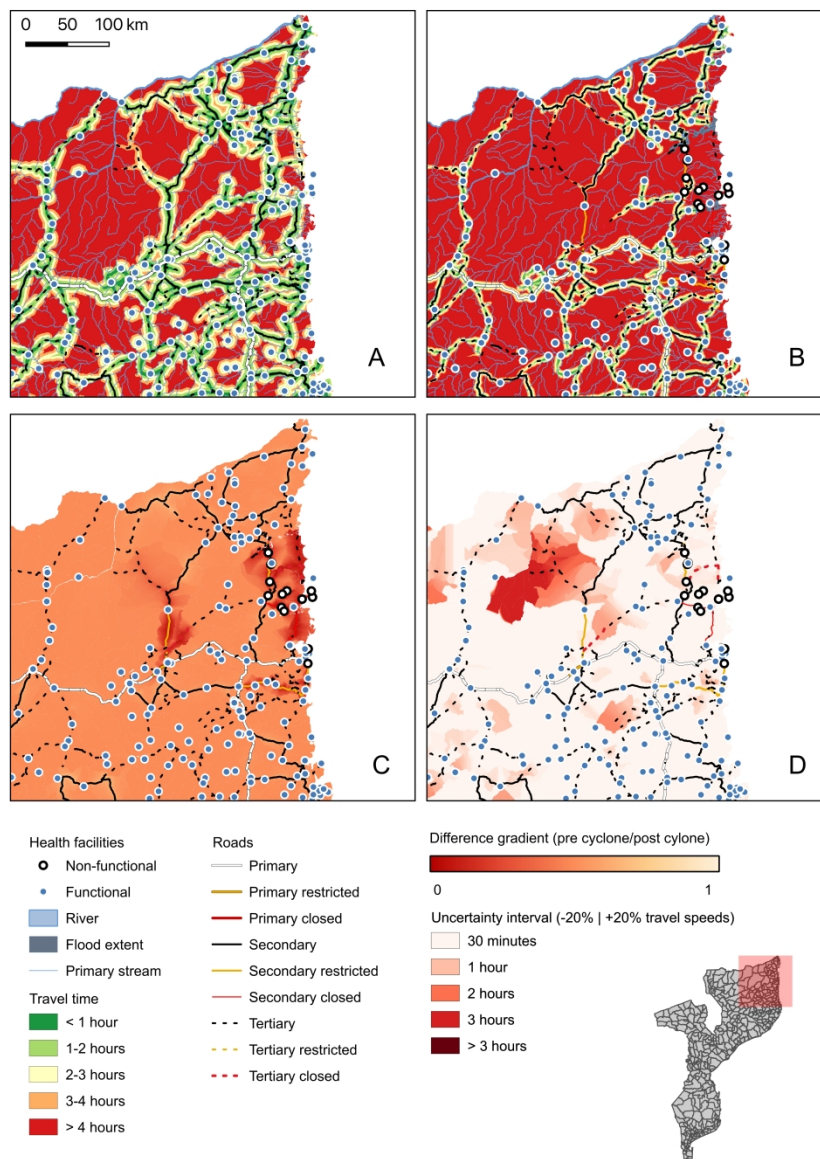


Figure 4 – Accessibility modelling results Kenneth districts. Pre-cyclone travel time raster (A). Post-cyclone travel time raster (B). Difference ratio raster between pre- and post-cyclone travel time (C). Uncertainty raster, as a result of the difference between -20% and +20% travel speed accessibility (D).

SUPPLEMENTARY MATERIAL

S1-Data preparation for use in AccessMod

All data preparation was carried out in Quantum Geographical Information System (QGIS) (version 3.4)²⁴ in limited combination with R (version 3.5.2)²⁵. As indicated in Table 1, most data layers were retrieved from open data platforms. All raster- and shapefiles were saved in the projection system of Mozambique, i.e. UTM-37S [EPSG:32737]. All raster files were aligned using the digital elevation model (DEM) as reference. The data preparation process is fully described below for each data set.

Elevation

Anisotropic accessibility analyses, in other words analyses accounting for travel speeds on slopes, were carried out for this study. The digital elevation model (DEM) data were obtained in tiles at a resolution of 30 meters²⁶. All separate tiles were first mosaiced in QGIS 3.4.

Land cover

The land cover data set of the African continent²⁷ was clipped to the extent of Mozambique, leaving a small buffer around the country to prevent loss of data cells at the border. The data set was resampled at a resolution of 30 meters using nearest neighbor interpolation.

Road network

The pre-cyclone road network dataset was retrieved from Open Street Map (OSM) through the Geonode Platform of the National Institute for Disaster Management Mozambique (INGC), as this dataset was perceived to represent the most recent information on the roads and could be linked to the damaged roads, as indicated by the Logistics Cluster of the World Food Program (LOG-WFP). Road classes that were not indicated as official classification by OSM, were removed from the data⁴⁸.

LOG-WFP provided the most up to date data on road network damages. However, the road constraint shapefile was updated frequently by overwriting previous versions, without

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3 storing data historically. Therefore, historical post-cyclone status of roads and road
4 segments was manually digitized from pdf maps provided by LOG-WFP ^{28 29}. The pdf maps
5 were manually cross-referenced with the OSM road network layer, to include post-cyclone
6 status, i.e. 1) open 2) restricted 3) closed.
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12 Roads were then reclassified based on the unique combination of road type and post-
13 cyclone status, resulting in 34 unique road classes (e.g. primary road, primary road
14 restricted, secondary road closed). All roads were given a specific travel speed, accounting
15 for the different scenarios. In the pre-cyclone scenario for instance, all primary road classes
16 (i.e. primary road, primary road restricted, primary road closed) had the same travel speed.
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18 Whereas in the post cyclone scenario, the restricted and closed road types had a travel
19 speed and travel mode accounted for their damages, as can be seen from Supplementary 2.
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26 *Barriers to movement*

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28 Rivers and lake shapefiles were obtained as lines and polygons from the National
29 Directorate for Water Resource Management (DNGRH) and accuracy was checked using
30 satellite imagery as a reference. Only primary rivers and lakes were taken for the analyses,
31 under the assumption that smaller rivers and streams were passable by the population.
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33 Water bodies were perceived as being impassable at all scales.
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40 Flood extent caused by Cyclone Idai was taken from 19 March 2019 and flood extent for
41 Cyclone Kenneth was taken from 2 May 2019, because extents were visually inspected and
42 found to be largest on those dates and thus represent the biggest constraints for health care
43 access. All flooded areas were treated as impassable at those dates, considering the depth
44 and extent of the floods.
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50 *Population data*

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52 High resolution population density estimates for children under five were downloaded at 30
53 meter resolution from the Facebook Connectivity Lab and Center for International Earth
54 Science Information network ³⁰. The raster was projected in Mozambique's projection
55 system, UTM-37S [EPSG:32737], by using nearest neighbor interpolation. Loss of population
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3 caused by reprojection and clipping to country borders, was corrected for by smoothing the
4 lost population equally over the raster cells, using the raster calculator.
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8 *Health facilities*

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10 The geographic coordinates of all health facilities were obtained through the Humanitarian
11 Data Exchange platform (HDX) and were originally sourced from the Ministry of Health in
12 Mozambique (SIS-MA). The data was cleaned to exclude coordinates far outside of the
13 country borders. Coordinates that fell just outside Mozambique were relocated within the
14 country extents. Five health facilities were cross-referenced with other data sources (e.g.
15 Neonatal Inventory Survey UNICEF, OpenStreetMap, Google Maps) because they were
16 located on barriers, such as open sea, rivers or lakes.
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25 Information on damaged health facilities was provided by the World Health Organization
26 (WHO). This data did not include GPS coordinates, thus names of the damaged health
27 facilities were cross referenced with the original health facility shapefile to include post-
28 cyclone status of each facility, i.e. functional or non-functional. For damaged health facilities
29 that were not included in the original health facility shapefile, coordinates were retrieved
30 from a neonatal inventory performed by United Nations Children Fund (UNICEF) and also
31 added as facility to the original health facility data, representing the pre-cyclone situation.
32 Non-functional health facilities were filtered-out for geographical accessibility analyses
33 reflecting the post-cyclone scenarios.
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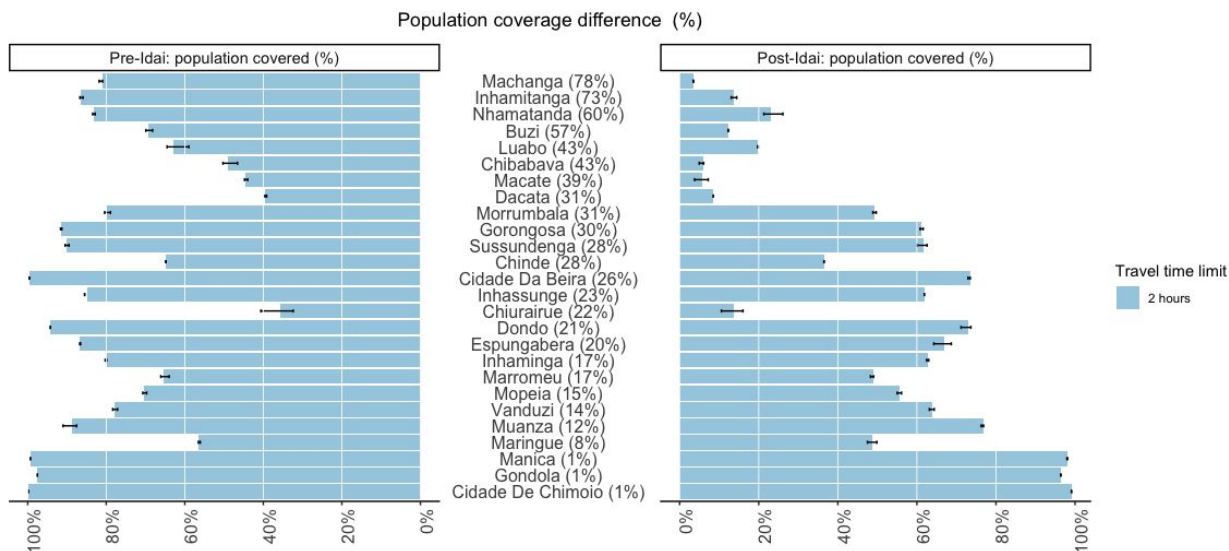
43 *Travel scenario*

44
45 Both our travel scenarios were developed in close collaboration with country
46 representatives from UNICEF and were adapted to our target population, namely children
47 under five accompanied by a parent (Supplementary 2). Flood waters were assumed to be a
48 full barrier to movement to the target population, thus health facilities located in flooded
49 zones were completely inaccessible and flood waters were impassable.
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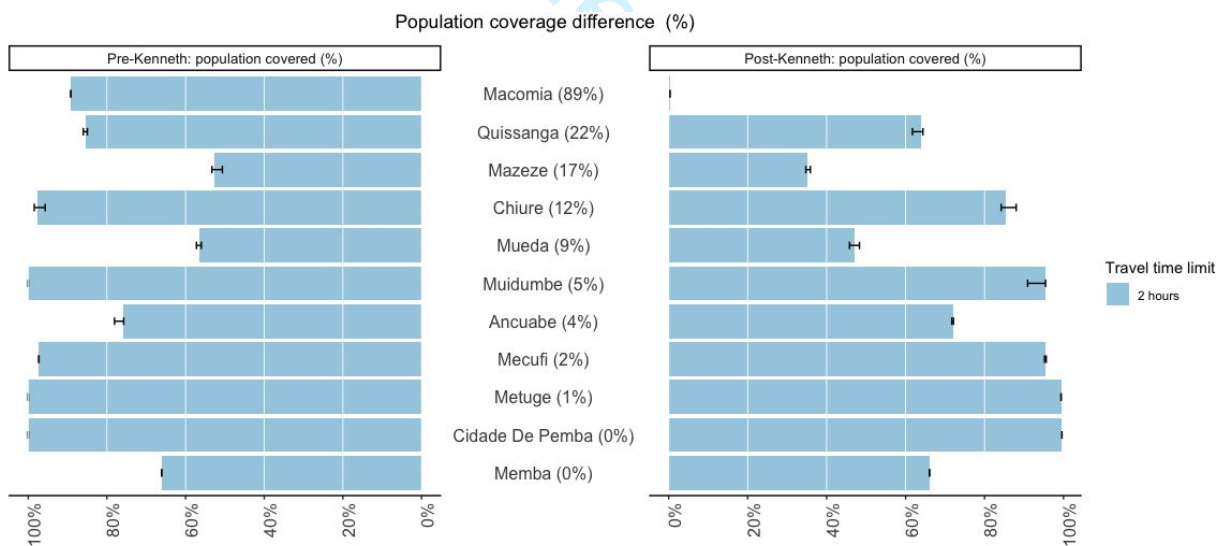
Supplementary 2- Travel scenarios pre-cyclone and post-cyclone

Label	Pre-cyclone		Post-cyclone	
	Travel speed (km/h)	Travel mode	Travel speed (km/h)	Travel mode
Shrubs	3	Walking	1.5	Walking
Herbaceous Vegetation	3	Walking	1.5	Walking
Cultivated and Managed Vegetation	3	Walking	1.5	Walking
Agriculture Cropland				
Urban Built Up	3	Walking	1.5	Walking
Bare Sparse Vegetation	3	Walking	1.5	Walking
Permanent Water Bodies	3	Walking	1.5	Walking
Temporary Water Bodies	3	Walking	1.5	Walking
Herbaceous Wetland	3	Walking	1.5	Walking
Closed Forest Evergreen Broad Leaf	3	Walking	1.5	Walking
Closed Forest Deciduous Broad Leaf	3	Walking	1.5	Walking
Open Forest Evergreen Broad Leaf	3	Walking	1.5	Walking
Open Forest Deciduous Broad Leaf	3	Walking	1.5	Walking
Open Sea	3	Walking	1.5	Walking
Trunk	80	Motorized	50	Motorized
Trunk Restricted	80	Motorized	1.5	Walking
Trunk Closed	80	Motorized	1.5	Walking
Primary	80	Motorized	50	Motorized
Primary Restricted	80	Motorized	1.5	Walking
Primary Closed	80	Motorized	1.5	Walking
Secondary	50	Motorized	40	Motorized
Secondary Restricted	50	Motorized	1.5	Walking
Secondary Closed	50	Motorized	1.5	Walking
Tertiary	30	Motorized	15	Motorized
Tertiary Closed	30	Motorized	1.5	Walking
Tertiary Restricted	30	Motorized	1.5	Walking
Road	20	Motorized	10	Motorized
Raceway	3	Walking	3	Walking
Residential	20	Motorized	10	Motorized
Residential Closed	20	Motorized	1.5	Walking
Living Street	20	Motorized	10	Motorized
Service	3	Walking	1.5	Walking
Track	15	Motorized	10	Motorized
Pedestrian	3	Walking	1.5	Walking
Pier	3	Walking	1.5	Walking
Path Closed	3	Walking	1.5	Walking
Path	3	Walking	1.5	Walking
Footway	3	Walking	1.5	Walking
Bridleway	3	Walking	1.5	Walking
Cycleway	3	Walking	1.5	Walking
Steps	3	Walking	1.5	Walking
Unclassified	3	Walking	1.5	Walking

Supplementary 3- Relative population coverage pre- and post-cyclone Idai. Ordered on relative difference. Difference indicated between parentheses. Error bars indicate the coverage uncertainty, considering -20% and +20% travel speeds.



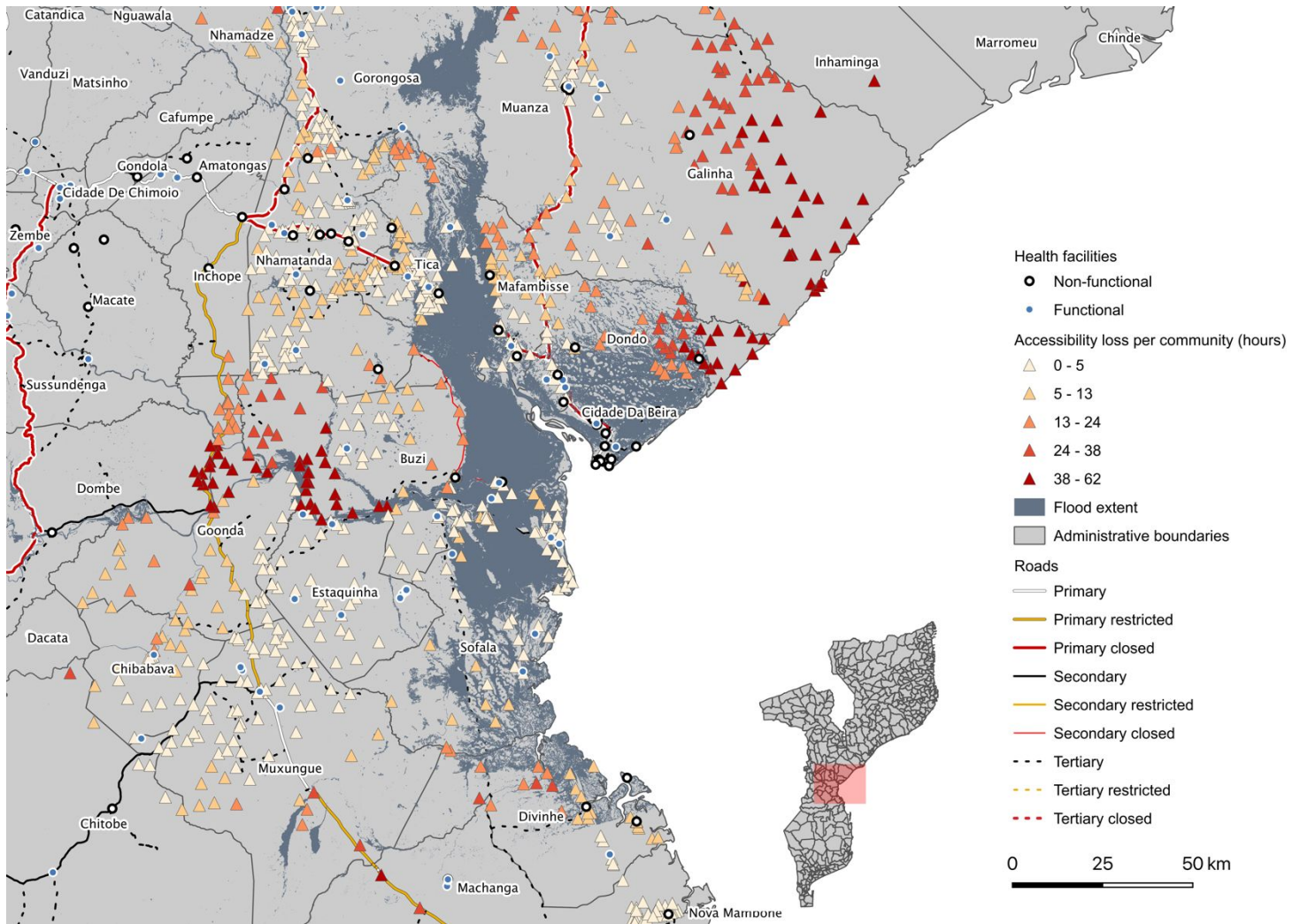
Supplementary 4- Relative population coverage pre- and post-cyclone Kenneth. Ordered on relative difference. Difference indicated between parentheses. Error bars indicate the coverage uncertainty, considering -20% and +20% travel speeds.



Supplementary 5- Travel time per community in Idai affected districts. Fifty most affected communities by means of accessibility loss. Ordered on absolute travel time difference.

Community	District	Pre-cyclone travel time (h)	Post-cyclone travel time (h)	Difference pre- and post-cyclone (h)
Mucinemo	Buzi	1.3	63.6	62.3
Bupira	Buzi	1.1	62.3	61.3
Massuinda	Buzi	1.2	60.1	58.9
Njanga	Buzi	4.3	59.1	54.7
Guenje-Sede	Buzi	2.9	57.3	54.4
Mbereaizique	Buzi	2.9	57.3	54.4
Shinizia Chinhale	Muanza	24.0	77.8	53.8
Chipota	Muanza	24.4	78.0	53.6
Wiriquizi	Muanza	22.2	74.1	51.9
Chingamuzi	Muanza	22.7	74.5	51.8
Mussacazwidje	Buzi	3.5	55.3	51.8
Mussacazwidje	Buzi	3.5	55.3	51.8
Magua	Buzi	4.8	56.6	51.8
Nkolone Praia	Muanza	20.7	72.3	51.7
Mukulumba 1	Muanza	20.4	71.8	51.4
Mukulumba cidade	Muanza	20.2	71.4	51.2
Nhanganga	Muanza	19.9	70.8	50.9
Mutanda	Buzi	5.4	55.3	49.9
Macova-Mutanda	Buzi	6.3	55.1	48.9
Puanda	Buzi	2.9	51.6	48.7
Luanda 1	Muanza	18.8	67.4	48.6
Nhamacalango	Muanza	17.4	65.8	48.4
Sengo	Dondo	5.3	53.5	48.2
Luanda 2	Muanza	18.0	65.8	47.8
Praia Nova	Dondo	3.9	51.5	47.6
Praia Farol	Dondo	3.8	51.4	47.6
Bingue Sede	Muanza	16.4	63.8	47.4
Nkonde 2	Muanza	16.4	63.8	47.4
Massitche	Dondo	7.1	54.5	47.4
Goonda Majaca	Chibabava	6.5	53.3	46.8
Ngomole	Muanza	10.1	56.7	46.6
Ngalazi	Dondo	6.0	52.3	46.3
Nhacudjica	Buzi	6.3	52.4	46.1
Chitundo	Dondo	2.0	47.7	45.7
Macarate	Chibabava	5.3	51.0	45.7
Nhamissassa	Muanza	15.9	61.5	45.6
Docue	Buzi	5.7	51.3	45.6
Khome 1	Dondo	1.4	46.8	45.4
Nherere 2	Muanza	14.0	59.0	45.0
Parange	Buzi	3.6	48.6	45.0
Njocho	Buzi	5.9	50.9	45.0
Binda	Machanga	0.7	45.2	44.6
Khome 2	Dondo	0.6	45.2	44.6
Veruca	Chibabava	4.1	48.6	44.5
Mamunge	Buzi	5.1	49.2	44.1
Birirane	Muanza	13.1	57.2	44.1
Vala-vala	Buzi	5.2	49.2	44.1
Muche	Gorongosa	1.5	45.5	44.0
Machiquire	Buzi	2.6	46.1	43.5
Nhazwicasse	Gorongosa	1.0	44.5	43.5

Supplementary 6- Travel time per community in Idai affected districts. Point locations of communities in Idai affected districts.



only

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Modelling geographical accessibility to support disaster response and rehabilitation of a health care system:

An impact analysis of Cyclones Idai and Kenneth in Mozambique

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International health services, organization of health services, geographical mapping, risk management

1 **ABSTRACT**

2 **Objectives**

3 Modelling and assessing the loss of geographical accessibility is key to support disaster
4 response and rehabilitation of the health care system. The aim of this study was therefore
5 to estimate post-disaster travel times to functional health facilities and analyze losses in
6 accessibility coverage after Cyclones Idai and Kenneth in Mozambique in 2019.

7 **Setting**

8 We modeled travel time of vulnerable population to the nearest functional health facility in
9 two cyclone-affected regions in Mozambique. Modelling was done using AccessMod 5,
10 where roads, rivers, lakes, flood extent, topography, and land cover datasets were overlaid
11 with health facility coordinates and high-resolution population data to obtain accessibility
12 coverage estimates under different travel scenarios.

13 **Outcome measures**

14 Travel time to functional health facilities and accessibility coverage estimates were used to
15 identify spatial differences between pre-disaster and post-disaster geographical
16 accessibility.

17 **Results**

18 We found that accessibility coverage decreased in the flood affected districts, as a result of
19 reduced travel speeds, road constraints and non-functional health facilities. In Idai-affected
20 districts, accessibility coverage decreased from 78.8% to 52.5%, implying that 136,941
21 children under 5 were no longer able to reach the nearest facility within 2 hours travel time.
22 In Kenneth-affected districts, accessibility coverage decreased from 82.2% to 71.5%,
23 corresponding to 14,330 children under 5 having to travel more than 2 hours to reach the
24 nearest facility. Damage to transport networks and reduced travel speeds resulted in the
25 most substantial accessibility coverage losses in both Idai and Kenneth-affected districts.

29 **Conclusions**

30 Post-disaster accessibility modelling can increase our understanding of spatial differences in
31 geographic access to care in the direct aftermath of a disaster and can inform targeting and
32 prioritization of limited resources. Our results reflect opportunities for integrating
33 accessibility modelling in early disaster response, and to inform discussions on health
34 system recovery, mitigation and preparedness.

36 **STRENGTHS AND LIMITATIONS OF THIS STUDY**

- 38 • This is the first study presenting the applicability of post-disaster geographical
39 accessibility modelling.
- 40 • The approach enables quantification of disaster impacts on geographical health care
41 accessibility to prioritize post-disaster interventions and to build resilience for future
42 disasters.
- 43 • To account for uncertainty of the assumed travel speeds, we considered -20% and
44 +20% intervals on motorized travel speeds.
- 45 • Data from various sources and administrative levels were combined to represent the
46 post-cyclone situation as realistically as possible, but since data gathering was
47 ongoing, it was expected that some data were incomplete or not fully processed at
48 the time of usage.
- 49 • Our accessibility modelling assumes that patients always travel to the nearest health
50 facility. However, literature has shown that patients sometimes bypass health
51 facilities in search of higher quality care in Mozambique.

1. INTRODUCTION

Geographical proximity to health facilities is a crucial aspect of accessibility, utilization and the provision of health services to populations in need¹. Road networks and natural barriers (such as rivers, water bodies, and flooded areas) are important factors that determine the geographical (i.e. physical) accessibility of a population to the network of functional health facilities. During natural disasters, roads and health facilities are often damaged, yet health care demand rises substantially at the same time due to injuries and increased communicable disease risks^{2,3}. The interplay between the disruption of health infrastructure, transport network, and the rise in health care demand, is known to disable a large portion of the population's access to care they need in the aftermath of a disaster^{3,4}. This is especially the case in already medically underserved regions, where the event can lead to new health disparities or exacerbate existing ones².

In March and April 2019, two cyclones made landfall in Mozambique. This was the first time in history that two strong cyclones hit Mozambique consecutively in the same season⁵. On 14 March 2019 Tropical Cyclone Idai made landfall in Beira, followed by a week of heavy rains and winds, the storm ended on 21 March 2019⁶. In the middle of the humanitarian emergency response for Cyclone Idai, a second cyclone hit Northern Mozambique. Cyclone Kenneth, a category 4 cyclone and the strongest recorded cyclone on the African continent, made landfall in Pemba, Cabo Delgado on 25 April 2019^{7,8}. The two cyclones combined had a death toll of 648, with 603 fatalities due to Idai and 45 deaths caused by Kenneth, and left over 2.2 million people in need of humanitarian assistance⁵. The cyclone's destruction isolated entire communities for weeks due to flood waters, destroyed telecommunication networks, and extensive road damage^{9,10}. In addition, stagnant waters, inability in accessing safe water and sanitation, and overcrowding in temporary accommodation led to a cholera outbreak and a significant increase in malaria cases^{5,8,11,12}. Major damage to 113 health facilities were reported after both cyclones, causing severe disruption in health service provision and restricting the population's access to adequate health care^{13,14}. Although many humanitarian actors have estimated substantial losses in health care accessibility and availability^{5,9,10,13,15}, the quantitative impact of Cyclone Idai and Kenneth on geographical accessibility to health care remains unknown.

1
2
3 83 Since 2005 the humanitarian sector applies a *cluster approach* to coordinate emergency
4 operations between all humanitarian response organizations involved¹⁶. This means that
5 84 all humanitarian organizations are cooperating in the main sectors of humanitarian action
6
7 85 (e.g. water, health, logistics) and have clear responsibilities for coordination¹⁶. A post
8
9 86 disaster needs assessment (PDNA) is the first step in the humanitarian response cycle to
10
11 87 formulate a disaster response and recovery plan¹⁷. Guidelines from the World Health
12
13 88 Organization (WHO) for a PDNA for the health cluster specifically, advise on a comparison
14
15 89 between baseline and post-disaster accessibility through the evaluation of key indicators in
16
17 90 their presented framework¹⁸. However, the suggested key indicators reflect rather static
18
19 91 measures of accessibility, such as hospital beds per 10,000 population or number of
20
21 92 damaged health facilities¹⁸. Yet, international efforts to support humanitarian responses on
22
23 93 the ground accelerate post-disaster data gathering, enabling a more realistic quantification
24
25 94 of accessibility to health care by means of health facility damages, loss of road access, and
26
27 95 barriers to movement such as flood waters¹⁹. Guidance on assessing loss in geographical
28
29 96 accessibility while considering spatial barriers remains abstract or even lacking in disaster
30
31 97 management frameworks. Meanwhile, geographical accessibility models hold actionable
32
33 98 information and have the potential to quantify gaps and overlaps in (temporary) service
34
35 100 provisioning, enabling coordinated, targeted and centralized decision making for
36
37 101 humanitarian action²⁰, enhancing both financial and operational efficiency^{21,22}.

38 102

39
40 103 This study therefore presents a data processing and spatial accessibility modelling method
41
42 104 to assess post-disaster accessibility to health facilities and analyze accessibility coverage
43
44 105 losses as a result of cyclones Idai and Kenneth in Mozambique. The approach enables
45
46 106 quantification of disaster impacts on geographical health care accessibility to prioritize post-
47
48 107 disaster interventions and to build resilience for future disasters. This is the first study
49
50 108 presenting the applicability of post-disaster geographical accessibility modelling.

51 109

52 110 **2. METHODS**

53 111 **2.1 Overall methodology**

54
55 112 In this study, *accessibility* is measured as the travel time to health facilities and *accessibility*
56
57 113 *coverage* (i.e. coverage) is defined as the estimated number or percentage of people
58
59 114 covered or located within a travel time catchment area²³. To model accessibility to health

115 facilities, we consider topography, road networks, constraints to movement (e.g. rivers,
 116 lakes and flood extent), target population distribution, and the locations of functional health
 117 facilities. We accessed and prepared multiple data layers (Table 1) assembled in the
 118 aftermath of Cyclone Idai and Kenneth, between April-September 2019. A total of three
 119 scenarios were prepared, representing 1) pre-Idai and pre-Kenneth (before March 2019), 2)
 120 post-Idai (up to one-week post-cyclone), and 3) post-Kenneth (up to one-week post-cyclone)
 121 situations. We modeled population travel time to the nearest health facility and accessibility
 122 coverage, for two cyclone-affected regions.

123

124 **Table 1** – Overview of data layers and data sources

Layer name	Source ^a	Source date ^b	Download date	Type	Original resolution
Administrative boundaries	INE & UN-OCHA ROSEA (HDX) ²⁴	02.04.19	31.07.19	Polygon	-
Cyclone trajectory (Idai/Kenneth)	GDACS ^{25,26}	15.03.19/25.04.19	08.03.2020	Polygon	-
Land cover	Copernicus ²⁷	15.11.18	31.07.19	Raster	100 meters
Elevation	SRTM CGIAR ²⁸	25.11.18	20.09.19	Raster	30 meters
Rivers and lakes	DNGRH	12.8.19	19.9.19	Polygon	-
Primary streams	DNGRH	12.8.19	19.9.19	Lines	-
Flood extent, Idai	UNOSAT/ Sentinel-1 (HDX) ²⁹	19.03.19	31.07.19	Polygon	-
Flood extent, Kenneth	Copernicus EMSR354 (INGC Geonode) ³⁰	02.05.19	31.07.19	Polygon	-
Roads	OpenStreetMap (INGC Geonode) ³¹	25.11.18	07.08.19	Lines	-
Road damages (Idai/Kenneth)	LOG-WFP ^{32,33}	19.03.19/03.05.19	23.09.19	PDF file	-
Health facilities	SIS-MA (HDX) ³⁴	31.12.17	08.08.19	Points	-
Health facilities damages	Provided by WHO-Mozambique	Represents health facility status 48h until 1 week post cyclone	17.09.19	Points	-
Population density	Facebook/CIESIN population density ³⁵	01.10.18	06.08.19	Raster	30 meters

125 ^a Abbreviations: CIESN = Center for International Earth Science Information Network, DNGRH = National Directorate for
 126 Water Resource Management, HDX = Humanitarian Data Exchange, GDACS = Global Disaster Alert and Coordination
 127 System, INE = National Institute for Statistics Mozambique, INGC = National Institute for Disaster Management
 128 Mozambique, SIS-MA = Ministry of Health Mozambique, SRTM = Shuttle Radar Topography Mission, UN-OCHA ROSEA =
 129 United Nations Office for the Coordination of Humanitarian Affairs Southern and Eastern Africa, UNOSAT = United Nations
 130 Operational Satellite Applications Program, LOG-WFP = Logistics Cluster World Food Program

1
2
3 131 ^b Source date represents the imagery acquisition date for the flood extents and the release date for all other data^{2.2}
4

5 132 **Data sources and preparation**

6
7 133 The projection, resolution and alignment of geospatial data was processed using Quantum
8
9 134 Geographical Information System (QGIS) (version 3.4)³⁶ and, to a limited extent, R (version
10
11 135 3.5.2)³⁷. As indicated in Table 1, most data layers were retrieved from open data platforms.
12
13 136 All rasters and shapefiles were saved in the projection system of Mozambique, i.e. UTM-37S
14
15 137 [EPSG:32737]. The data preparation process is briefly described below, and fully detailed in
16
17 138 Supplement 1.
18

19
20 140 Elevation data were obtained from the Shuttle Radar Topography Mission (SRTM) in tiles at
21
22 141 a resolution of 30 meters and mosaiced to cover the whole country³⁸. Slopes were derived
23
24 142 from it and accounted for when modelling walking movements.
25

26
27 144 Land cover data was downloaded for the whole African continent at 100 meter resolution
28
29 145 from Copernicus Global Land Service²⁷ and was clipped to the extent of Mozambique. As
30
31 146 analyses were carried out at 30-meter resolution the land cover raster was resampled at a
32
33 147 resolution of 30 meters, using nearest neighbor interpolation.
34

35
36 149 The pre-cyclone road network dataset was retrieved from Open Street Map (OSM) through
37
38 150 the Geonode Platform of the National Institute for Disaster Management Mozambique
39
40 151 (INGC), and linked to the road damage information as indicated by the Logistics Cluster of
41
42 152 the World Food Program (LOG-WFP)^{39,40}. Historical post-cyclone status of roads and road
43
44 153 segments were manually digitized from PDF maps provided by LOG-WFP. The maps were
45
46 154 cross-referenced with the OSM road network layer, to include post-cyclone road damage
47
48 155 status, (i.e. 1) open, 2) restricted, and 3) closed). Road damages as a consequence of
49
50 156 cyclones Idai and Kenneth were taken from maps dated March 19 and May 3, 2019,
51
52 157 respectively (Table 1)^{39,40}. Information on road type and damage were combined in order to
53
54 158 obtain unique road type-damage combinations (Supplement 2).
55

56
57 160 Information on rivers and lake layout were obtained as shapefiles from the National
58
59 161 Directorate for Water Resource Management (DNGRH). Only primary rivers and lakes were
60
162 considered as barriers to movement, under the informed assumption that smaller rivers and

1
2
3 163 streams were passable by the population. This assumption was checked for several
4
5 164 instances against background satellite imagery. Flood extents for Idai (on 19 March 2019)²⁹
6
7 165 and Kenneth (on 2 May 2019)³⁰ were sourced as shapefiles from Sentinel-1 and Copernicus
8
9 166 EMSR354, respectively. The flood extents were visually inspected and found to be largest on
10
11 167 those two dates, and thus represent the biggest constraints for health care access. All
12
13 168 flooded areas were treated under two scenarios: 1) as being impassable, under the
14
15 169 assumption that people avoid traversing flood water to prevent further injury, 2) as being
16
17 170 passable by foot at an average walking speed of 1.5 km/h. In the first scenario, health
18
19 171 facilities located on flood extents were always treated as inaccessible since they are located
20
21 172 on barriers.

22 173

23 174 While cyclones impact entire populations, the burden disproportionately affects children
24
25 175 and women ⁴¹. It is estimated that for cyclones Idai and Kenneth more than 50% of the
26
27 176 affected population were children, and with flood waters rising above 6 meters, their
28
29 177 movements to safety and health care were particularly limited ⁵. Moreover, children under
30
31 178 5 represent the age group used as benchmark for child survival targets in both the
32
33 179 Millennium Development Goals (MDGs) and the Sustainable Development Goals (SDGs), as
34
35 180 such this cohort is frequently used as baseline⁴². In this context and through the
36
37 181 collaborative work with UNICEF, this analysis aimed at informing the impact of the disasters
38
39 182 on the burden for specific child health services that target children under 5, (e.g.
40
41 183 immunization). We therefore focused our analyses on children under 5.

42 184

43 185 High-resolution population density estimates for children under five were obtained from the
44
45 186 Facebook Connectivity Lab and Center for International Earth Science Information Network
46
47 187 (CIESN)³⁵ with a 30-meter resolution. Although several gridded populations datasets are
48
49 188 available, the Facebook CIESN dataset was assumed to have the most realistic reallocation
50
51 189 of population to settlements⁴³. In addition, other frequently used high resolution gridded
52
53 190 population datasets, such as WorldPop⁴⁴, use distances from roads and villages as
54
55 191 covariates, and this can produce collinearity when used in conjunction with accessibility
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57 192 models. Population density was used to run zonal statistics on the cyclone-affected districts.
58
59 193 In this step the total population per district is summed and the estimated absolute number
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3 194 of children under 5 that are able to reach a facility in a pre-defined travel time catchment
4
5 195 are calculated.
6

7 196

8
9 197 Additionally, geographic coordinates of all villages (i.e. communities) in Idai-affected
10
11 198 districts were obtained from UNICEF Mozambique, which had gathered this information
12
13 199 through a community mapping initiative conducted by health officials, 6 to 8 months before
14
15 200 Cyclone Idai made landfall. These community locations were used to extract pre- and post-
16
17 201 cyclone travel time for each community to the nearest functional health center.

18 202 Unfortunately, geographic coordinates of villages in Kenneth-affected districts were not
19
20 203 available at the time of study.
21

22 204

23 205 The geographic coordinates of all health facilities were sourced from the health
24
25 206 management information system, Ministry of Health in Mozambique (SIS-MA). Data
26
27 207 cleaning was undertaken in cases where the geographic coordinates for health facilities
28
29 208 were located outside the international border of Mozambique or for coordinates falling on
30
31 209 barriers to movement (Supplement 1). Information on damaged health facilities was
32
33 210 provided in tabular format by the World Health Organization (WHO). The health system in
34
35 211 Mozambique comprises 4 levels; the primary level consists of urban and rural health
36
37 212 centers, the secondary level consists of general, rural and district hospitals, the tertiary level
38
39 213 comprises provincial capital hospitals, and quaternary facilities comprise the central and
40
41 214 specialized hospitals⁴⁵. Health facilities of all levels were included in the model.
42

43 215

44 216 Districts that were most affected by Cyclones Idai and Kenneth ("cyclone-affected districts",
45
46 217 thereafter) were identified in close collaboration with UNICEF and humanitarian responders.
47
48 218 All statistics presented below were calculated for these identified districts, with 26 such
49
50 219 districts in the Idai-affected region and 11 districts in the Kenneth-affected region (Figure 1a
51
52 220 & 1b). Storm trajectories of both cyclones and road damages in both districts are also
53
54 221 presented (Figure 1c-1f).
55

56 222

57 223 **2.3 Geographical accessibility modelling**

58 224 To model travel times and accessibility coverages, we used AccessMod 5 (version 5.6.30), in
59
60 225 particular the "accessibility" and "zonal statistics" modules^{23,46}. AccessMod models

1
2
3 226 geographic accessibility using terrain-based least-cost path distance calculation. This open-
4
5 227 source software has been successfully applied in many different settings, among which
6
7 228 accessibility and referral assessments of health facility networks, optimization modelling of
8
9 229 health programs in obstetric and neonatal care (EmONC)⁴⁷, primary health care⁴⁸,
10
11 230 emergency care⁴⁹, referral times⁵⁰, and treatment of fever cases⁵¹.

12 231

14 232 Using the “merge land cover” module in AccessMod, we overlaid the roads, rivers, lakes,
15
16 233 flood extent, and landcover datasets to obtain a single 30-m resolution raster dataset, to
17
18 234 which different travel scenarios were applied.

19 235

21 236 The travel scenarios (presented in Supplement 2) were derived using local information as
22
23 237 model inputs on pre-cyclone and post-cyclone travel speeds and travel modes. Both
24
25 238 scenarios were developed in close collaboration with UNICEF Mozambique, with focus on
26
27 239 geographical accessibility to functional health facilities for the target population of children
28
29 240 under 5. Post-cyclone travel speeds were adjusted for wet weather conditions as heavy
30
31 241 rains persisted in the direct aftermath of both cyclones. During the post-cyclone situation,
32
33 242 restricted and closed roads that were not inundated were assumed to be unpassable by any
34
35 243 vehicle; but they were perceived to be accessible by foot. All landcover classes outside of
36
37 244 the road network and the barriers were considered as passable. We assumed a functional
38
39 245 bridge where a road segment crossed a river.

40 246

41 247 To account for uncertainty of the assumed travel speeds, we also considered both pre- and
42
43 248 post-cyclone motorized travel speeds with a 20% slower and 20% faster speed, as adapted
44
45 249 from Ouma et al.⁴⁹. Accessibility coverage of the network of health centers was calculated at
46
47 250 the 2-hour maximum travel time limit. This limit was deemed appropriate to capture the
48
49 251 extent of effective access, and is often used in health accessibility studies, notably in
50
51 252 maternal health⁴⁷.

52 253

54 254 **FIGURE 1**

56 255

58 256

257 **2.4 Patients and the public involvement**

258 There was no patient or public involvement in this study. Health facility functionality status
259 was shared in tabular format by WHO. All other geospatial data were publicly available.

260

261 **3. RESULTS**

262 All statistics mentioned in the results are estimates of children covered by functional health
263 facilities based on our accessibility model.

264

265 **3.1 Pre-cyclone accessibility**

266 Pre-cyclone coverage in Idai-affected districts (Figure 2a) was highest in Cidade De Chimoio
267 and Cidade Da Beira, with 99.8% and 99.5% of all children under 5 covered within the 2 hour
268 catchment limit, respectively (Supplement 3). However, this coverage ranged from 35.8-
269 99.8% in all Idai-affected districts (Supplement 3). Absolute pre-cyclone coverage was also
270 highest in Cidade De Chimoio and Cidade Da Beira, where 57,476, and 66,135 children were
271 within 2 hours travel time from a health facility (Figure 2). In Kenneth-affected districts
272 (Figure 2b), pre-cyclone coverage was highest in Cidade De Pemba, where 100% of the
273 children under 5 were expected to be able to reach a health facility within 2 hours travel
274 time (Supplement 4). The lowest pre-cyclone coverage was seen in Mazeze, where only
275 52.6% of children under 5 were within 2 hours travel time from a health facility (Supplement
276 4). Absolute pre-cyclone coverage in Kenneth-affected districts was highest in Cidade De
277 Pemba (n = 35,467 children) and Chiure (n= 18,257 children) (Figure 2). Pre-cyclone travel
278 time rasters for the cyclone-affected areas were mapped (Figure 3A & Figure 4A).

279

280 **FIGURE 2**

281

282

283 **3.2 Losses in accessibility coverage**

284 Geographical accessibility to health care decreased in the cyclone-affected districts, as a
285 result of reduced travel speeds, road constraints and non-functional health facilities (Figure
286 3B and Figure 4B). Ratios of pre-cyclone and post-cyclone travel time rasters are mapped for
287 Idai-affected districts, with ratios close to 1 indicating similar travel times pre- and post-
288 cyclone, and ratios closer to 0 indicating large pre- and post-cyclone accessibility differences

(Figure 3C). The same results for Kenneth-affected districts are presented (Figure 4C). Regions shown in red indicate localities with relatively large differences between pre- and post-cyclone travel times (Figure 3C). In the Idai-affected region, especially in the districts surrounding the flood water and closed roads, accessibility is severely impacted. In Idai-affected districts, the percentage of children under 5 covered within 2 hours travel time, generally decreased from 78.8% to 52.5%, implying that 136,941 previously covered children under 5, lost timely access to health care (Table 2).

Table 2- Overview of pre- and post-cyclone accessibility coverage in Idai and Kenneth-affected districts.

Cyclone	Travel time	Pre-cyclone		Post-cyclone			
		Children <5 covered (nr.)	Children <5 covered (%)	Children <5 covered (nr.)	Children <5 covered (%)	Children <5 coverage loss (nr.)	Children <5 coverage loss (%)
Idai	30 minutes	298,432	57.3	153,842	29.5	144,591	27.7
	1 hour	346,409	66.5	206,610	39.6	139,799	26.8
	2 hours	410,696	78.8	273,755	52.5	136,941	26.3
Kenneth	30 minutes	131,120	72.0	63,953	48.8	304,15	23.2
	1 hour	99,056	73.8	86,997	64.8	12,060	9.0
	2 hours	110,348	82.2	96,019	71.5	14,330	10.7

The largest relative accessibility coverage decline, within 2 hours travel time, was observed in Machanga, where 77.6% of the previously covered population was no longer able to access a facility under 2 hours in the aftermath of Idai (Figure 2). In terms of absolute coverage, Nhamatanda was the most affected district, with a coverage loss of 25,121 children under 5, followed by Morrumbala (n = 19,554 children), Cidade Da Beira (n = 17,355 children), and Buzi (n= 9,949 children) (Figure 2). Uncertainty modelling, by accounting for 20% slower and 20% faster motorized travel speeds⁴⁹, indicated localities with travel time differences up to 3-hours comparing slower and faster travel speeds (Figure 3D & Figure 4D). This information indicates where our travel time assumptions have the largest effect on accessibility and coverage losses and where this may be either under- or overestimated based which can help guide resource allocation for decreasing this uncertainty.

1
2
3 313 Relative accessibility coverage in all Kenneth-affected districts decreased from 82.2% to
4
5 314 71.5%, corresponding to 14,330 children having lost access to the nearest facility within 2
6
7 315 hours travel time (Table 2). The most affected district in terms of relative coverage loss was
8
9 316 Macomia, where 88.9% of the children that were covered pre-cyclone lost access
10
11 317 (Supplement 3 & 4). Mazeze was the most affected district in terms of absolute coverage
12
13 318 loss, as 5,496 children lost access in the aftermath of cyclone Kenneth, followed by
14
15 319 Macomia (n= 3,727 children), Chiure (n= 2,307 children), Quissanga (n= 1,270 children) and
16
17 320 Mueda (n= 750 children) (Figure 2).

18 321
19
20 322 Since flood waters slowly receded in the days/weeks after the cyclones, we ran an
21
22 323 additional scenario where flood waters were passable at a 1.5km/h walking speed.
23
24 324 Considering this scenario, absolute coverage losses for Idai-affected districts within 2 hours
25
26 325 travel time were highest in Morrumbala (n= 29,566 children), Nhamatanda (n= 25,758
27
28 326 children), Dacata (n= 8,914 children), and Bùzi (n= 8,757 children). In Kenneth-affected
29
30 327 districts, Mazeze (n= 6,167 children), Chiure (n= 4,684 children) and Macomia (n= 3,727
31
32 328 children) had the highest coverage losses in 2 hour catchments under the passable scenario.

330 3.3 Travel time in affected communities

331 The most affected villages in Idai-affected districts, in terms of reduced accessibility to the
332 nearest health facility were communities located in Bùzi and Muanza districts in Sofala
333 province. Mucinemo in Bùzi district was found to have a pre-cyclone travel time of 1.3 hours
334 to the nearest health facility. However, this travel time upsurged to 63.6 hours in the direct
335 aftermath of cyclone Idai (Supplements 5 & 6). Generally, the 6 most affected communities
336 in terms of accessibility in Idai-affected districts all had a pre-cyclone travel time between 1
337 hour and 3 hours, while all post-cyclone travel times increased to over 55 hours
338 (Supplement 6). Overall, post-cyclone accessibility ranged from some minutes up to 78
339 hours, with the highest travel time found in Chipota, in Muanza district.

340
341
342
343

FIGURE 3 & 4

3.4 Health facility closures

1
2
3 344 The effect of non-functioning health facilities were isolated by comparing two separate
4
5 345 scenarios; 1) a post-cyclone scenario where all health facilities were considered functional,
6
7 346 and 2) a post-cyclone scenario where modified functionality status was considered. By
8
9 347 comparing these pre-cyclone and post-cyclone scenarios, the coverage losses caused by the
10
11 348 transportation-specific disruptions (i.e. adjusted travel speeds and road constraints) could
12
13 349 be isolated from the reduction in coverage due to the damage to health facilities (i.e. non-
14
15 350 functional health facilities), providing a way to assess the likely impact of future programs
16
17 351 aimed at reinforcing health facilities for disasters. In order to make these comparisons in
18
19 352 this specific example, both scenarios were run under the assumption that flood waters were
20
21 353 fully passable. In all other instances throughout the paper, flood waters were considered
22
23 354 impassable. In case all health facilities remained functional in Idai-affected districts (i.e.
24
25 355 disruption was due to transportation only), the overall coverage within 2 hours travel time
26
27 356 would decrease from 79.3% to 57.7%, a difference of 21.6% (n = 112,538 children). Damage
28
29 357 to health facilities caused an additional coverage decline of 5.3% (n = 27,840 children) in
30
31 358 Idai-affected districts. However, hospital closures did not evenly affect all districts. In 17 out
32
33 359 of 26 Idai-affected districts, hospital closures had no additional effect on accessibility.
34
35 360 However, in the remaining 9 Idai-affected districts, hospital closures were responsible for an
36
37 361 additional 1.9-59.7% coverage loss within 2 hours catchment. Health facility closures in
38
39 362 Machanga affected the relative coverage the most, with 59.7% coverage loss (n= 3,642
40
41 363 children) caused by non-functionality of 3 out of 6 health facilities. Absolute coverage losses
42
43 364 as an effect of non-functional health facilities, were highest in Nhamatanda, where 12,946
44
45 365 (31.0%) children under 5 years old lost access due to health facility closures. In
46
47 366 Nhamatanda, 9 out of 16 health facilities became unfunctional as a consequence of Cyclone
48
49 367 Idai. Health facility closures did not have an additional effect on post-cyclone accessibility in
50
51 368 Kenneth-affected districts.

369

370 **4. DISCUSSION**

371 Accessibility coverage decreased and travel times substantially increased, in the direct
372
373 aftermath of the cyclones. Damage to transport networks and reduced travel speeds
374
375 resulted in the most substantial accessibility coverage losses in both Idai- and Kenneth-
affected districts. In Kenneth-affected districts, it was found that hospital closures did not
have an additional effect on post-cyclone accessibility this is likely caused by the fact that

1
2
3 376 flood extents and hospital closures were of much smaller magnitudes in the Kenneth-
4
5 377 affected region than in the Idai-affected region.

6
7 378 In a post-disaster setting, access to health care is essential for effective response and
8
9 379 recovery⁵². The results of our study can be implemented beyond the response phase of the
10
11 380 cyclones. Although the emphasis of the results is on identification of decreased accessibility
12
13 381 coverage directly after the cyclones, the information presented here also provides a
14
15 382 platform for discussing health system recovery, mitigation and preparedness⁵³.

16 383
17
18 384 Early identification of underserved districts in the response phase can help reduce the
19
20 385 impacts caused by health service interruption, through targeted deployment of medical
21
22 386 services in districts with largest accessibility coverage losses and lowest baseline
23
24 387 accessibility⁵⁴. Information on accessibility coverage losses per cyclone-affected district can
25
26 388 support decision-making in the prioritization and planning of these medical services, by
27
28 389 targeting where the deployment of medical services reaches the highest number of people.
29
30 390 Growing access to open data and post-disaster information enables prompt accessibility
31
32 391 modelling in the aftermath of a natural disaster and the growing ability to quickly assemble
33
34 392 this data provides an opportunity to integrate accessibility modelling in the early response
35
36 393 phase of a natural disaster, so resources can be allocated in an informed way and health
37
38 394 impacts can be reduced. In this specific study, all data for an initial post-cyclone accessibility
39
40 395 study became available between 1 week and 1 month post-disaster (Table 1). This allows for
41
42 396 an accessibility analysis in the early stages of a disaster response. Generally, data on flood
43
44 397 extents and road damages, acquired from satellite imagery, were downloadable within 1
45
46 398 week post-disaster. Whereas information that had to be ground validated, such as health
47
48 399 facility functionality, became available approximately 1 month post-disaster.

49 400
50
51 401 Furthermore, the extensive damages to the road network will continue to limit movements
52
53 402 of the population, further complicating physical accessibility⁵. Our results indicate that road
54
55 403 damages are responsible for a relatively large loss of accessibility. This calls for a concerted
56
57 404 effort between road and health authorities when prioritizing reconstruction efforts. It was
58
59 405 estimated by WHO that damages to (health) infrastructure translated into 200,000 people
60
406 living more than 5 kilometers from a functioning health facility⁵⁵. However, our results,
407
which provide a more realistic representation of accessibility, by accounting for topography,

1
2
3 408 barriers to movement, and population distribution, suggest this figure is an underestimate.
4
5 409 We estimated that as a result of the damage to infrastructure and barriers to movement,
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7 410 314,591 children under 5 live further than 1 hour travelling from a functioning health
8
9 411 facility.
10
11 412
12 413 Fourteen percent of all health facilities in Cyclone Idai- and Kenneth-affected cyclone-
13
14 414 districts have been damaged or fully destroyed, although more health facilities were
15
16 415 temporarily impacted in service provisioning due to flooding, electricity constraints or
17
18 416 damage to equipment^{14,56}. While it is critical to restore access to essential health services as
19
20 417 soon as possible, the WHO reported that the reconstruction of all destructed and damaged
21
22 418 facilities may take up to 5 years¹⁴. To restore baseline accessibility, the establishment of
23
24 419 mobile outreach units, deployment of community health workers (CHWs), together with the
25
26 420 reconstruction of damaged facilities should be implemented. However, under the umbrella
27
28 421 of *Building Back Better* (BBB), rebuilding more resilient facilities and infrastructure, that are
29
30 422 able to withstand future hazards under the “Hospitals Safe from Disasters” approach, are
31
32 423 needed to prevent similar impacts in future disasters^{55,56}. The results presented here show
33
34 424 the importance of joint efforts to reduce both impacts on health facilities and the existing
35
36 425 road network. However, resources are limited, and efficient financial planning is needed to
37
38 426 outline health system investment plans^{5,11}. The results of our accessibility modelling can be
39
40 427 used to prioritize health facility reconstruction for facilities with highest accessibility
41
42 428 coverages. Cyclone Idai for instance, caused the destruction of the only tertiary hospital in 4
43
44 429 affected provinces that serves an estimated 12 million people⁵². Targeting hospitals with
45
46 430 coverage numbers like these, to be strengthened for future disaster impacts and to support
47
48 431 them in providing continuity of care in the aftermath of future disasters can help reduce
49
50 432 health losses⁵⁷.
51
52 433
53 434 Due to the persisting health system disruption, humanitarian responders have identified the
54
55 435 need to deploy community health workers (CHWs) and mobile outreach services to cover
56
57 436 accessibility losses caused by the cyclones and to extend the reach of existing functional
58
59 437 services^{52,58}. These study findings can assist policymakers in identifying and prioritizing
60
438 severely impacted districts and communities and regions where deployment of CHWs can
439 make a difference. Supplementary material 3 to 6 present the most affected communities in

1
2
3 440 terms of increased travel time and coverage losses, directly post-cyclone. These analyses
4
5 441 can be routinely updated to assess the effect of health system recovery on accessibility.
6
7 442 The districts that were most affected by Cyclone Idai and Kenneth were historically, and are
8
9 443 in the future, also prone to disasters due to their topography (i.e. coastal cities, cyclone belt
10
11 444 Indian Ocean, and low elevation)^{52,55}. Ideally, accessibility modelling could be applied to
12
13 445 simulate the effects of historical disasters on accessibility, as indicated in Supplement 5 and
14
15 446 Supplement 6, so targeted preventive measures can be taken for future disasters. Post-
16
17 447 disaster accessibility modelling can help identify weak spots in geographical accessibility to
18
19 448 the health system and helps to distinguish pre-existing accessibility gaps (Figure 3A and 4A)
20
21 449 from accessibility coverage losses as a result of disasters (Figure 3B and 4B). This
22
23 450 information is essential in health system recovery, strengthening and preparing for future
24
25 451 disasters.

25
26 452
27 453 Limitations and uncertainties of this study were primarily linked to the data. While the
28
29 454 occurrence of natural disasters generally accelerates data availability in affected countries,
30
31 455 there also are challenges of data quality, consistency, and format⁵⁹. In this study, data from
32
33 456 various sources were combined to represent the post-cyclone situation as realistically as
34
35 457 possible, but since data gathering was ongoing, it was expected that some data were
36
37 458 incomplete or not fully processed at the time of usage. Health facility coordinates for
38
39 459 instance had duplicate occurrences in the database and health facility damages were solely
40
41 460 indicated by name, which resulted in manual spatial merging. Co-occurrences of rivers that
42
43 461 were indicated as floods were seen in the flood extent layer, minimally overestimating
44
45 462 actual flood extents in some parts of the affected regions. Besides post-disaster data
46
47 463 uncertainty, pre-disaster spatial data were also checked against background satellite
48
49 464 imagery. The hydrography of primary rivers stored in the data was found not to be fully
50
51 465 representative for actual hydrography in some regions. This could be a consequence of
52
53 466 digitizing against a less granular spatial resolution⁶⁰. In some cases, passages and bridges
54
55 467 were detected on satellite background imagery where the OpenStreetMap road layer did
56
57 468 not present presence of roads. In places where hydrography is potentially overestimated
58
59 469 and not all roads are mapped, isolated land pockets are created in the merged land cover.
60
470 When modelling accessibility in these land pockets the population is assumed to be fully
471 isolated from health care.

1
2
3 472

473 Next to data uncertainties, travel scenarios present a source of uncertainty as assumptions
474 on travel speeds and modes are uniformly generalized across regions. In addition, we
475 assumed that roads indicated as being restricted or closed, were considered only passable
476 by foot if they were not inundated. However, some of the restricted roads were in fact
477 passable by 4x4 vehicles. Other means of transport (e.g., bicycle, motorcycle) may also have
478 been used in some places, which would increase accessibility to health centres. Since car
479 ownership and access to motorized transport by the target population was expected to be
480 very low, especially post-cyclone, it was decided to run the accessibility model for restricted
481 and closed roads only by means of walking.

21 482

483 Our accessibility modelling assumes that patients always travel to the nearest health facility.
484 However, literature has shown that patients sometimes bypass health facilities in search of
485 higher quality care in Mozambique^{61,62}. Previous research, has shown that 30.8% of
486 pregnant women bypassed the nearest health facility in search of better prenatal care⁶¹.
487 Our results can therefore present slight underestimations of actual travel times.

32 488

489 Despite some of the limitations, the results presented here provide important initial
490 information for post-cyclone health system recovery which can be expanded through future
491 research. Since post-disaster needs continuously change based on the nature of the event
492 (e.g. receding flood waters, reconstruction efforts, and deployment of temporary medical
493 services), following studies should also be focused on the ability to dynamically model
494 accessibility based on these changes, so accessibility can be continuously monitored and
495 humanitarian service delivery can be updated accordingly in disaster-affected districts.
496 Additionally, it would be interesting to assess the effect of CHW deployment and mobile
497 outreach communities on improved accessibility and accessibility coverage estimates, to
498 quantify the effect of these interventions.

52 499

500 Post-disaster accessibility modelling can increase our understanding of spatial differences in
501 health care needs in the direct aftermath of a disaster and can help target limited resources
502 efficiently. Currently, there is no standardized approach in the humanitarian program cycle
503 to assess post-disaster accessibility losses against baseline accessibility¹⁸. The lack of a

1
2
3 504 standardized methodology to spatially assess disaster impacts on accessibility can result in
4
5 505 uncoordinated decision making for temporary health facility locations, introducing
6
7 506 duplication probability, and complicates prioritization in recovery efforts. The results in this
8
9 507 paper not only reflect the importance of incorporating accessibility modelling in early
10
11 508 disaster response, but also provide a platform for discussing health system recovery,
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13 509 mitigation and preparedness.
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33
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35
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37
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39

40 526
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47 528 Data available upon request.
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39 658 [5060f0adb1feb/1588770424043/Leaving+no+one+off+the+map-4.pdf](https://static1.squarespace.com/static/5b4f63e14eddec374f416232/t/5eb2b65ec575060f0adb1feb/1588770424043/Leaving+no+one+off+the+map-4.pdf)
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6 716 **Figure 1 - Cyclone affected districts, cyclone trajectory, and road damages.** (A) Idai affected
7 717 districts. (B) Kenneth affected districts. (C) Idai cyclone trajectory*. (D) Kenneth cyclone
8 718 trajectory*. (E) Road damages in Idai-affected districts. (F) Road damages in Kenneth-
9 719 affected districts.

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11 720 *Cyclone paths as reported on Global Disaster Alert and Coordination System (GDACS)^{25,26}.
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14 722 **Figure 2- Absolute and relative reduction in population coverage pre- and post-cyclone**

15 723 **Idai (A) and Kenneth (B).** Labels on top of bars indicate absolute reduction in population
16 724 coverage of children under 5. Labels under districts indicate relative reduction in population
17 725 coverage. Maximum limits of the bars indicate the absolute pre-cyclone coverage within 2
18 726 hours travel time. Limits of the blue filled bar indicate the absolute post-cyclone coverage.
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20 727 The x-axis is ordered according to relative reduction in population coverage.
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24 729 **Figure 3 – Accessibility modelling results for Idai districts.** Pre-cyclone travel time raster

25 730 (A). Post-cyclone travel time raster (B). Difference ratio raster between pre- and post-
26 731 cyclone travel time (C). Uncertainty raster, as a result of the difference between -20% and
27 732 +20% travel speed accessibility (D).
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30 734 **Figure 4 – Accessibility modelling results Kenneth districts.** Pre-cyclone travel time raster

31 735 (A). Post-cyclone travel time raster (B). Difference ratio raster between pre- and post-
32 736 cyclone travel time (C). Uncertainty raster, as a result of the difference between -20% and
33 737 +20% travel speed accessibility (D).
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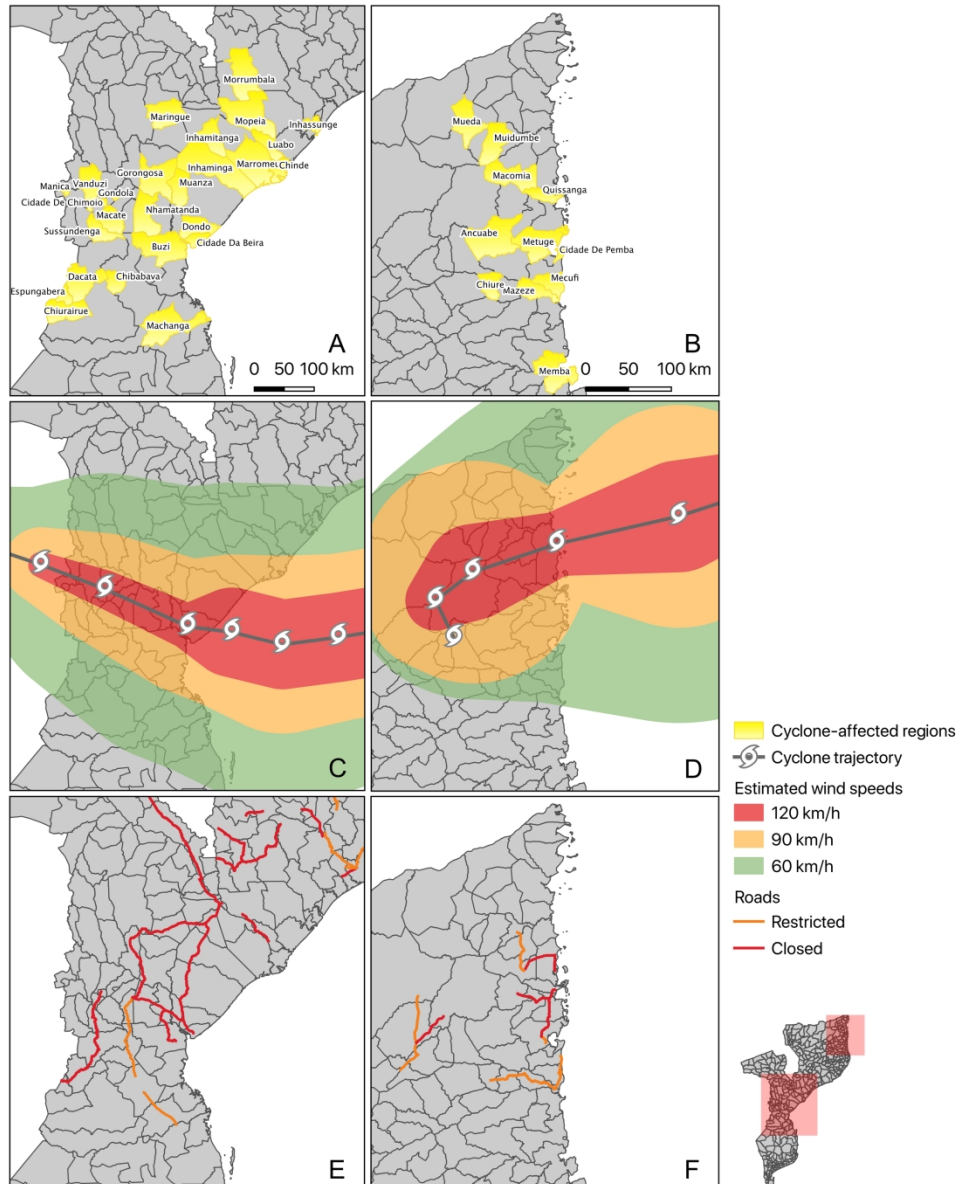


Figure 1 - Cyclone affected districts, cyclone trajectory, and road damages. (A) Idai affected districts. (B) Kenneth affected districts. (C) Idai cyclone trajectory*. (D) Kenneth cyclone trajectory*. (E) Road damages in Idai-affected districts. (F) Road damages in Kenneth-affected districts.

*Cyclone paths as reported on Global Disaster Alert and Coordination System (GDACS) 25,26.

236x292mm (300 x 300 DPI)

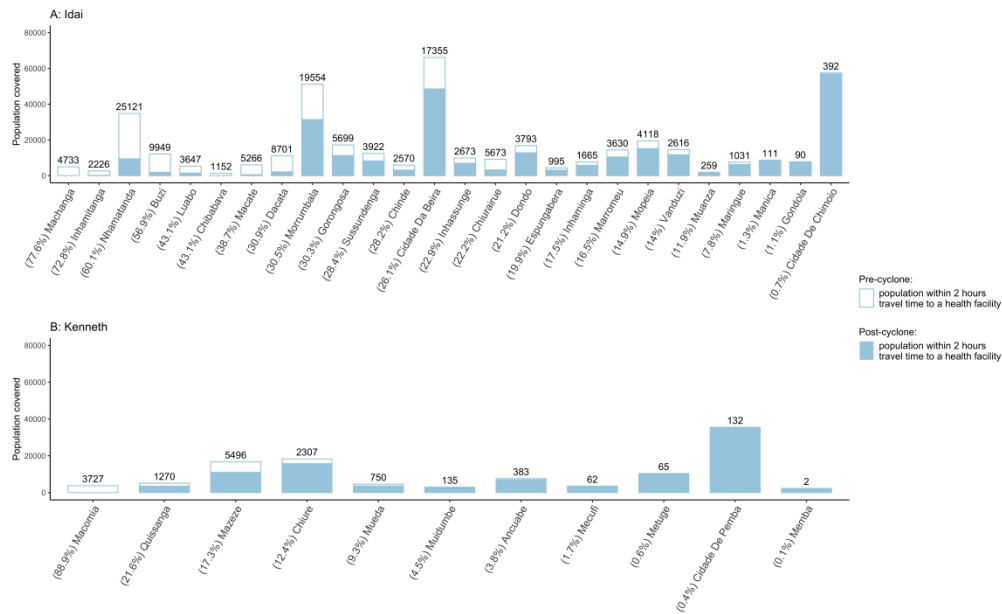
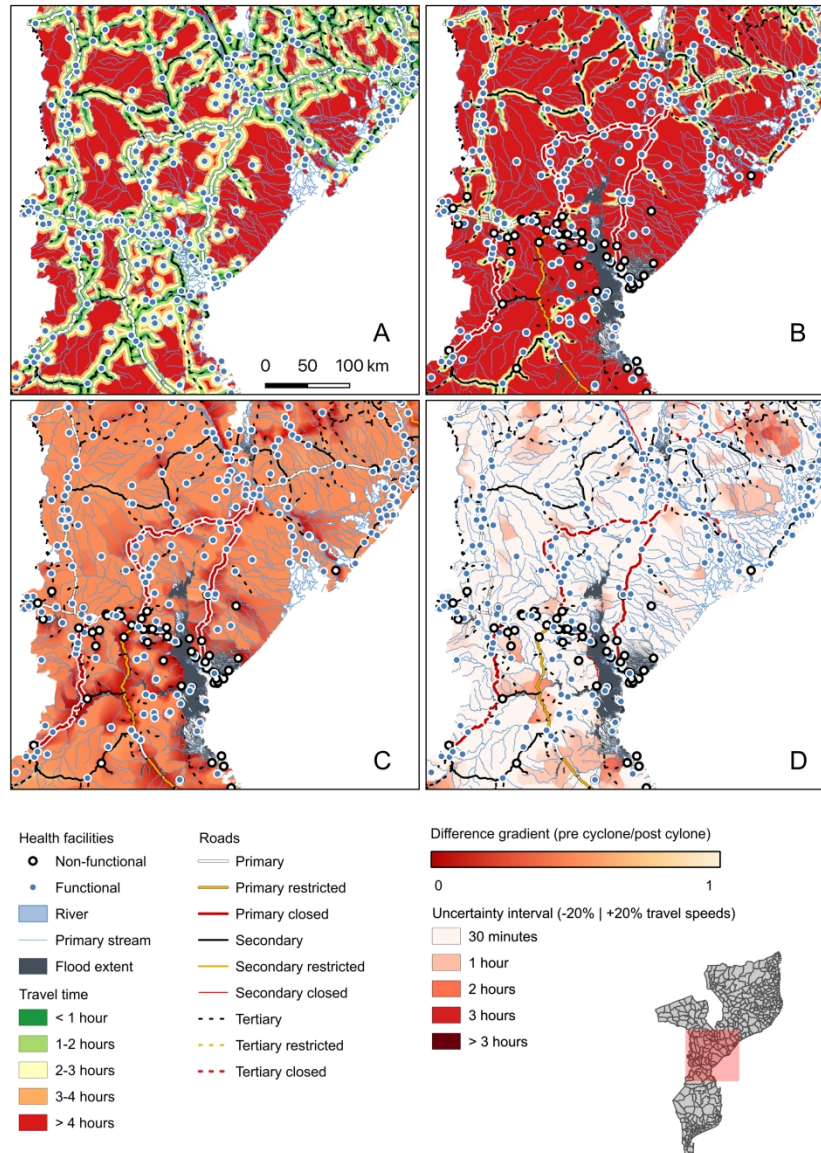


Figure 2- Absolute and relative reduction in population coverage pre- and post-cyclone Idai (A) and Kenneth (B). Labels on top of bars indicate absolute reduction in population coverage of children under 5. Labels under districts indicate relative reduction in population coverage. Maximum limits of the bars indicate the absolute pre-cyclone coverage within 2 hours travel time. Limits of the blue filled bar indicate the absolute post-cyclone coverage. The x-axis is ordered according to relative reduction in population coverage.

2777x1736mm (72 x 72 DPI)



45 Figure 3 – Accessibility modelling results for Idai districts. Pre-cyclone travel time raster (A). Post-cyclone
 46 travel time raster (B). Difference ratio raster between pre- and post-cyclone travel time (C). Uncertainty
 47 raster, as a result of the difference between -20% and +20% travel speed accessibility (D).

48 209x296mm (300 x 300 DPI)

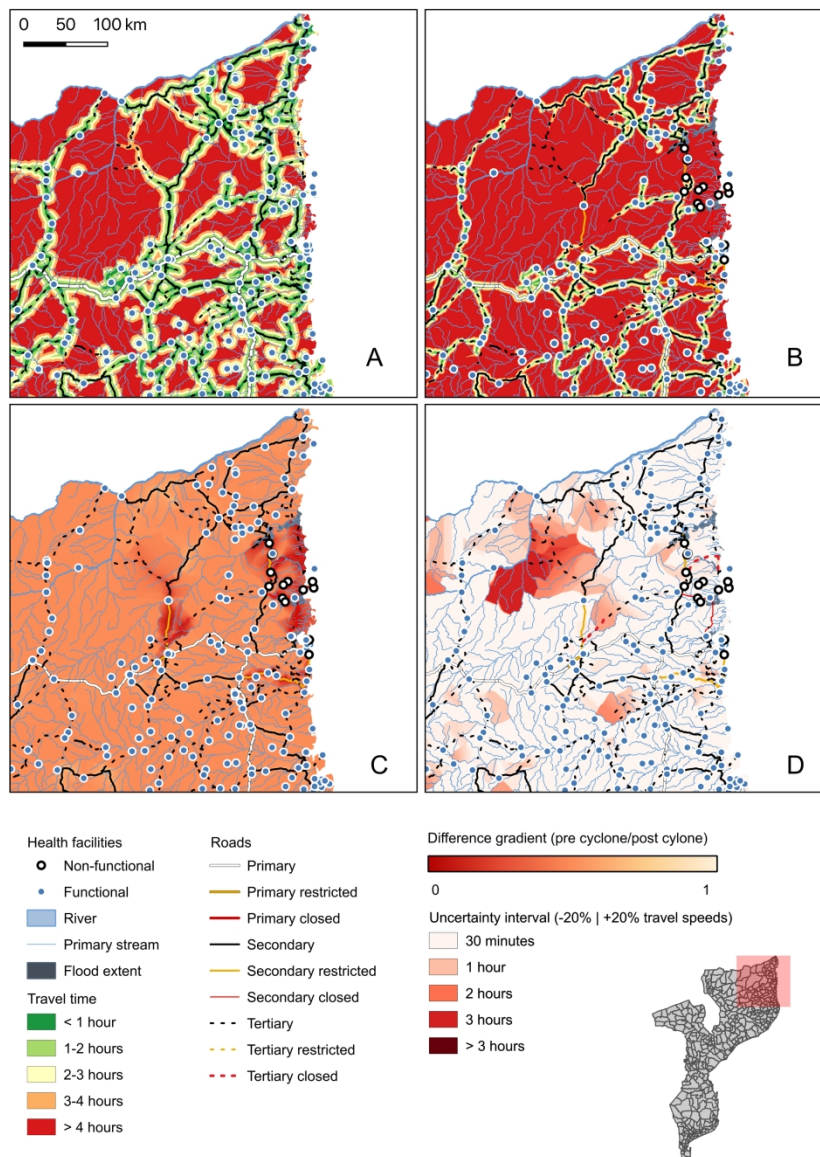


Figure 4 – Accessibility modelling results Kenneth districts. Pre-cyclone travel time raster (A). Post-cyclone travel time raster (B). Difference ratio raster between pre- and post-cyclone travel time (C). Uncertainty raster, as a result of the difference between -20% and +20% travel speed accessibility (D).

209x296mm (300 x 300 DPI)

SUPPLEMENTARY MATERIAL

Supplement 1-Data preparation for use in AccessMod

All data preparation was carried out in Quantum Geographical Information System (QGIS) (version 3.4)²⁴ in limited combination with R (version 3.5.2)²⁵. As indicated in Table 1, most data layers were retrieved from open data platforms. All raster- and shapefiles were saved in the projection system of Mozambique, i.e. UTM-37S [EPSG:32737]. All raster files were aligned using the digital elevation model (DEM) as reference. The data preparation process is fully described below for each data set.

Elevation

Anisotropic accessibility analyses, in other words analyses accounting for travel speeds on slopes, were carried out for this study. Elevation data were obtained from the Shuttle Radar Topography Mission (SRTM) in tiles at a resolution of 30 meters and mosaiced to cover the whole country³⁸. Slopes were derived from it and accounted for when modelling walking movements.

Land cover

The land cover data set of the African continent²⁷ was clipped to the extent of Mozambique, leaving a small buffer around the country to prevent loss of data cells at the border. The data set was resampled at a resolution of 30 meters using nearest neighbor interpolation.

Road network

The pre-cyclone road network dataset was retrieved from Open Street Map (OSM) through the Geonode Platform of the National Institute for Disaster Management Mozambique (INGC), as this dataset was perceived to represent the most recent information on the roads and could be linked to the damaged roads, as indicated by the Logistics Cluster of the World Food Program (LOG-WFP). Road classes that were not indicated as official classification by OSM, were removed from the data⁴⁸.

LOG-WFP provided the most up to date data on road network damages. However, the road constraint shapefile was updated frequently by overwriting previous versions, without

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3 storing data historically. Therefore, historical post-cyclone status of roads and road
4 segments was manually digitized from PDF maps provided by LOG-WFP^{28,29}. The PDF maps
5 were manually cross-referenced with the OSM road network layer, to include post-cyclone
6 status, i.e. 1) open 2) restricted 3) closed.
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12 Roads were then reclassified based on the unique combination of road type and post-
13 cyclone status, resulting in 34 unique road classes (e.g. primary road, primary road
14 restricted, secondary road closed). All roads were given a specific travel speed, accounting
15 for the different scenarios. In the pre-cyclone scenario for instance, all primary road classes
16 (i.e. primary road, primary road restricted, primary road closed) had the same travel speed.
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18 Whereas in the post cyclone scenario, the restricted and closed road types had a travel
19 speed and travel mode accounted for their damages, as can be seen from Supplement 2.
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26 27 *Barriers to movement*

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29 Rivers and lake shapefiles were obtained as lines and polygons from the National
30 Directorate for Water Resource Management (DNGRH) and accuracy was checked using
31 satellite imagery as a reference, using Microsoft Bing Imagery as a background through the
32 QGIS QuickMapServices Plugin. Only primary rivers and lakes were taken for the analyses,
33 under the assumption that smaller rivers and streams were passable by the population.
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35 Water bodies were perceived as being impassable at all scales.
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42 Flood extent caused by Cyclone Idai was taken from 19 March 2019 and flood extent for
43 Cyclone Kenneth was taken from 2 May 2019, because extents were visually inspected and
44 found to be largest on those dates and thus represent the biggest constraints for health care
45 access. All flooded areas were treated as impassable at those dates, considering the depth
46 and extent of the floods.
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51 52 *Population data*

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54 High resolution population density estimates for children under five were downloaded at 30
55 meter resolution from the Facebook Connectivity Lab and Center for International Earth
56 Science Information network³⁰. The raster was projected in Mozambique's projection
57 system, UTM-37S [EPSG:32737], by using nearest neighbor interpolation. Loss of population
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3 caused by reprojection and clipping to country borders, was corrected for by smoothing the
4 lost population equally over the raster cells. This was done by using a multiplication factor
5 of the difference between the total sum of population before and after data processing
6 using the raster calculator.
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10 11 12 *Health facilities*

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14 The geographic coordinates of all health facilities were obtained through the Humanitarian
15 Data Exchange platform (HDX) and were originally sourced from the Ministry of Health in
16 Mozambique (SIS-MA)³⁴. The data was cleaned to exclude coordinates far outside of the
17 country borders. Coordinates that fell just outside Mozambique were relocated within the
18 country extents. Five health facilities were cross-referenced with other data sources (e.g.
19 Neonatal Inventory Survey UNICEF, OpenStreetMap, Google Maps) because they were
20 located on barriers, such as open sea, rivers or lakes.
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29 Information on damaged health facilities was provided by the World Health Organization
30 (WHO). This data did not include GPS coordinates, thus names of the damaged health
31 facilities were cross referenced with the original health facility shapefile to include post-
32 cyclone status of each facility, i.e. functional or non-functional. For damaged health facilities
33 that were not included in the original health facility shapefile, coordinates were retrieved
34 from a neonatal inventory performed by United Nations Children Fund (UNICEF) and also
35 added as facility to the original health facility data, representing the pre-cyclone situation.
36 Non-functional health facilities were filtered-out for geographical accessibility analyses
37 reflecting the post-cyclone scenarios.
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48 *Travel scenario*

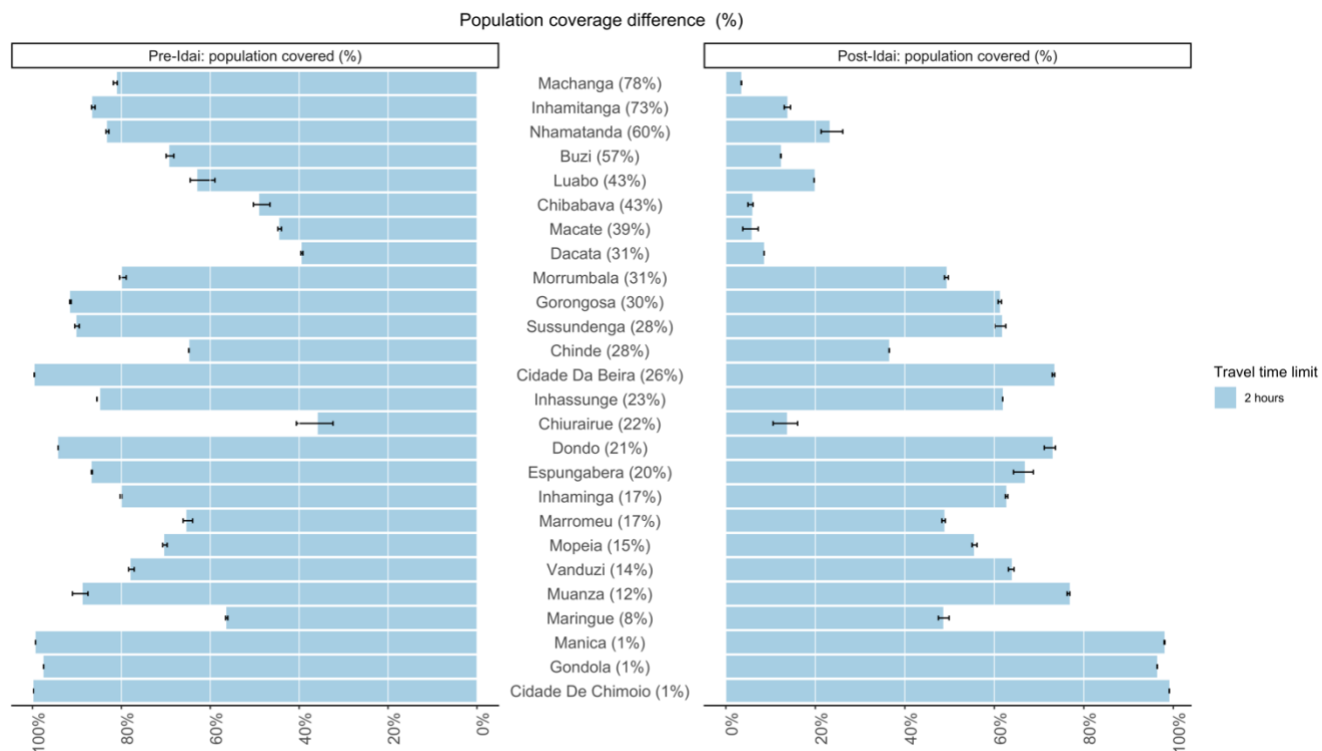
49 Both our travel scenarios were developed in close collaboration with country
50 representatives from UNICEF and were adapted to our target population, namely children
51 under five accompanied by a parent (Supplement 2). Flood waters were assumed to be a full
52 barrier to movement to the target population, thus health facilities located in flooded zones
53 were completely inaccessible and flood waters were impassable.
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Supplement 2- Travel scenarios pre-cyclone and post-cyclone

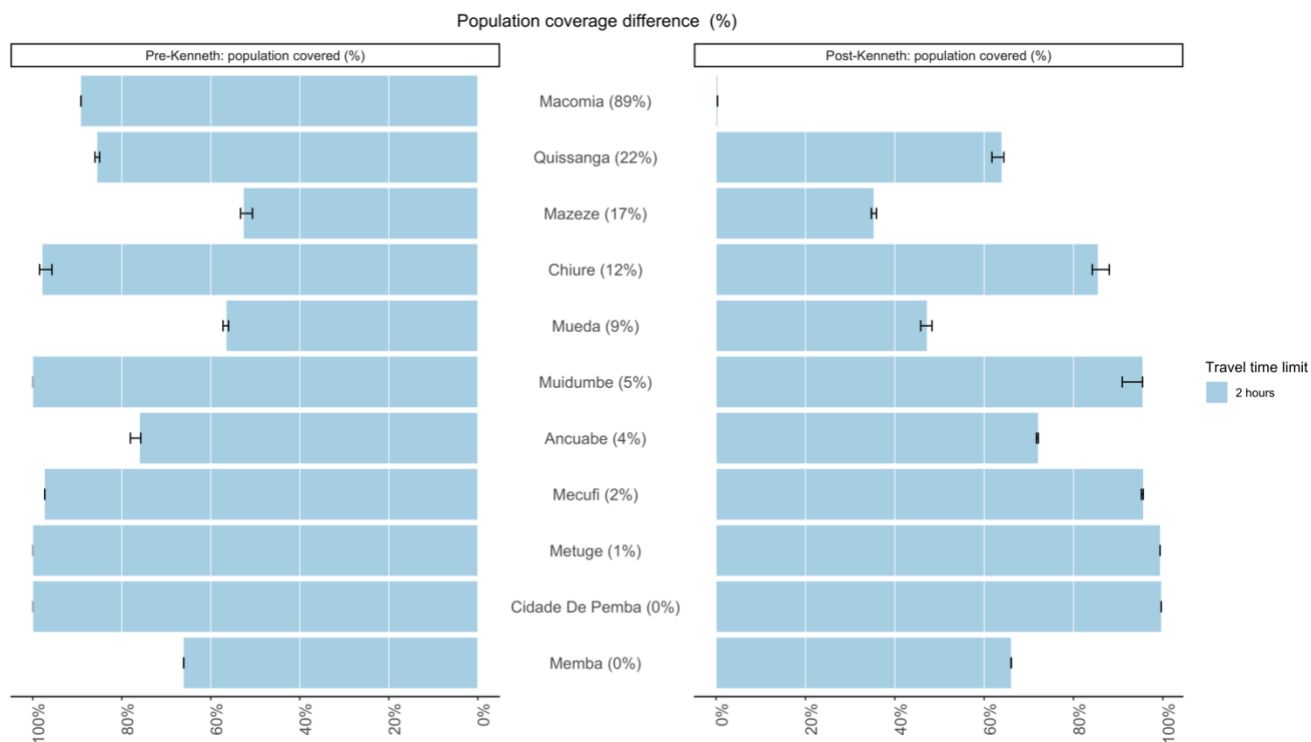
Label	Pre-cyclone		Post-cyclone	
	Travel speed (km/h)	Travel mode	Travel speed (km/h)	Travel mode
Shrubs	3	Walking	1.5	Walking
Herbaceous Vegetation	3	Walking	1.5	Walking
Cultivated and Managed Vegetation	3	Walking	1.5	Walking
Agriculture Cropland				
Urban Built Up	3	Walking	1.5	Walking
Bare Sparse Vegetation	3	Walking	1.5	Walking
Permanent Water Bodies	3	Walking	1.5	Walking
Temporary Water Bodies	3	Walking	1.5	Walking
Herbaceous Wetland	3	Walking	1.5	Walking
Closed Forest Evergreen Broad Leaf	3	Walking	1.5	Walking
Closed Forest Deciduous Broad Leaf	3	Walking	1.5	Walking
Open Forest Evergreen Broad Leaf	3	Walking	1.5	Walking
Open Forest Deciduous Broad Leaf	3	Walking	1.5	Walking
Open Sea	3	Walking	1.5	Walking
Trunk	80	Motorized	50	Motorized
Trunk Restricted	80	Motorized	1.5	Walking
Trunk Closed	80	Motorized	1.5	Walking
Primary	80	Motorized	50	Motorized
Primary Restricted	80	Motorized	1.5	Walking
Primary Closed	80	Motorized	1.5	Walking
Secondary	50	Motorized	40	Motorized
Secondary Restricted	50	Motorized	1.5	Walking
Secondary Closed	50	Motorized	1.5	Walking
Tertiary	30	Motorized	15	Motorized
Tertiary Closed	30	Motorized	1.5	Walking
Tertiary Restricted	30	Motorized	1.5	Walking
Road	20	Motorized	10	Motorized
Raceway	3	Walking	3	Walking
Residential	20	Motorized	10	Motorized
Residential Closed	20	Motorized	1.5	Walking
Living Street	20	Motorized	10	Motorized
Service	3	Walking	1.5	Walking
Track	15	Motorized	10	Motorized
Pedestrian	3	Walking	1.5	Walking
Pier	3	Walking	1.5	Walking
Path Closed	3	Walking	1.5	Walking
Path	3	Walking	1.5	Walking
Footway	3	Walking	1.5	Walking
Bridleway	3	Walking	1.5	Walking
Cycleway	3	Walking	1.5	Walking
Steps	3	Walking	1.5	Walking
Unclassified	3	Walking	1.5	Walking

Supplement 3- Relative population coverage pre- and post-cyclone Idai. Ordered on relative difference. Difference indicated between parentheses. Error bars indicate the coverage uncertainty, considering -20% and +20% travel speeds.



view only

Supplement 4- Relative population coverage pre- and post-cyclone Kenneth. Ordered on relative difference. Difference indicated between parentheses. Error bars indicate the coverage uncertainty, considering -20% and +20% travel speeds.

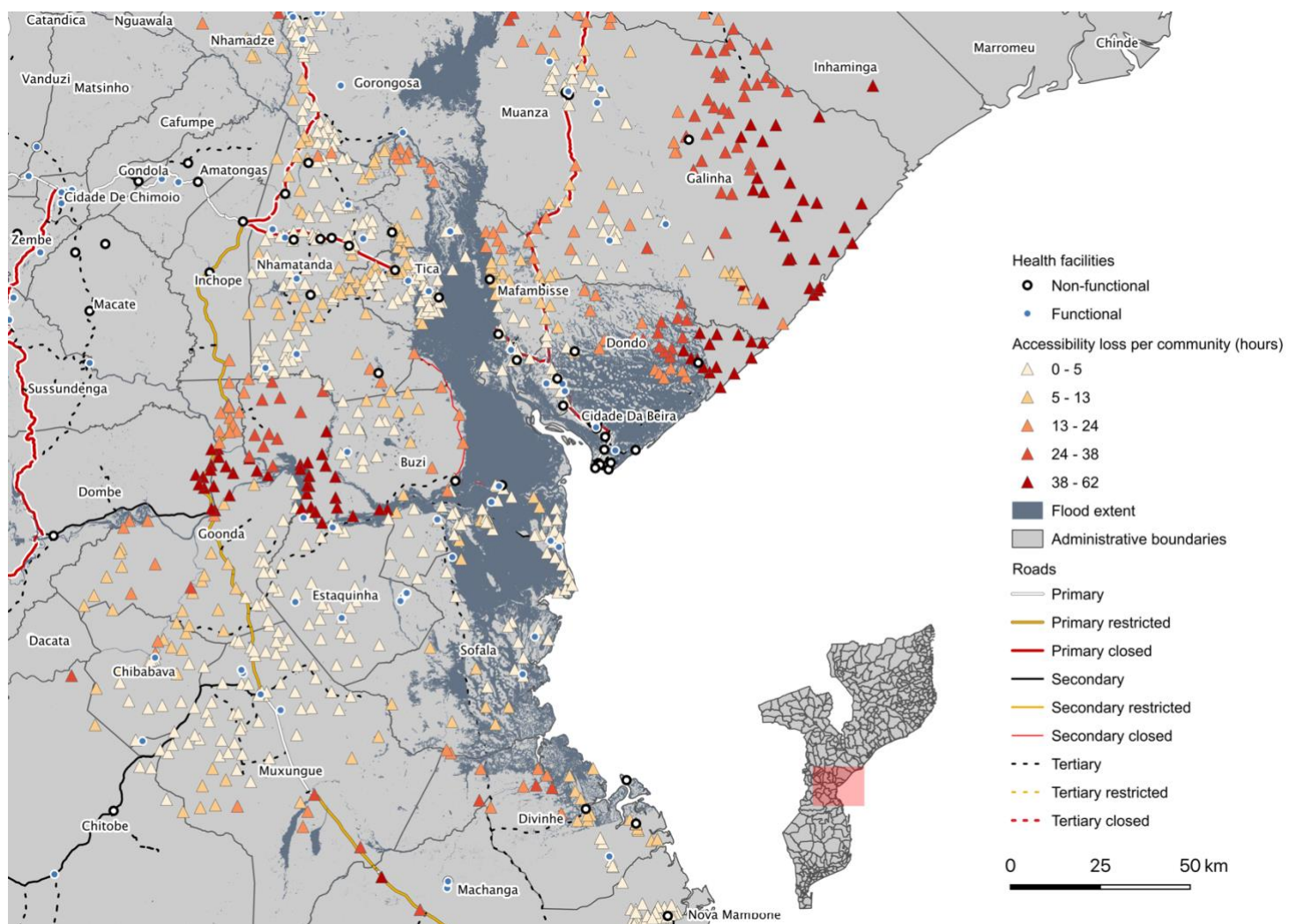


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Supplement 5- Travel time per community in Idai affected districts. Fifty most affected communities by means of accessibility loss. Ordered on absolute travel time difference.

Community	District	Pre-cyclone travel time (h)	Post-cyclone travel time (h)	Difference pre- and post-cyclone (h)
Mucinemo	Buzi	1.3	63.6	62.3
Bupira	Buzi	1.1	62.3	61.3
Massuinda	Buzi	1.2	60.1	58.9
Njanga	Buzi	4.3	59.1	54.7
Guenje-Sede	Buzi	2.9	57.3	54.4
Mbereaizique	Buzi	2.9	57.3	54.4
Shinizia Chinhale	Muanza	24.0	77.8	53.8
Chipota	Muanza	24.4	78.0	53.6
Wiriquizi	Muanza	22.2	74.1	51.9
Chingamuzi	Muanza	22.7	74.5	51.8
Mussacazwidje	Buzi	3.5	55.3	51.8
Mussacazwidje	Buzi	3.5	55.3	51.8
Magua	Buzi	4.8	56.6	51.8
Nkolone Praia	Muanza	20.7	72.3	51.7
Mukulumba 1	Muanza	20.4	71.8	51.4
Mukulumba cidade	Muanza	20.2	71.4	51.2
Nhanganga	Muanza	19.9	70.8	50.9
Mutanda	Buzi	5.4	55.3	49.9
Macova-Mutanda	Buzi	6.3	55.1	48.9
Puanda	Buzi	2.9	51.6	48.7
Luanda 1	Muanza	18.8	67.4	48.6
Nhamacalango	Muanza	17.4	65.8	48.4
Sengo	Dondo	5.3	53.5	48.2
Luanda 2	Muanza	18.0	65.8	47.8
Praia Nova	Dondo	3.9	51.5	47.6
Praia Farol	Dondo	3.8	51.4	47.6
Bingue Sede	Muanza	16.4	63.8	47.4
Nkonde 2	Muanza	16.4	63.8	47.4
Massitche	Dondo	7.1	54.5	47.4
Goonda Majaca	Chibabava	6.5	53.3	46.8
Ngomole	Muanza	10.1	56.7	46.6
Ngalazi	Dondo	6.0	52.3	46.3
Nhacudjica	Buzi	6.3	52.4	46.1
Chitundo	Dondo	2.0	47.7	45.7
Macarate	Chibabava	5.3	51.0	45.7
Nhamissassa	Muanza	15.9	61.5	45.6
Docue	Buzi	5.7	51.3	45.6
Khome 1	Dondo	1.4	46.8	45.4
Nherere 2	Muanza	14.0	59.0	45.0
Parange	Buzi	3.6	48.6	45.0
Njocho	Buzi	5.9	50.9	45.0
Binda	Machanga	0.7	45.2	44.6
Khome 2	Dondo	0.6	45.2	44.6
Veruca	Chibabava	4.1	48.6	44.5
Mamunge	Buzi	5.1	49.2	44.1
Birirane	Muanza	13.1	57.2	44.1
Vala-vala	Buzi	5.2	49.2	44.1
Muche	Gorongosa	1.5	45.5	44.0
Machiquire	Buzi	2.6	46.1	43.5
Nhazwicasse	Gorongosa	1.0	44.5	43.5

Supplement 6- Travel time per community in Idai affected districts. Point locations of communities in Idai affected districts.



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Modelling geographical accessibility to support disaster response and rehabilitation of a health care system: An impact analysis of Cyclones Idai and Kenneth in Mozambique

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Modelling geographical accessibility to support disaster response and rehabilitation of a health care system:

An impact analysis of Cyclones Idai and Kenneth in Mozambique

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International health services, organization of health services, geographical mapping, risk management

1 **ABSTRACT**

2 **Objectives**

3 Modelling and assessing the loss of geographical accessibility is key to support disaster
4 response and rehabilitation of the health care system. The aim of this study was therefore
5 to estimate post-disaster travel times to functional health facilities and analyze losses in
6 accessibility coverage after Cyclones Idai and Kenneth in Mozambique in 2019.

7 **Setting**

8 We modeled travel time of vulnerable population to the nearest functional health facility in
9 two cyclone-affected regions in Mozambique. Modelling was done using AccessMod version
10 5.6.30, where roads, rivers, lakes, flood extent, topography, and land cover datasets were
11 overlaid with health facility coordinates and high-resolution population data to obtain
12 accessibility coverage estimates under different travel scenarios.

13 **Outcome measures**

14 Travel time to functional health facilities and accessibility coverage estimates were used to
15 identify spatial differences between pre-disaster and post-disaster geographical
16 accessibility.

17 **Results**

18 We found that accessibility coverage decreased in the flood affected districts, as a result of
19 reduced travel speeds, road constraints and non-functional health facilities. In Idai-affected
20 districts, accessibility coverage decreased from 78.8% to 52.5%, implying that 136,941
21 children under 5 were no longer able to reach the nearest facility within 2 hours travel time.
22 In Kenneth-affected districts, accessibility coverage decreased from 82.2% to 71.5%,
23 corresponding to 14,330 children under 5 having to travel more than 2 hours to reach the
24 nearest facility. Damage to transport networks and reduced travel speeds resulted in the
25 most substantial accessibility coverage losses in both Idai and Kenneth-affected districts.

29 **Conclusions**

30 Post-disaster accessibility modelling can increase our understanding of spatial differences in
31 geographic access to care in the direct aftermath of a disaster and can inform targeting and
32 prioritization of limited resources. Our results reflect opportunities for integrating
33 accessibility modelling in early disaster response, and to inform discussions on health
34 system recovery, mitigation and preparedness.

36 **STRENGTHS AND LIMITATIONS OF THIS STUDY**

- 38 • This is the first study presenting the applicability of post-disaster geographical
39 accessibility modelling.
- 40 • The approach enables quantification of disaster impacts on geographical health care
41 accessibility to prioritize post-disaster interventions and to build resilience for future
42 disasters.
- 43 • To account for uncertainty of the assumed travel speeds, we considered -20% and
44 +20% intervals on motorized travel speeds.
- 45 • Data from various sources and administrative levels were combined to represent the
46 post-cyclone situation as realistically as possible, but since data gathering was
47 ongoing, it was expected that some data were incomplete or not fully processed at
48 the time of usage.
- 49 • Our accessibility modelling assumes that patients always travel to the nearest health
50 facility. However, literature has shown that patients sometimes bypass health
51 facilities in search of higher-quality care in Mozambique.

1. INTRODUCTION

Geographical proximity to health facilities is a crucial aspect of accessibility, utilization and the provision of health services to populations in need¹. Road networks and natural barriers (such as rivers, water bodies, and flooded areas) are important factors that determine the geographical (i.e. physical) accessibility of a population to the network of functional health facilities. During natural disasters, roads and health facilities are often damaged, yet health care demand rises substantially at the same time due to injuries and increased communicable disease risks^{2,3}. The interplay between the disruption of health infrastructure, transport network, and the rise in health care demand, is known to disable a large portion of the population's access to care they need in the aftermath of a disaster^{3,4}. This is especially the case in already medically underserved regions, where the event can lead to new health disparities or exacerbate existing ones².

In March and April 2019, two cyclones made landfall in Mozambique. This was the first time in history that two strong cyclones hit Mozambique consecutively in the same season⁵. On 14 March 2019, Tropical Cyclone Idai made landfall in Beira. Followed by a week of heavy rains and winds the storm ended on 21 March 2019⁶. In the middle of the humanitarian emergency response for Cyclone Idai, a second cyclone hit Northern Mozambique. Cyclone Kenneth, a category 4 cyclone and the strongest recorded cyclone on the African continent, made landfall in Pemba, Cabo Delgado on 25 April 2019^{7,8}. The two cyclones combined had a death toll of 648, with 603 fatalities due to Idai and 45 deaths caused by Kenneth, and left over 2.2 million people in need of humanitarian assistance⁵. The cyclone's destruction isolated entire communities for weeks due to flood waters, destroyed telecommunication networks, and extensive road damage^{9,10}. In addition, stagnant waters, inability in accessing safe water and sanitation, and overcrowding in temporary accommodation led to a cholera outbreak and a significant increase in malaria cases^{5,8,11,12}. Major damage to 113 health facilities were reported after both cyclones, causing severe disruption in health service provision and restricting the population's access to adequate health care^{13,14}. Although many humanitarian actors have estimated substantial losses in health care accessibility and availability^{5,9,10,13,15}, the quantitative impact of Cyclone Idai and Kenneth on geographical accessibility to health care remains unknown. Modelling geographical accessibility and population coverage by means of travel time to health facilities, can give important insights

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3 84 for targeting humanitarian action and preparing for future disasters in a coordinated
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5 85 manner¹⁶.
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9 87 Currently, quantitative post-disaster accessibility assessments are not a part of standardized
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11 88 response guidelines, preventing coordinated and centralized decision making on temporary
12
13 89 facility location to serve beneficiaries in the most optimal way¹⁶. Guidelines for a post-
14
15 90 disaster needs assessment from the World Health Organization (WHO)¹⁷, advise on a
16
17 91 comparison between baseline and post-disaster accessibility through the evaluation of key
18
19 92 indicators. However, the suggested key indicators reflect rather static measures of
20
21 93 accessibility, such as hospital beds per 10,000 population or number of damaged health
22
23 94 facilities¹⁷.
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27 96 Yet, international efforts to support humanitarian responses on the ground accelerate post-
28
29 97 disaster data gathering, enabling a more realistic quantification of accessibility to health
30
31 98 care by means of health facility damages, loss of road access, and barriers to movement
32
33 99 such as flood waters¹⁸. Guidance on assessing loss in geographical accessibility while
34
35 100 considering spatial barriers remains abstract or even lacking in disaster management
36
37 101 frameworks. Meanwhile, geographical accessibility models hold actionable information and
38
39 102 have the potential to quantify gaps and overlaps in (temporary) service provisioning,
40
41 103 enabling coordinated, targeted and centralized decision making for humanitarian action¹⁶,
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43 104 enhancing both financial and operational efficiency^{19,20}.
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46
47 106 This study therefore presents a data processing and spatial accessibility modelling method
48
49 107 to assess post-disaster accessibility to health facilities and analyze accessibility coverage
50
51 108 losses as a result of cyclones Idai and Kenneth in Mozambique. The approach enables
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53 109 quantification of disaster impacts on geographical health care accessibility to prioritize post-
54
55 110 disaster interventions and to build resilience for future disasters. This is the first study
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57 111 presenting the applicability of post-disaster geographical accessibility modelling.
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112 2. METHODS

113 2.1 Overall methodology

114 In this study, *accessibility* is measured as the travel time to health facilities and *accessibility*
 115 *coverage* (i.e. coverage) is defined as the estimated number or percentage of people
 116 covered or located within a travel time catchment area²¹. To model accessibility to health
 117 facilities, we consider topography, road networks, constraints to movement (e.g. rivers,
 118 lakes and flood extent), target population distribution, and the locations of functional health
 119 facilities. We accessed and prepared multiple data layers (Table 1) assembled in the
 120 aftermath of Cyclones Idai and Kenneth, between April-September 2019. A total of three
 121 scenarios were prepared, representing 1) pre-Idai and pre-Kenneth (before March 2019), 2)
 122 post-Idai (up to one-week post-cyclone), and 3) post-Kenneth (up to one-week post-cyclone)
 123 situations. We modeled population travel time to the nearest health facility and accessibility
 124 coverage, for two cyclone-affected regions.

125

126 **Table 1** – Overview of data layers and data sources

Layer name	Source ^a	Source date ^b	Download date	Type	Original resolution
Administrative boundaries	INE & UN-OCHA ROSEA (HDX) ²²	02.04.19	31.07.19	Polygon	-
Cyclone trajectory (Idai/Kenneth)	GDACS ^{23,24}	15.03.19/25.04.19	08.03.2020	Polygon	-
Land cover	Copernicus ²⁵	15.11.18	31.07.19	Raster	100 meters
Elevation	SRTM CGIAR ²⁶	25.11.18	20.09.19	Raster	30 meters
Rivers and lakes	DNGRH	12.8.19	19.9.19	Polygon	-
Primary streams	DNGRH	12.8.19	19.9.19	Lines	-
Flood extent, Idai	UNOSAT/ Sentinel-1 (HDX) ²⁷	19.03.19	31.07.19	Polygon	-
Flood extent, Kenneth	Copernicus EMSR354 (INGC Geonode) ²⁸	02.05.19	31.07.19	Polygon	-
Roads	OpenStreetMap (INGC Geonode) ²⁹	25.11.18	07.08.19	Lines	-
Road damages (Idai/Kenneth)	LOG-WFP ^{30,31}	19.03.19/03.05.19	23.09.19	PDF file	-
Health facilities	SIS-MA (HDX) ³²	31.12.17	08.08.19	Points	-
Health facilities damages	Provided by WHO-Mozambique	Represents health facility status 48h until 1 week post-cyclone	17.09.19	Points	-
Population density	Facebook/CIESIN population density ³³	01.10.18	06.08.19	Raster	30 meters

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2
3 127 ^a Abbreviations: CIESN = Center for International Earth Science Information Network, DNGRH = National Directorate for
4 128 Water Resource Management, HDX = Humanitarian Data Exchange, GDACS = Global Disaster Alert and Coordination
5 129 System, INE = National Institute for Statistics Mozambique, INGC = National Institute for Disaster Management
6 130 Mozambique, SIS-MA = Ministry of Health Mozambique, SRTM = Shuttle Radar Topography Mission, UN-OCHA ROSEA =
7 131 United Nations Office for the Coordination of Humanitarian Affairs Southern and Eastern Africa, UNOSAT = United Nations
8 132 Operational Satellite Applications Program, LOG-WFP = Logistics Cluster World Food Program

9 133 ^b Source date represents the imagery acquisition date for the flood extents and the release date for all other data
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15 135 **2.2 Data sources and preparation**

16
17 136 The projection, resolution and alignment of geospatial data was processed using Quantum
18 137 Geographical Information System (QGIS) (version 3.4)³⁴ and, to a limited extent, R (version
19 138 3.5.2)³⁵. As indicated in Table 1, most data layers were retrieved from open data platforms.
20
21 139 All rasters and shapefiles were saved in the projection system of Mozambique, i.e. UTM-37S
22 140 [EPSG:32737]. The data preparation process is briefly described below and is fully detailed
23 141 in Supplement 1.
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30 143 Elevation data were obtained from the Shuttle Radar Topography Mission (SRTM) in tiles at
31 144 a resolution of 30 meters and mosaiced to cover the whole country³⁶. Slopes were derived
32 145 from it and were accounted for when modelling walking movements.
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36 146
37 147 Land cover data was downloaded for the whole African continent at 100 meter resolution
38 148 from Copernicus Global Land Service²⁵ and was clipped to the extent of Mozambique. As
39 149 analyses were carried out at 30-meter resolution, the land cover raster was resampled at a
40 150 resolution of 30 meters, using nearest neighbor interpolation.
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45 151
46 152 The pre-cyclone road network dataset was retrieved from Open Street Map (OSM) through
47 153 the Geonode Platform of the National Institute for Disaster Management Mozambique
48 154 (INGC), and linked to the road damage information as indicated by the Logistics Cluster of
49 155 the World Food Program (LOG-WFP)^{37,38}. Historical post-cyclone status of roads and road
50 156 segments were manually digitized from PDF maps provided by LOG-WFP. The maps were
51 157 cross-referenced with the OSM road network layer, to include post-cyclone road damage
52 158 status, (i.e. 1) open, 2) restricted, and 3) closed). Road damages as a consequence of
53 159 cyclones Idai and Kenneth were taken from maps dated March 19 and May 3, 2019,
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3 160 respectively (Table 1)^{37,38}. Information on road type and damage were combined in order to
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5 161 obtain unique road type-damage combinations (Supplement 2).
6

7 162

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9 163 Information on rivers and lake layout were obtained as shapefiles from the National
10
11 164 Directorate for Water Resource Management (DNGRH). Only primary rivers and lakes were
12
13 165 considered as barriers to movement, under the informed assumption that smaller rivers and
14
15 166 streams were passable by the population. This assumption was checked for several
16
17 167 instances against background satellite imagery. Flood extents for Idai (on 19 March 2019)
18
19 168 and Kenneth (on 2 May 2019) were sourced as shapefiles from Sentinel-1 and Copernicus
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21 169 EMSR354, respectively^{27,28}. The flood extents were visually inspected and found to be
22
23 170 largest on those two dates, and thus represent the biggest constraints for health care
24
25 171 access. All flooded areas were treated under two scenarios: 1) as being impassable, under
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27 172 the assumption that people avoid traversing flood water to prevent further injury, 2) as
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29 173 being passable by foot at an average walking speed of 1.5 km/h. In the first scenario, health
30
31 174 facilities located on flood extents were always treated as inaccessible since they are located
32
33 175 on barriers.

32 176

34 177 While cyclones impact entire populations, the burden disproportionately affects children
35
36 178 and women³⁹. It is estimated that for cyclones Idai and Kenneth more than 50% of the
37
38 179 affected population were children, and with flood waters rising above 6 meters, their
39
40 180 movements to safety and health care were particularly limited⁵. Moreover, children under 5
41
42 181 represent the age group used as benchmark for child survival targets in both the Millennium
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44 182 Development Goals (MDGs) and the Sustainable Development Goals (SDGs)⁴⁰. In this
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46 183 context and through the collaborative work with UNICEF, this analysis aimed at informing
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48 184 the impact of the disasters on the burden for specific child health services that target
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50 185 children under 5 (e.g. immunization).

51 186

52
53 187 High-resolution population density estimates for children under five were obtained from the
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55 188 Facebook Connectivity Lab and Center for International Earth Science Information Network
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57 189 (CIESN)³³ with a 30-meter resolution. Although several gridded populations datasets are
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59 190 available, the Facebook CIESN dataset was assumed to have the most realistic reallocation
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191 of population to settlements⁴¹. In addition, other frequently used high-resolution gridded

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3 192 population datasets, such as WorldPop⁴², use distances from roads and villages as
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5 193 covariates, and this can produce collinearity when used in conjunction with accessibility
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7 194 models. Population density was used to run zonal statistics on the cyclone-affected districts.
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9 195 In this step the total population per district is summed and the estimated absolute number
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11 196 of children under 5 that are able to reach a facility in a pre-defined travel time catchment
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13 197 are calculated.

14 198

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16 199 Additionally, geographic coordinates of all villages (i.e. communities) in Idai-affected
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18 200 districts were obtained from UNICEF Mozambique, which had gathered this information
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20 201 through a community mapping initiative conducted by health officials, 6 to 8 months before
21
22 202 Cyclone Idai made landfall. These community locations were used to extract pre- and post-
23
24 203 cyclone travel time for each community to the nearest functional health center.
25
26 204 Unfortunately, geographic coordinates of villages in Kenneth-affected districts were not
27
28 205 available at the time of study.

29 206

30
31 207 The geographic coordinates of all health facilities were sourced from the health
32
33 208 management information system, Ministry of Health in Mozambique (SIS-MA)³². Data
34
35 209 cleaning was undertaken in cases where the geographic coordinates for health facilities
36
37 210 were located outside the international border of Mozambique or for coordinates falling on
38
39 211 barriers to movement (Supplement 1). Information on damaged health facilities was
40
41 212 provided in tabular format by the World Health Organization (WHO). The health system in
42
43 213 Mozambique comprises 4 levels; the primary level consists of urban and rural health
44
45 214 centers, the secondary level consists of general, rural and district hospitals, the tertiary level
46
47 215 comprises provincial capital hospitals, and quaternary facilities comprise the central and
48
49 216 specialized hospitals⁴³. Health facilities of all levels were included in the model.

50 217

51 218 Districts that were most affected by Cyclones Idai and Kenneth ("cyclone-affected districts",
52
53 219 thereafter) were identified in close collaboration with UNICEF and humanitarian responders.
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55 220 All statistics presented below were calculated for these identified districts, with 26 such
56
57 221 districts in the Idai-affected region and 11 districts in the Kenneth-affected region (Figures
58
59 222 1a & 1b). Storm trajectories of both cyclones and road damages in both districts are also
60
223 presented (Figure 1c-1f).

224

225 **2.3 Geographical accessibility modelling**

226 To model travel times and accessibility coverages, we used AccessMod 5 (version 5.6.30), in
227 particular the “accessibility” and “zonal statistics” modules^{21,44}. AccessMod models
228 geographical accessibility using terrain-based least-cost path distance calculation. This open-
229 source software has been successfully applied in many different settings, among which
230 accessibility and referral assessments of health facility networks, optimization modelling of
231 health programs in obstetric and neonatal care (EmONC)⁴⁵, primary health care⁴⁶,
232 emergency care⁴⁷, referral times⁴⁸, and treatment of fever cases⁴⁹.

233

234 Using the “merge land cover” module in AccessMod, we overlaid the roads, rivers, lakes,
235 flood extent, and landcover datasets to obtain a single 30-m resolution raster dataset, to
236 which different travel scenarios were applied.

237

238 The travel scenarios (presented in Supplement 2) were derived using local information as
239 model inputs on pre-cyclone and post-cyclone travel speeds and travel modes. Both
240 scenarios were developed in close collaboration with UNICEF Mozambique, with focus on
241 geographical accessibility to functional health facilities for the target population of children
242 under 5. Post-cyclone travel speeds were adjusted for wet weather conditions as heavy
243 rains persisted in the direct aftermath of both cyclones. During the post-cyclone situation,
244 restricted and closed roads that were not inundated were assumed to be unpassable by any
245 vehicle; but they were perceived to be accessible by foot. All landcover classes outside of
246 the road network and the barriers were considered as passable. We assumed a functional
247 bridge where a road segment crossed a river.

248

249 To account for uncertainty of the assumed travel speeds, we also considered both pre- and
250 post-cyclone motorized travel speeds with a 20% slower and 20% faster speed, as adapted
251 from Ouma et al.⁴⁷. Accessibility coverage of the network of health centers was calculated at
252 the 2-hour maximum travel time limit. This limit was deemed appropriate to capture the
253 extent of effective access, and is often used in health accessibility studies, notably in
254 maternal health⁴⁵.

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FIGURE 1

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2.4 Patients and the public involvement

258
259 There was no patient or public involvement in this study. Health facility functionality status
260 was shared in tabular format by WHO. All other geospatial data were publicly available.

261

3. RESULTS

262
263 All statistics mentioned in the results are estimates of children covered by functional health
264 facilities based on our accessibility model.

265

3.1 Pre-cyclone accessibility

266
267 Pre-cyclone coverage in Idai-affected districts (Figure 2a) was highest in Cidade De Chimoio
268 and Cidade Da Beira, with 99.8% and 99.5% of all children under 5 covered within the 2 hour
269 catchment limit, respectively (Supplement 3). However, this coverage ranged from 35.8-
270 99.8% in all Idai-affected districts (Supplement 3). Absolute pre-cyclone coverage was also
271 highest in Cidade De Chimoio and Cidade Da Beira, where 57,476, and 66,135 children were
272 within 2 hours travel time from a health facility (Figure 2). In Kenneth-affected districts
273 (Figure 2b), pre-cyclone coverage was highest in Cidade De Pemba, where 100% of the
274 children under 5 were expected to be able to reach a health facility within 2 hours travel
275 time (Supplement 4). The lowest pre-cyclone coverage was seen in Mazeze, where only
276 52.6% of children under 5 were within 2 hours travel time from a health facility (Supplement
277 4). Absolute pre-cyclone coverage in Kenneth-affected districts was highest in Cidade De
278 Pemba (n = 35,467 children) and Chiure (n= 18,257 children) (Figure 2). Pre-cyclone travel
279 time rasters for the cyclone-affected areas were mapped (Figure 3A & Figure 4A).

280

281

FIGURE 2

282

283

3.2 Losses in accessibility coverage

284
285 Geographical accessibility to health care decreased in the cyclone-affected districts, as a
286 result of reduced travel speeds, road constraints and non-functional health facilities (Figure

287 3B and Figure 4B). Ratios of pre-cyclone and post-cyclone travel time rasters are mapped for
 288 Idai-affected districts, with ratios close to 1 indicating similar travel times pre- and post-
 289 cyclone, and ratios closer to 0 indicating large pre- and post-cyclone accessibility differences
 290 (Figure 3C). The same results for Kenneth-affected districts are presented (Figure 4C).
 291 Regions shown in red indicate localities with relatively large differences between pre- and
 292 post-cyclone travel times (Figure 3C). In the Idai-affected region, especially in the districts
 293 surrounding the flood water and closed roads, accessibility is severely impacted. In Idai-
 294 affected districts, the percentage of children under 5 covered within 2 hours travel time,
 295 generally decreased from 78.8% to 52.5%, implying that 136,941 previously-covered
 296 children under 5, lost timely access to health care (Table 2).

297
 298 **Table 2-** Overview of pre- and post-cyclone accessibility coverage in Idai and Kenneth-
 299 affected districts.

Cyclone	Travel time	Pre-cyclone		Post-cyclone			
		Children <5 covered (nr.)	Children <5 covered (%)	Children <5 covered (nr.)	Children <5 covered (%)	Children <5 coverage loss (nr.)	Children <5 coverage loss (%)
Idai	30 minutes	298,432	57.3	153,842	29.5	144,591	27.7
	1 hour	346,409	66.5	206,610	39.6	139,799	26.8
	2 hours	410,696	78.8	273,755	52.5	136,941	26.3
Kenneth	30 minutes	131,120	72.0	63,953	48.8	304,15	23.2
	1 hour	99,056	73.8	86,997	64.8	12,060	9.0
	2 hours	110,348	82.2	96,019	71.5	14,330	10.7

300
 301 The largest relative accessibility coverage decline, within 2 hours travel time, was observed
 302 in Machanga, where 77.6% of the previously covered population was no longer able to
 303 access a facility under 2 hours in the aftermath of Idai (Figure 2). In terms of absolute
 304 coverage, Nhamatanda was the most affected district, with a coverage loss of 25,121
 305 children under 5, followed by Morrumbala (n = 19,554 children), Cidade Da Beira (n =
 306 17,355 children), and Buzi (n= 9,949 children) (Figure 2). Uncertainty modelling, by
 307 accounting for 20% slower and 20% faster motorized travel speeds⁴⁷, indicated localities
 308 with travel time differences up to 3-hours comparing slower and faster travel speeds (Figure
 309 3D & Figure 4D). This information indicates where our travel time assumptions have the
 310 largest effect on accessibility and coverage losses and where this may be either under- or
 311 overestimated which can help guide resource allocation for decreasing this uncertainty.

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5 313 Relative accessibility coverage in all Kenneth-affected districts decreased from 82.2% to
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7 314 71.5%, corresponding to 14,330 children having lost access to the nearest facility within 2
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9 315 hours travel time (Table 2). The most affected district in terms of relative coverage loss was
10
11 316 Macomia, where 88.9% of the children that were covered pre-cyclone lost access
12
13 317 (Supplement 3 & 4). Mazeze was the most affected district in terms of absolute coverage
14
15 318 loss, as 5,496 children lost access in the aftermath of cyclone Kenneth, followed by
16
17 319 Macomia (n= 3,727 children), Chiure (n= 2,307 children), Quissanga (n= 1,270 children) and
18
19 320 Mueda (n= 750 children) (Figure 2).

20 321
21 322 Since flood waters slowly receded in the days/weeks after the cyclones, we ran an
22
23 323 additional scenario where flood waters were passable at a 1.5km/h walking speed.
24
25 324 Considering this scenario, absolute coverage losses for Idai-affected districts within 2 hours
26
27 325 travel time were highest in Morrumbala (n= 29,566 children), Nhamatanda (n= 25,758
28
29 326 children), Dacata (n= 8,914 children), and Bùzi (n= 8,757 children). In Kenneth-affected
30
31 327 districts, Mazeze (n= 6,167 children), Chiure (n= 4,684 children) and Macomia (n= 3,727
32
33 328 children) had the highest coverage losses in 2 hour catchments under the passable scenario.

34 329

35 330 **3.3 Travel time in affected communities**

36 331 The most affected villages in Idai-affected districts, in terms of reduced accessibility to the
37
38 332 nearest health facility were communities located in Bùzi and Muanza districts in Sofala
39
40 333 province. Mucinemo in Bùzi district was found to have a pre-cyclone travel time of 1.3 hours
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42 334 to the nearest health facility. However, this travel time upsurged to 63.6 hours in the direct
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44 335 aftermath of cyclone Idai (Supplements 5 & 6). Generally, the 6 most affected communities
45
46 336 in terms of accessibility in Idai-affected districts all had a pre-cyclone travel time between 1
47
48 337 hour and 3 hours, while all post-cyclone travel times increased to over 55 hours
49
50 338 (Supplement 6). Overall, post-cyclone accessibility ranged from some minutes up to 78
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52 339 hours, with the highest travel time found in Chipota, in Muanza district.

53 340

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FIGURE 3 & 4

344 **3.4 Health facility closures**

345 The effects of non-functioning health facilities were isolated by comparing two separate
346 scenarios; 1) a post-cyclone scenario where all health facilities were considered functional,
347 and 2) a post-cyclone scenario where modified functionality status was considered. By
348 comparing these pre-cyclone and post-cyclone scenarios, the coverage losses caused by the
349 transportation-specific disruptions (i.e. adjusted travel speeds and road constraints) could
350 be isolated from the reduction in coverage due to the damage to health facilities (i.e. non-
351 functional health facilities), providing a way to assess the likely impact of future programs
352 aimed at reinforcing health facilities for disasters. In order to make these comparisons in
353 this specific example, both scenarios were run under the assumption that flood waters were
354 fully passable. In all other instances throughout the paper, flood waters were considered
355 impassable. In case all health facilities remained functional in Idai-affected districts (i.e.
356 disruption was due to transportation only), the overall coverage within 2 hours travel time
357 would decrease from 79.3% to 57.7%, a difference of 21.6% (n = 112,538 children). Damage
358 to health facilities caused an additional coverage decline of 5.3% (n = 27,840 children) in
359 Idai-affected districts. However, hospital closures did not evenly affect all districts. In 17 out
360 of 26 Idai-affected districts, hospital closures had no additional effect on accessibility.
361 However, in the remaining 9 Idai-affected districts, hospital closures were responsible for an
362 additional 1.9-59.7% coverage loss within 2 hours catchment. Health facility closures in
363 Machanga affected the relative coverage the most, with 59.7% coverage loss (n= 3,642
364 children) caused by non-functionality of 3 out of 6 health facilities. Absolute coverage losses
365 as an effect of non-functional health facilities, were highest in Nhamatanda, where 12,946
366 (31.0%) children under 5 years old lost access due to health facility closures. In
367 Nhamatanda, 9 out of 16 health facilities became unfunctional as a consequence of Cyclone
368 Idai. Health facility closures did not have an additional effect on post-cyclone accessibility in
369 Kenneth-affected districts.

370

371 **4. DISCUSSION**

372 Accessibility coverage decreased and travel times substantially increased in the direct
373 aftermath of the cyclones. Damage to transport networks and reduced travel speeds
374 resulted in the most substantial accessibility coverage losses in both Idai- and Kenneth-
375 affected districts. In Kenneth-affected districts, it was found that hospital closures did not

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3 376 have an additional effect on post-cyclone accessibility this is likely caused by the fact that
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5 377 flood extents and hospital closures were of much smaller magnitudes in the Kenneth-
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7 378 affected region than in the Idai-affected region.
8

9 379

10 380 In a post-disaster setting, access to health care is essential for effective response and
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12 381 recovery⁵⁰. The results of our study can be implemented beyond the response phase of the
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14 382 cyclones. Although the emphasis of the results is on identification of decreased accessibility
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16 383 coverage directly after the cyclones, the information presented here also provides a
17
18 384 platform for discussing health system recovery, mitigation and preparedness⁵¹.

19 385

20
21 386 Early identification of underserved districts in the response phase can help reduce the
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23 387 impacts caused by health service interruption, through targeted deployment of medical
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25 388 services in districts with the largest accessibility coverage losses and lowest baseline
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27 389 accessibility⁵². Information on accessibility coverage losses per cyclone-affected district can
28
29 390 support decision-making in the prioritization and planning of these medical services, by
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31 391 targeting where the deployment of medical services reaches the highest number of people.
32
33 392 Growing access to open data and post-disaster information enables prompt accessibility
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35 393 modelling in the aftermath of a natural disaster and the growing ability to quickly assemble
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37 394 this data provides an opportunity to integrate accessibility modelling in the early response
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39 395 phase of a natural disaster, so resources can be allocated in an informed way and health
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41 396 impacts can be reduced. In this specific study, all data for an initial post-cyclone accessibility
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43 397 study became available between 1 week and 1 month post-disaster (Table 1). This allows for
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45 398 an accessibility analysis in the early stages of a disaster response. Generally, data on flood
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47 399 extents and road damages, acquired from satellite imagery, were downloadable within 1
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49 400 week post-disaster. Whereas information that had to be ground validated, such as health
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51 401 facility functionality, became available approximately 1 month post-disaster.

52 402

53 403 Furthermore, the extensive damages to the road network will continue to limit movements
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55 404 of the population, further complicating physical accessibility⁵. Our results indicate that road
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57 405 damages are responsible for a relatively large loss of accessibility. This calls for a concerted
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59 406 effort between road and health authorities when prioritizing reconstruction efforts. It was
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407 estimated by WHO that damages to (health) infrastructure translated into 200,000 people

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3 408 living more than 5 kilometers from a functioning health facility⁵³. However, our results,
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5 409 which provide a more realistic representation of accessibility, by accounting for topography,
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7 410 barriers to movement, and population distribution, suggest this figure is an underestimate.
8
9 411 We estimated that as a result of the damage to infrastructure and barriers to movement,
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11 412 314,591 children under 5 live further than 1 hour travelling from a functioning health
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13 413 facility.

14 414

15
16 415 Fourteen percent of all health facilities in Cyclone Idai- and Kenneth-affected cyclone-
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18 416 districts have been damaged or fully destroyed, although more health facilities were
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20 417 temporarily impacted in service provisioning due to flooding, electricity constraints or
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22 418 damage to equipment^{14,54}. While it is critical to restore access to essential health services as
23
24 419 soon as possible, the WHO reported that the reconstruction of all destructed and damaged
25
26 420 facilities may take up to 5 years¹⁴. To restore baseline accessibility, the establishment of
27
28 421 mobile outreach units, deployment of community health workers (CHWs), together with the
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30 422 reconstruction of damaged facilities should be implemented. However, under the umbrella
31
32 423 of *Building Back Better* (BBB), rebuilding more resilient facilities and infrastructure, that are
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34 424 able to withstand future hazards under the “Hospitals Safe from Disasters” approach, are
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36 425 needed to prevent similar impacts in future disasters^{53,54}. The results presented here show
37
38 426 the importance of joint efforts to reduce both impacts on health facilities and the existing
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40 427 road network. However, resources are limited, and efficient financial planning is needed to
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42 428 outline health system investment plans^{5,11}. The results of our accessibility modelling can be
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44 429 used to prioritize health facility reconstruction for facilities with highest accessibility
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46 430 coverages. Cyclone Idai for instance, caused the destruction of the only tertiary hospital in 4
47
48 431 affected provinces that serves an estimated 12 million people⁵⁰. Targeting hospitals with
49
50 432 coverage numbers like these, to be strengthened for future disaster impacts and to support
51
52 433 them in providing continuity of care in the aftermath of future disasters can help reduce
53
54 434 health losses⁵⁵.

55 435

56 436 Due to the persisting health system disruption, humanitarian responders have identified the
57
58 437 need to deploy CHWs and mobile outreach services to cover accessibility losses caused by
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60 438 the cyclones and to extend the reach of existing functional services^{50,56}. These study findings
439 439 can assist policymakers in identifying and prioritizing severely impacted districts and

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3 440 communities and regions where deployment of CHWs can make a difference.

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5 441 Supplementary materials 3-6 present the most affected communities in terms of increased
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7 442 travel time and coverage losses post-cyclone. These analyses can be routinely updated to
8
9 443 assess the effect of health system recovery on accessibility.

10 444 The districts that were most affected by Cyclone Idai and Kenneth were historically, and are
11
12 445 in the future, also prone to disasters due to their topography (i.e. due to their location as
13
14 446 low-lying coastal cities in the cyclone belt near the Indian Ocean)^{50,53}. Ideally, accessibility
15
16 447 modelling could be applied to simulate the effects of historical disasters on accessibility, as
17
18 448 indicated in Supplement 5 and Supplement 6, so targeted preventive measures can be taken
19
20 449 for future disasters. Post-disaster accessibility modelling can help identify weak spots in
21
22 450 geographical accessibility to the health system and helps to distinguish pre-existing
23
24 451 accessibility gaps (Figure 3A and 4A) from accessibility coverage losses as a result of
25
26 452 disasters (Figure 3B and 4B). This information is essential in health system recovery,
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28 453 strengthening and preparing for future disasters.

29 454

30 455 Limitations and uncertainties of this study were primarily linked to the data. While the
31
32 456 occurrence of natural disasters generally accelerates data availability in affected countries,
33
34 457 there also are challenges of data quality, consistency, and format⁵⁷. In this study, data from
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36 458 various sources were combined to represent the post-cyclone situation as realistically as
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38 459 possible. But since data gathering was ongoing, it was expected that some data were
39
40 460 incomplete or not fully processed at the time of usage. Health facility coordinates had
41
42 461 duplicate occurrences in the database and health facility damages were solely indicated by
43
44 462 name, which resulted in manual spatial merging. Co-occurrences of rivers that were
45
46 463 indicated as floods were seen in the flood extent layer, minimally overestimating actual
47
48 464 flood extents in some parts of the affected regions. Besides post-disaster data uncertainty,
49
50 465 pre-disaster spatial data were also checked against background satellite imagery. The
51
52 466 hydrography of primary rivers stored in the data was found not to be fully representative for
53
54 467 actual hydrography in some regions. This could be a consequence of digitizing against a less
55
56 468 granular spatial resolution⁵⁸. In some cases, passages and bridges were detected on satellite
57
58 469 background imagery where the OpenStreetMap road layer did not present presence of
59
60 470 roads. In places where hydrography was potentially overestimated and not all roads are
471 471 mapped, isolated land pockets were created in the merged land cover. When modelling

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3 472 accessibility in these land pockets the population is assumed to be fully isolated from health
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5 473 care. In general, we would advise upon a more rigorous and sustainable data management
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7 474 during and after humanitarian emergency operations to ensure the applicability of
8
9 475 spatiotemporal data analyses to quantify disaster impacts.

10 476
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12 477 Next to data uncertainties, travel scenarios present a source of uncertainty as assumptions
13
14 478 on travel speeds and modes are uniformly generalized across regions. In addition, we
15
16 479 assumed that roads indicated as being restricted or closed were considered only passable by
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18 480 foot if they were not inundated. However, some of the restricted roads were in fact
19
20 481 passable by 4x4 vehicles. Other means of transport (e.g., bicycle, motorcycle) may also have
21
22 482 been used in some places, which would increase accessibility to health centres. Since car
23
24 483 ownership and access to motorized transport by the target population was expected to be
25
26 484 very low, especially post-cyclone, it was decided to run the accessibility model for restricted
27
28 485 and closed roads only by means of walking.

29 486
30
31 487 Our accessibility modelling assumes that patients always travel to the nearest health facility.
32
33 488 However, literature has shown that patients sometimes bypass health facilities in search of
34
35 489 higher quality care in Mozambique^{59,60}. Previous research, has shown that 30.8% of
36
37 490 pregnant women bypassed the nearest health facility in search of better prenatal care⁵⁹.
38
39 491 Our results can therefore present slight underestimations of actual travel times.

40 492
41
42 493 Despite some of the limitations, the results presented here provide important initial
43
44 494 information for post-cyclone health system recovery which can be expanded through future
45
46 495 research. Since post-disaster needs continuously change based on the nature of the event
47
48 496 (e.g. receding flood waters, reconstruction efforts, and deployment of temporary medical
49
50 497 services), following studies should also be focused on the ability to dynamically model
51
52 498 accessibility based on these changes, so accessibility can be continuously monitored and
53
54 499 humanitarian service delivery can be updated accordingly in disaster-affected districts.
55
56 500 Additionally, it would be interesting to assess the effect of CHW deployment and mobile
57
58 501 outreach communities on improved accessibility and accessibility coverage estimates, to
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60 502 quantify the effect of these interventions.

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3 504 Post-disaster accessibility modelling can increase our understanding of spatial differences in
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5 505 health care needs in the direct aftermath of a disaster and can help target limited resources
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7 506 efficiently. Currently, there is no standardized approach in the humanitarian program cycle
8
9 507 to assess post-disaster accessibility losses against baseline accessibility¹⁷. The lack of a
10
11 508 standardized methodology to spatially assess disaster impacts on accessibility can result in
12
13 509 uncoordinated decision making for temporary health facility locations, introducing
14
15 510 duplication probability, and complicates prioritization in recovery efforts. The results in this
16
17 511 paper not only reflect the importance of incorporating accessibility modelling in early
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19 512 disaster response, but also provide a platform for discussing health system recovery,
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21 513 mitigation and preparedness.
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5
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12

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14

15 519 The authors declare that they have no known competing financial interests or personal
16
17 520 relationships that could have appeared to influence the work reported in this paper.
18
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24

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27

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29

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31

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33
34 527 visualization, supervision. **Nelson Rodrigues**: data sharing, methodology, writing, editing,
35
36 528 validation. **Maria Muñiz**: writing, editing. **Rocco Panciera**: methodology, writing, editing.
37
38 529 **Nicolas Ray**: conceptualization, methodology, writing, editing, validation, supervision.
39
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41 530
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44 531 **DATA SHARING STATEMENT**
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46
47 532 Data available upon reasonable request. Most data used in this study are openly accessible
48
49 533 through the indicated data sources in Table 1. Other data are available upon request.
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33 657 [5060f0adb1feb/1588770424043/Leaving+no+one+off+the+map-4.pdf](https://static1.squarespace.com/static/5b4f63e14eddec374f416232/t/5eb2b65ec575060f0adb1feb/1588770424043/Leaving+no+one+off+the+map-4.pdf)
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6 716 **Figure 1 - Cyclone affected districts, cyclone trajectory, and road damages.** (A) Idai affected
7 717 districts. (B) Kenneth affected districts. (C) Idai cyclone trajectory*. (D) Kenneth cyclone
8 718 trajectory*. (E) Road damages in Idai-affected districts. (F) Road damages in Kenneth-
9 719 affected districts. *Cyclone paths as reported on Global Disaster Alert and Coordination System
10 720 (GDACS)^{25,26}.
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14 722 **Figure 2- Absolute and relative reduction in population coverage pre- and post-cyclone**
15 723 **Idai (A) and Kenneth (B).** Labels on top of bars indicate absolute reduction in population
16 724 coverage of children under 5. Labels under districts indicate relative reduction in population
17 725 coverage. Maximum limits of the bars indicate the absolute pre-cyclone coverage within 2
18 726 hours travel time. Limits of the blue filled bar indicate the absolute post-cyclone coverage.
19 727 The x-axis is ordered according to relative reduction in population coverage.
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24 729 **Figure 3 – Accessibility modelling results for Idai districts.** Pre-cyclone travel time raster
25 730 (A). Post-cyclone travel time raster (B). Difference ratio raster between pre- and post-
26 731 cyclone travel time (C). Uncertainty raster, as a result of the difference between -20% and
27 732 +20% travel speed accessibility (D).
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31 734 **Figure 4 – Accessibility modelling results in Kenneth districts.** Pre-cyclone travel time raster
32 735 (A). Post-cyclone travel time raster (B). Difference ratio raster between pre- and post-
33 736 cyclone travel time (C). Uncertainty raster, as a result of the difference between -20% and
34 737 +20% travel speed accessibility (D).
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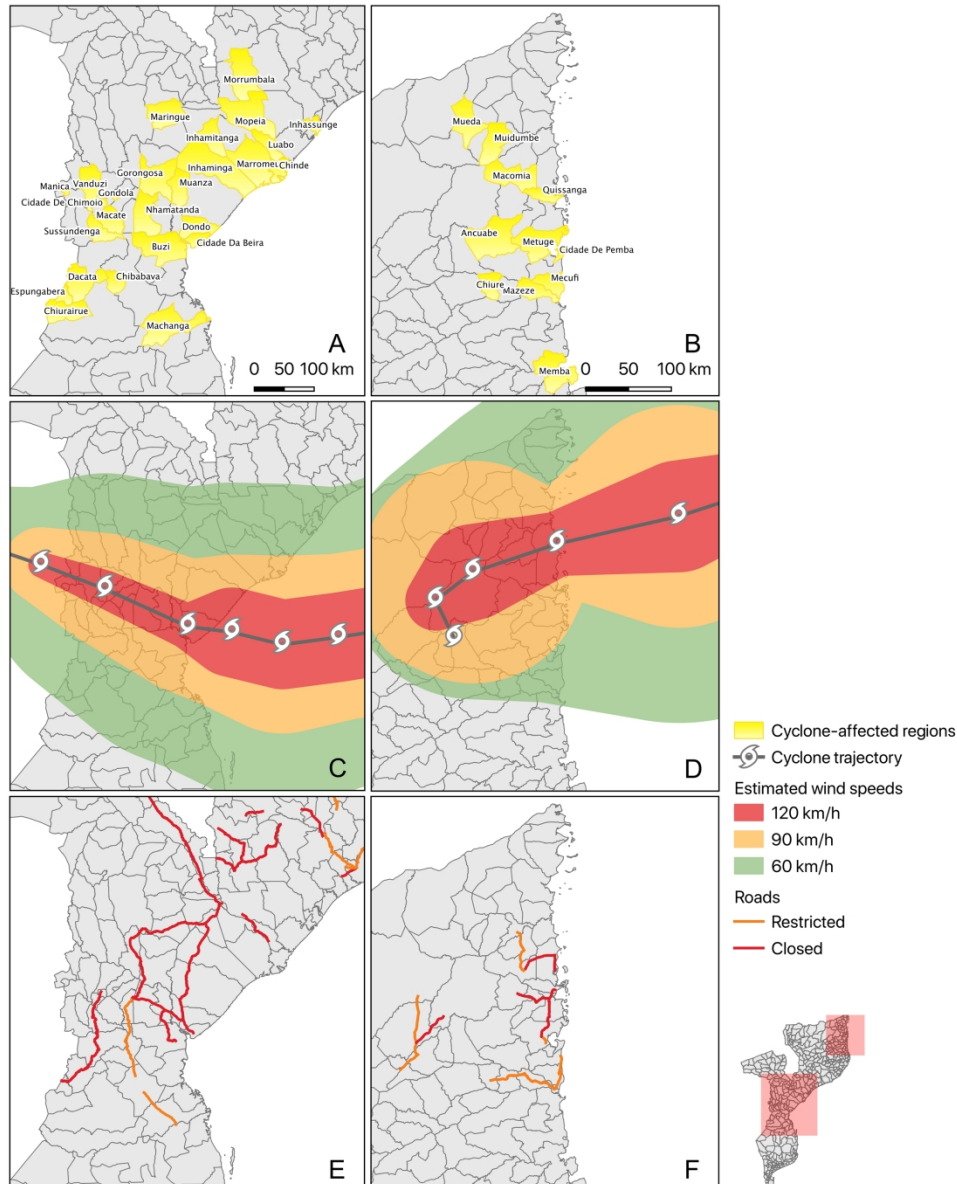


Figure 1 - Cyclone affected districts, cyclone trajectory, and road damages. (A) Idai affected districts. (B) Kenneth affected districts. (C) Idai cyclone trajectory*. (D) Kenneth cyclone trajectory*. (E) Road damages in Idai-affected districts. (F) Road damages in Kenneth-affected districts. *Cyclone paths as reported on Global Disaster Alert and Coordination System (GDACS)25,26.

236x292mm (300 x 300 DPI)

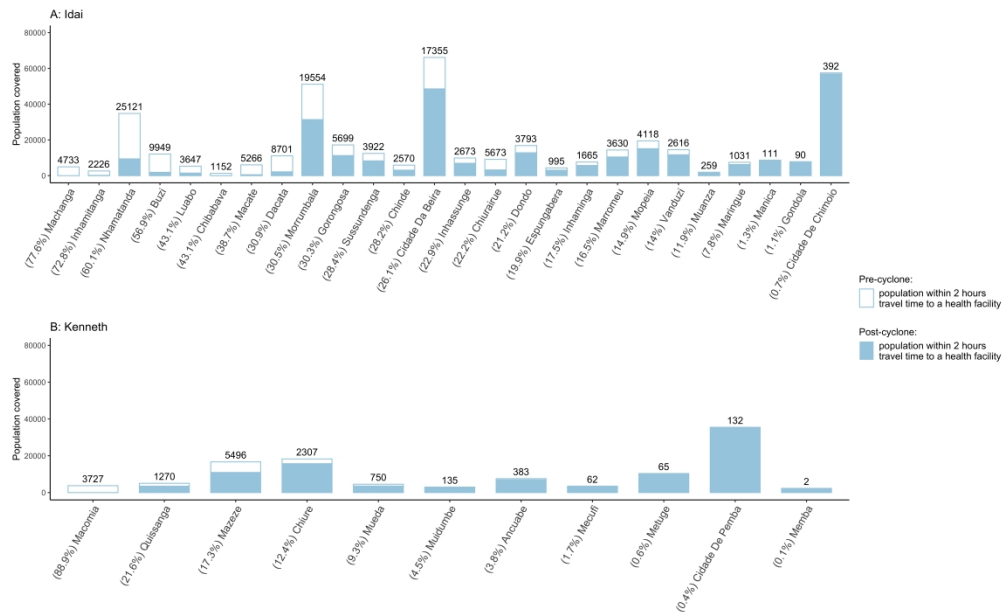
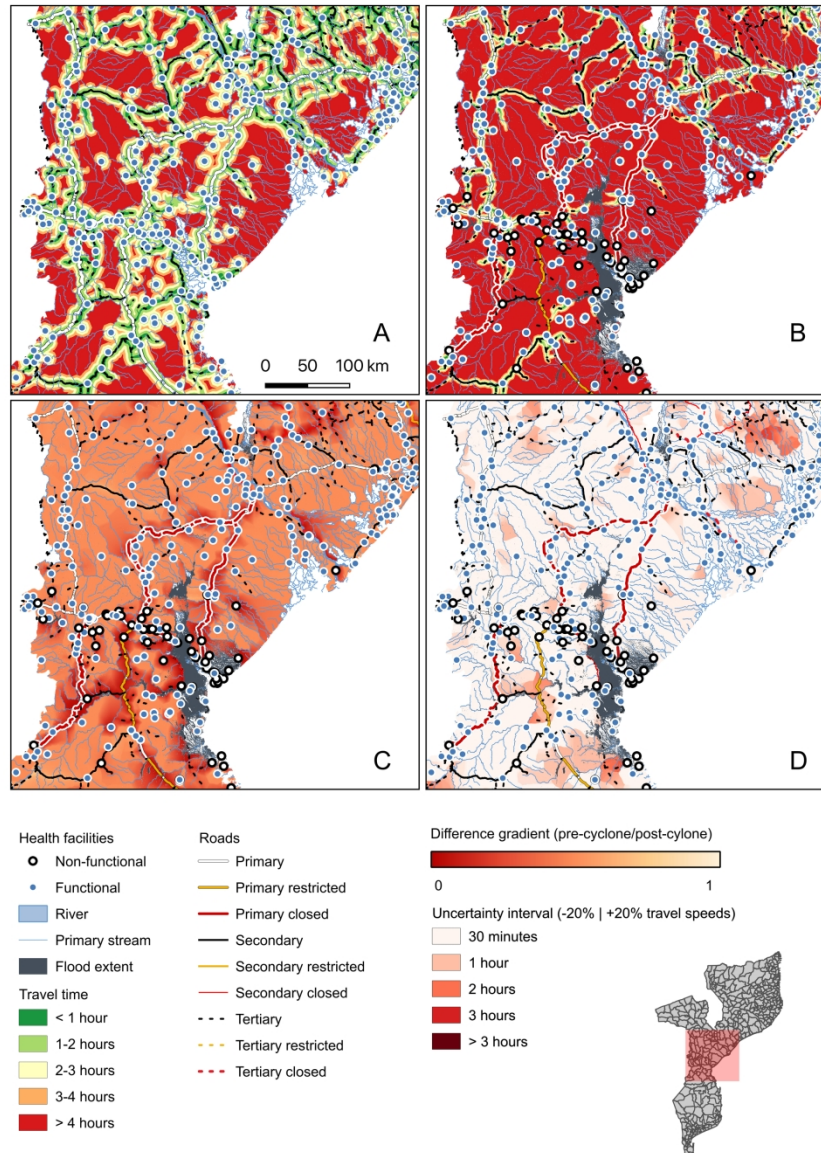


Figure 2- Absolute and relative reduction in population coverage pre- and post-cyclone Idai (A) and Kenneth (B). Labels on top of bars indicate absolute reduction in population coverage of children under 5. Labels under districts indicate relative reduction in population coverage. Maximum limits of the bars indicate the absolute pre-cyclone coverage within 2 hours travel time. Limits of the blue filled bar indicate the absolute post-cyclone coverage. The x-axis is ordered according to relative reduction in population coverage.

2777x1736mm (72 x 72 DPI)



45 Figure 3 – Accessibility modelling results for Idai districts. Pre-cyclone travel time raster (A). Post-cyclone
 46 travel time raster (B). Difference ratio raster between pre- and post-cyclone travel time (C). Uncertainty
 47 raster, as a result of the difference between -20% and +20% travel speed accessibility (D).

48 209x296mm (300 x 300 DPI)

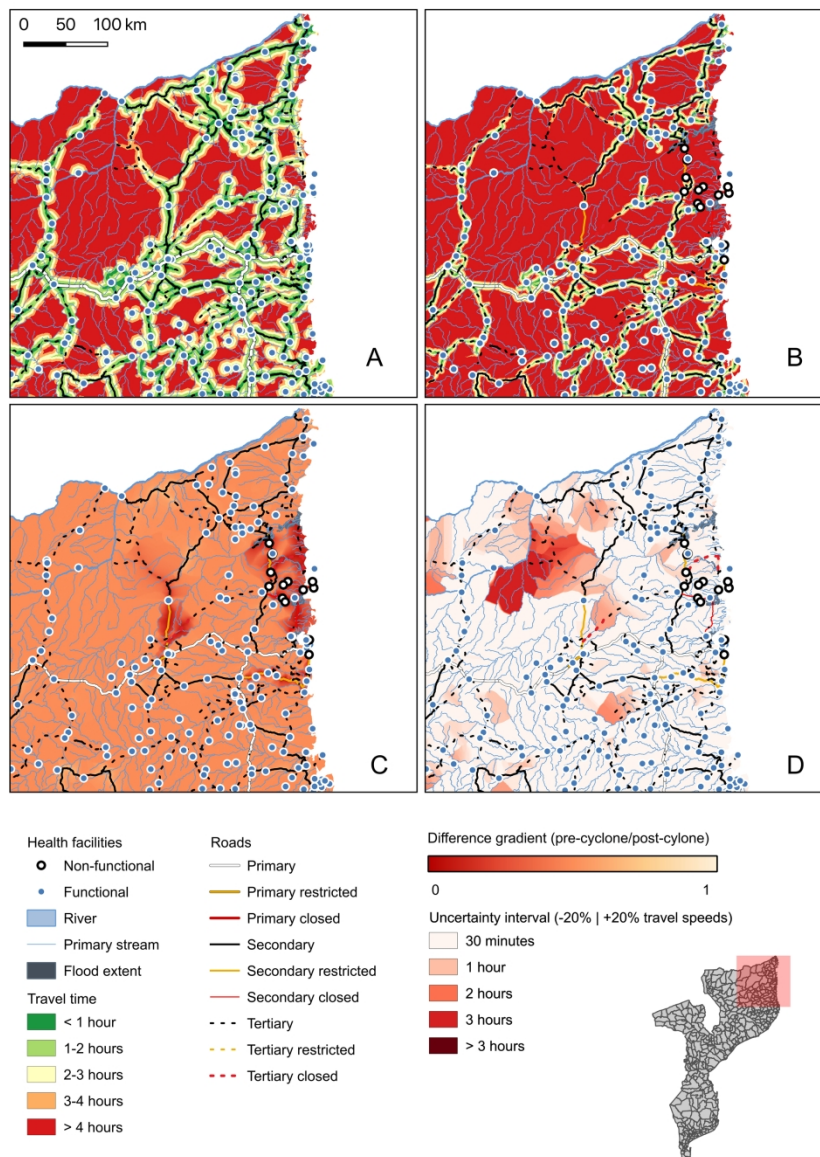


Figure 4 – Accessibility modelling results in Kenneth districts. Pre-cyclone travel time raster (A). Post-cyclone travel time raster (B). Difference ratio raster between pre- and post-cyclone travel time (C). Uncertainty raster, as a result of the difference between -20% and +20% travel speed accessibility (D).

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SUPPLEMENTAL MATERIAL

Supplement 1-Data preparation for use in AccessMod

All data preparation was carried out in Quantum Geographical Information System (QGIS) (version 3.4)²⁴ in limited combination with R (version 3.5.2)²⁵. As indicated in Table 1, most data layers were retrieved from open data platforms. All raster- and shapefiles were saved in the projection system of Mozambique, i.e. UTM-37S [EPSG:32737]. All raster files were aligned using the digital elevation model (DEM) as reference. The data preparation process is fully described below for each data set.

Elevation

Anisotropic accessibility analyses, in other words analyses accounting for travel speeds on slopes, were carried out for this study. Elevation data were obtained from the Shuttle Radar Topography Mission (SRTM) in tiles at a resolution of 30 meters and mosaiced to cover the whole country³⁸. Slopes were derived from it and accounted for when modelling walking movements.

Land cover

The land cover data set of the African continent²⁷ was clipped to the extent of Mozambique, leaving a small buffer around the country to prevent loss of data cells at the border. The data set was resampled at a resolution of 30 meters using nearest neighbor interpolation.

Road network

The pre-cyclone road network dataset was retrieved from Open Street Map (OSM) through the Geonode Platform of the National Institute for Disaster Management Mozambique (INGC), as this dataset was perceived to represent the most recent information on the roads and could be linked to the damaged roads, as indicated by the Logistics Cluster of the World Food Program (LOG-WFP). Road classes that were not indicated as official classification by OSM, were removed from the data⁴⁸.

LOG-WFP provided the most up to date data on road network damages. However, the road constraint shapefile was updated frequently by overwriting previous versions, without

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3 storing data historically. Therefore, historical post-cyclone status of roads and road
4 segments was manually digitized from PDF maps provided by LOG-WFP^{28,29}. The PDF maps
5 were manually cross-referenced with the OSM road network layer, to include post-cyclone
6 status, i.e. 1) open 2) restricted 3) closed.
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12 Roads were then reclassified based on the unique combination of road type and post-
13 cyclone status, resulting in 34 unique road classes (e.g. primary road, primary road
14 restricted, secondary road closed). All roads were given a specific travel speed, accounting
15 for the different scenarios. In the pre-cyclone scenario for instance, all primary road classes
16 (i.e. primary road, primary road restricted, primary road closed) had the same travel speed.
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18 Whereas in the post cyclone scenario, the restricted and closed road types had a travel
19 speed and travel mode accounted for their damages, as can be seen from Supplement 2.
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26 27 *Barriers to movement*

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29 Rivers and lake shapefiles were obtained as lines and polygons from the National
30 Directorate for Water Resource Management (DNGRH) and accuracy was checked using
31 satellite imagery as a reference, using Microsoft Bing Imagery as a background through the
32 QGIS QuickMapServices Plugin. Only primary rivers and lakes were taken for the analyses,
33 under the assumption that smaller rivers and streams were passable by the population.
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35 Water bodies were perceived as being impassable at all scales.
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42 Flood extent caused by Cyclone Idai was taken from 19 March 2019 and flood extent for
43 Cyclone Kenneth was taken from 2 May 2019, because extents were visually inspected and
44 found to be largest on those dates and thus represent the biggest constraints for health care
45 access. All flooded areas were treated as impassable at those dates, considering the depth
46 and extent of the floods.
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51 52 *Population data*

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54 High resolution population density estimates for children under five were downloaded at 30
55 meter resolution from the Facebook Connectivity Lab and Center for International Earth
56 Science Information network³⁰. The raster was projected in Mozambique's projection
57 system, UTM-37S [EPSG:32737], by using nearest neighbor interpolation. Loss of population
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3 caused by reprojection and clipping to country borders, was corrected for by smoothing the
4 lost population equally over the raster cells. This was done by using a multiplication factor
5 of the difference between the total sum of population before and after data processing
6 using the raster calculator.
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10 11 12 *Health facilities*

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14 The geographic coordinates of all health facilities were obtained through the Humanitarian
15 Data Exchange platform (HDX) and were originally sourced from the Ministry of Health in
16 Mozambique (SIS-MA)³⁴. The data was cleaned to exclude coordinates far outside of the
17 country borders. Coordinates that fell just outside Mozambique were relocated within the
18 country extents. Five health facilities were cross-referenced with other data sources (e.g.
19 Neonatal Inventory Survey UNICEF, OpenStreetMap, Google Maps) because they were
20 located on barriers, such as open sea, rivers or lakes.
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29 Information on damaged health facilities was provided by the World Health Organization
30 (WHO). This data did not include GPS coordinates, thus names of the damaged health
31 facilities were cross referenced with the original health facility shapefile to include post-
32 cyclone status of each facility, i.e. functional or non-functional. For damaged health facilities
33 that were not included in the original health facility shapefile, coordinates were retrieved
34 from a neonatal inventory performed by United Nations Children Fund (UNICEF) and also
35 added as facility to the original health facility data, representing the pre-cyclone situation.
36 Non-functional health facilities were filtered-out for geographical accessibility analyses
37 reflecting the post-cyclone scenarios.
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48 *Travel scenario*

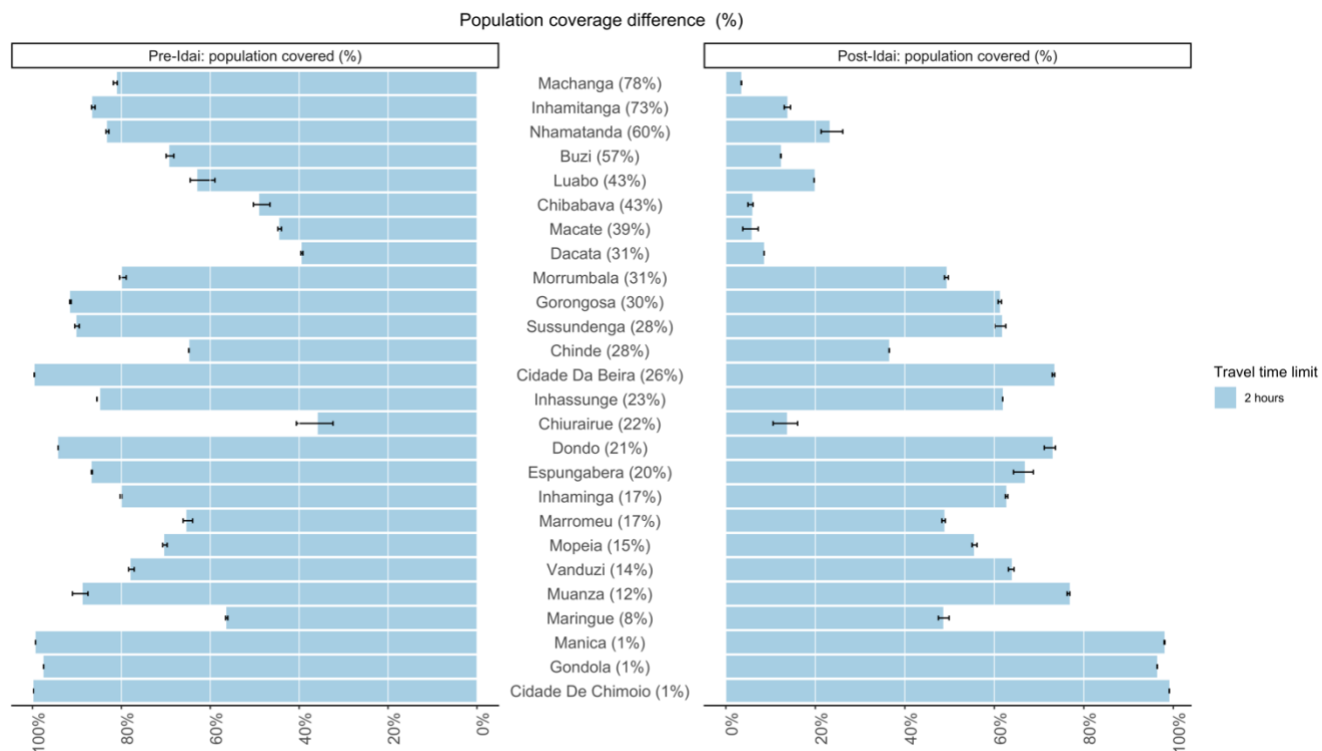
49 Both our travel scenarios were developed in close collaboration with country
50 representatives from UNICEF and were adapted to our target population, namely children
51 under five accompanied by a parent (Supplement 2). Flood waters were assumed to be a full
52 barrier to movement to the target population, thus health facilities located in flooded zones
53 were completely inaccessible and flood waters were impassable.
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Supplement 2- Travel scenarios pre-cyclone and post-cyclone

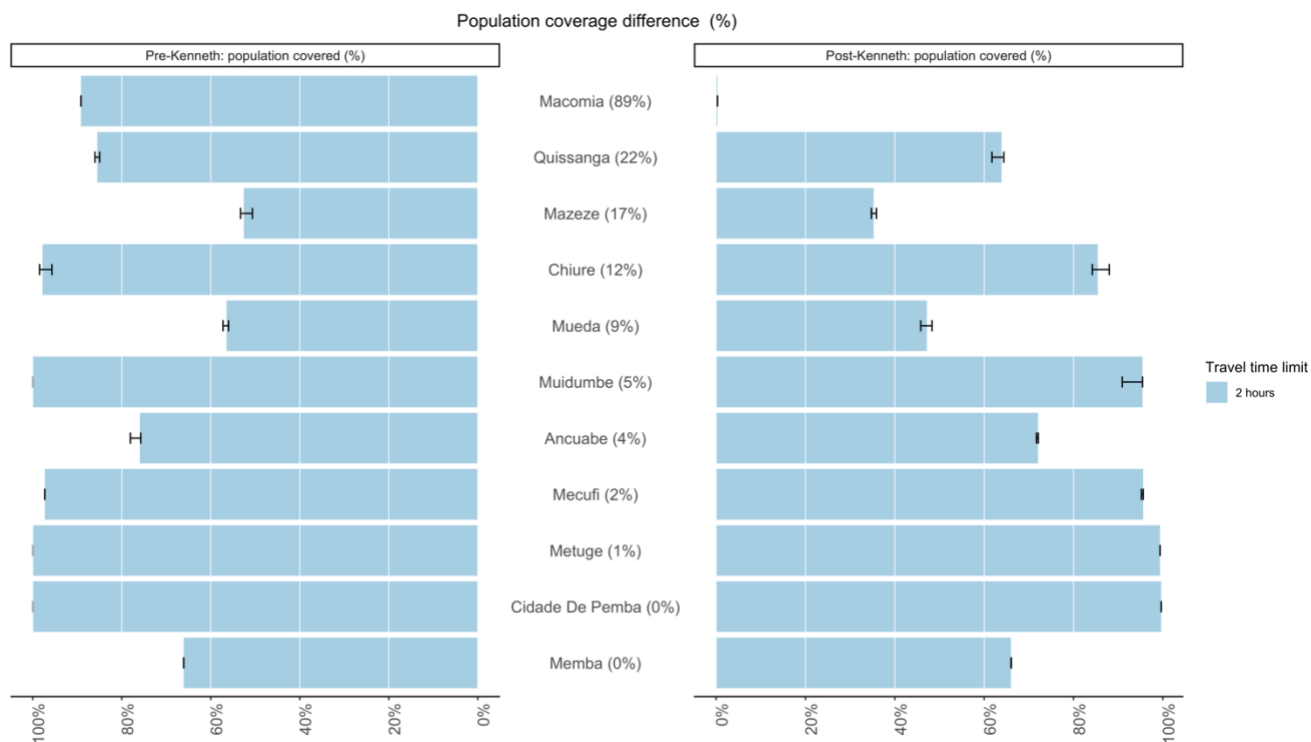
Label	Pre-cyclone		Post-cyclone	
	Travel speed (km/h)	Travel mode	Travel speed (km/h)	Travel mode
Shrubs	3	Walking	1.5	Walking
Herbaceous Vegetation	3	Walking	1.5	Walking
Cultivated and Managed Vegetation	3	Walking	1.5	Walking
Agriculture Cropland				
Urban Built Up	3	Walking	1.5	Walking
Bare Sparse Vegetation	3	Walking	1.5	Walking
Permanent Water Bodies	3	Walking	1.5	Walking
Temporary Water Bodies	3	Walking	1.5	Walking
Herbaceous Wetland	3	Walking	1.5	Walking
Closed Forest Evergreen Broad Leaf	3	Walking	1.5	Walking
Closed Forest Deciduous Broad Leaf	3	Walking	1.5	Walking
Open Forest Evergreen Broad Leaf	3	Walking	1.5	Walking
Open Forest Deciduous Broad Leaf	3	Walking	1.5	Walking
Open Sea	3	Walking	1.5	Walking
Trunk	80	Motorized	50	Motorized
Trunk Restricted	80	Motorized	1.5	Walking
Trunk Closed	80	Motorized	1.5	Walking
Primary	80	Motorized	50	Motorized
Primary Restricted	80	Motorized	1.5	Walking
Primary Closed	80	Motorized	1.5	Walking
Secondary	50	Motorized	40	Motorized
Secondary Restricted	50	Motorized	1.5	Walking
Secondary Closed	50	Motorized	1.5	Walking
Tertiary	30	Motorized	15	Motorized
Tertiary Closed	30	Motorized	1.5	Walking
Tertiary Restricted	30	Motorized	1.5	Walking
Road	20	Motorized	10	Motorized
Raceway	3	Walking	3	Walking
Residential	20	Motorized	10	Motorized
Residential Closed	20	Motorized	1.5	Walking
Living Street	20	Motorized	10	Motorized
Service	3	Walking	1.5	Walking
Track	15	Motorized	10	Motorized
Pedestrian	3	Walking	1.5	Walking
Pier	3	Walking	1.5	Walking
Path Closed	3	Walking	1.5	Walking
Path	3	Walking	1.5	Walking
Footway	3	Walking	1.5	Walking
Bridleway	3	Walking	1.5	Walking
Cycleway	3	Walking	1.5	Walking
Steps	3	Walking	1.5	Walking
Unclassified	3	Walking	1.5	Walking

Supplement 3- Relative population coverage pre- and post-cyclone Idai. Ordered on relative difference. Difference indicated between parentheses. Error bars indicate the coverage uncertainty, considering -20% and +20% travel speeds.



view only

Supplement 4- Relative population coverage pre- and post-cyclone Kenneth. Ordered on relative difference. Difference indicated between parentheses. Error bars indicate the coverage uncertainty, considering -20% and +20% travel speeds.



view only

Supplement 5- Travel time per community in Idai affected districts. Fifty most affected communities by means of accessibility loss. Ordered on absolute travel time difference.

Community	District	Pre-cyclone travel time (h)	Post-cyclone travel time (h)	Difference pre- and post-cyclone (h)
Mucinemo	Buzi	1.3	63.6	62.3
Bupira	Buzi	1.1	62.3	61.3
Massuinda	Buzi	1.2	60.1	58.9
Njanga	Buzi	4.3	59.1	54.7
Guenje-Sede	Buzi	2.9	57.3	54.4
Mbereaizique	Buzi	2.9	57.3	54.4
Shinizia Chinhale	Muanza	24.0	77.8	53.8
Chipota	Muanza	24.4	78.0	53.6
Wiriquizi	Muanza	22.2	74.1	51.9
Chingamuzi	Muanza	22.7	74.5	51.8
Mussacazwidje	Buzi	3.5	55.3	51.8
Mussacazwidje	Buzi	3.5	55.3	51.8
Magua	Buzi	4.8	56.6	51.8
Nkolone Praia	Muanza	20.7	72.3	51.7
Mukulumba 1	Muanza	20.4	71.8	51.4
Mukulumba cidade	Muanza	20.2	71.4	51.2
Nhanganga	Muanza	19.9	70.8	50.9
Mutanda	Buzi	5.4	55.3	49.9
Macova-Mutanda	Buzi	6.3	55.1	48.9
Puanda	Buzi	2.9	51.6	48.7
Luanda 1	Muanza	18.8	67.4	48.6
Nhamacalango	Muanza	17.4	65.8	48.4
Sengo	Dondo	5.3	53.5	48.2
Luanda 2	Muanza	18.0	65.8	47.8
Praia Nova	Dondo	3.9	51.5	47.6
Praia Farol	Dondo	3.8	51.4	47.6
Bingue Sede	Muanza	16.4	63.8	47.4
Nkonde 2	Muanza	16.4	63.8	47.4
Massitche	Dondo	7.1	54.5	47.4
Goonda Majaca	Chibabava	6.5	53.3	46.8
Ngomole	Muanza	10.1	56.7	46.6
Ngalazi	Dondo	6.0	52.3	46.3
Nhacudjica	Buzi	6.3	52.4	46.1
Chitundo	Dondo	2.0	47.7	45.7
Macarate	Chibabava	5.3	51.0	45.7
Nhamissassa	Muanza	15.9	61.5	45.6
Docue	Buzi	5.7	51.3	45.6
Khome 1	Dondo	1.4	46.8	45.4
Nherere 2	Muanza	14.0	59.0	45.0
Parange	Buzi	3.6	48.6	45.0
Njocho	Buzi	5.9	50.9	45.0
Binda	Machanga	0.7	45.2	44.6
Khome 2	Dondo	0.6	45.2	44.6
Veruca	Chibabava	4.1	48.6	44.5
Mamunge	Buzi	5.1	49.2	44.1
Birirane	Muanza	13.1	57.2	44.1
Vala-vala	Buzi	5.2	49.2	44.1
Muche	Gorongosa	1.5	45.5	44.0
Machiquire	Buzi	2.6	46.1	43.5
Nhazwicasse	Gorongosa	1.0	44.5	43.5

Supplement 6- Travel time per community in Idai-affected districts. Point locations of communities in Idai-affected districts.

