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Geographic Accessibility of Neonatal Incubators in Cameroon: Current and Prospective Modelling using Cost-Distance Analysis towards the African Union Agenda 2063

AFENUI NGUEFACK Nelly Leslie[1], Joachim ETOUNA[2], Cletus FORBA[3]

[1]Master in land surveying student, afenuinelly@gmail.com
[2]Consultant in Geographic Sciences and Technologies, jetouna36@gmail.com
[3]Doctor of Urban Geography, cletusforbafru@gmail.com

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ABSTRACT

Neonatal incubators are essential tracer equipment for newborn survival, yet in much of sub-Saharan Africa their benefit is limited less by their number than by how far a newborn must travel to reach one. This study analysed the geographic accessibility of neonatal incubators across Cameroon's 210 health districts using a raster-based cost-distance analysis implemented in AccessMod 5, which models travel time to the nearest incubator-equipped facility while accounting for road network, land cover, terrain, and hydrographic barriers. Population coverage was estimated at four travel-time thresholds (½, 1, 1½, 2 hours) for the current

situation (2024) and for two prospective scenarios projected to the African Union's Agenda 2063 horizon: a Catastrophic trajectory of infrastructure degradation and high population growth, and a Desirable trajectory combining road investment and targeted facility capacity-strengthening. Under the current, Status Quo situation, only 53.60% of the population was covered within half an hour, rising to 77.15% within 2 hours, 2.85 percentage points short of the WHO/Lancet Commission's 80% benchmark, with 42.86% of districts more than two hours' travel from care and marked disparity concentrated in the North-West, South-West, Far North and East regions. Under the Catastrophic scenario, 2-hour coverage was projected to fall to 67.14%, whereas the Desirable scenario raised it to 89.40%, lifting the number of WHO-compliant districts from 115 in Status Quo to 152 of 210 under that scenario. These findings show that Cameroon's neonatal incubator accessibility gap is severe but not fixed, and that targeted, spatially-informed investment in roads and facility capacity could close it well within the Agenda 2063 horizon.

Keywords: neonatal incubator, geographic accessibility, cost-distance analysis, AccessMod, Agenda 2063.

1. Introduction

Complications of prematurity remain the leading cause of death in the first 28 days of life, and the neonatal incubator is the single most effective clinical response to it [1], [2]. Across sub-Saharan Africa, however, incubators are frequently concentrated in capital cities and major urban centres, so that the equipment exists in the country but not within reach of the newborn who needs it [3]. Geographic inaccessibility is therefore not a peripheral inconvenience in neonatal health; it is a structural determinant of survival [4].

Cameroon records approximately 25 neonatal deaths per 1,000 live births, more than double the Sustainable Development Goal (SDG) 3.2 target of 12 per 1,000 [1]. The country's Stratégie Sectorielle de Santé 2016–2027 and Plan National de Développement Sanitaire (PNDS) 2021–2025 both commit explicitly to the equitable distribution of essential neonatal equipment across its ten regions [5], and the African Union's Agenda 2063 sets out, under Aspiration 1, a horizon by which good health and well-being should be assured for all Africans regardless of where they live [6]. Whether these commitments are being met, however, has not previously been assessed for neonatal incubators using an explicit measure of geographic travel time.

Geographic accessibility, understood as the physical relationship between where people live and where services are located, is most credibly measured not by straight-line distance but by the actual travel time a population would need to reach a facility across real terrain, road quality, and natural barriers [7]. Cost-distance analysis, of which AccessMod is the World Health Organization's own reference implementation, is now an established approach for this purpose and has previously been used to assess accessibility of emergency obstetric and newborn care in Ethiopia, Bangladesh and Malawi [8]. In Ethiopia, for instance, only 46.4% of live births were within two hours of travel time of a fully functioning emergency neonatal care facility in 2016, with coverage ranging from 15.3% to 100% across regions [8].

This work uses the same cost-distance logic to analyse the current and prospective geographic accessibility of neonatal incubators in Cameroon. It reports, first, the present-day (2024) travel-time and population-coverage picture at national and district level, and second, how that picture is projected to evolve by the African Union's 2063 horizon under a Catastrophic trajectory of continued neglect and a Desirable trajectory of targeted investment. The aim is to translate the accessibility gap into evidence that can directly inform where road investment and facility capacity-strengthening would do the best.

2. Study Area, Data and Method

2.1. Study Area

Cameroon covers approximately 475,650 km² across ten administrative regions and 210 health districts and lies between latitudes 1°N and 13°N and longitudes 8°E and 16°E. Its five agro-ecological zones, from the semi-arid plains of the Far North to the highland massifs of the West and North-West and the forested peneplain of the Centre and South, together with four major river basins, constitute substantial natural barriers to travel that are directly incorporated into the cost-distance surface. Less than 10% of the country's approximately 121,873 km of road network is paved, and the rural network is seasonally impassable in several regions during the rainy season. Figure 1 shows the geographic location of Cameroon.

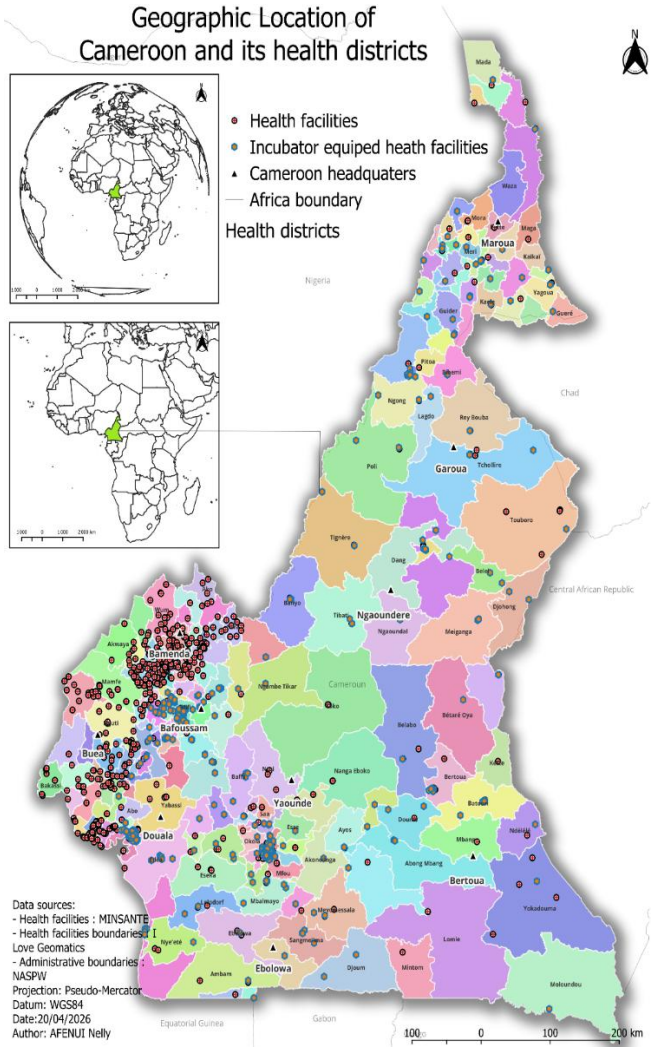

Figure 1. Geographic location of Cameroon and its health districts

2.2. Data Sources

The analysis combined a 2024 national inventory of incubator-equipped health facilities (371 facilities holding 832 functional incubators across 127 of 210 districts), a WorldPop 2024 gridded population layer, a digital elevation model, an 11-class land cover raster, the national road network classified into primary, secondary, tertiary and unclassified categories, and a hydrographic layer used to define absolute movement barriers. For the prospective analysis, the 2024 population layer was replaced with SSP1 and SSP3 Shared Socioeconomic Pathway population rasters interpolated to 2063 as shown in Figure 2.

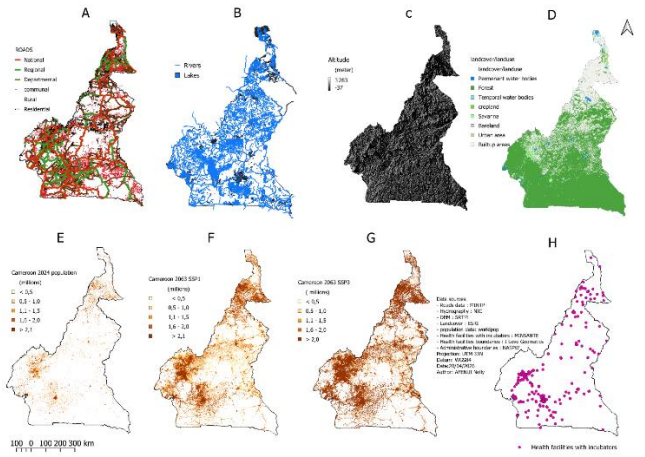

Figure 2. Vector and raster data sets used in the cost-distance analysis: (A) road network, (B) movement barriers, (C) digital elevation model, (D) land cover, (E) 2024 population raster, (F) 2063 SSP1 population raster, (G) 2063 SSP3 population raster, (H) incubator-equipped health facilities.

2.3. Cost-Distance Accessibility Modelling

Travel time to the nearest incubator-equipped facility was computed in AccessMod 5.8.2 through anisotropic least-cost path modelling. A merged travel surface was first produced by combining the land cover, road, and barrier layers, each assigned a travel speed: 100, 70, 50 and 30 km/h respectively for primary, secondary, tertiary and unclassified roads, taken as representative of ambulance travel at maximum permitted speed, with terrain slope further adjusting off-road speeds through Tobler's anisotropic function. A travel-time raster was then generated in the direction of the nearest facility, and zonal statistics were computed against the population raster at four travel-time thresholds, ½ hour, 1 hour, 1½ hours and 2 hours, for every health district. Districts and population were further screened against the WHO/Lancet Commission benchmark that at least 80% of a population should reach an appropriately equipped facility within 2 hours [9], with districts falling short classified into four priority tiers based on their 1½- and 2-hour coverage.

2.4. Prospective Scenario Modelling

Three scenarios were modelled to the Agenda 2063 horizon, keeping the cost-distance method identical across all three and varying only the road-speed and facility-network inputs. The Status Quo (S0) scenario reproduced the 2024 baseline described above. The Catastrophic (S1) scenario combined a road-degradation matrix, reflecting chronic under-maintenance (reductions of 10–20 km/h depending on road class), with the high-fertility, low-development SSP3 population projection for 2063. The Desirable (S2) scenario

combined an improved road-speed matrix with an expanded facility network, incorporating roughly 2,000 additional facilities identified through a weighted-overlay prioritisation of population demand, and the low-fertility, high-sustainability SSP1 population projection for 2063. Table 1 summarises the three scenarios.

Table 1. Master comparative overview of the three prospective scenarios.

Parameter	S0 – Status Quo	S1 – Catastrophic	S2 – Desirable
Population layer	WorldPop 2024	SSP3 2063	SSP1 2063
Road speeds	Baseline	Degraded	Improved
Facility network	2024 (371 facilities)	2024 (371 facilities)	371 + ~2,000 priority facilities
Travel-time / coverage thresholds	½, 1, 1½, 2 hours	½, 1, 1½, 2 hours	½, 1, 1½, 2 hours

3. Results

3.1. Current Travel Time to the Nearest Incubator-Equipped Facility

Table 2 classifies Cameroon's 210 health districts by travel time to the nearest incubator-equipped facility under the 2024 Status Quo. Only 15.71% of districts (33 of 210) fell within the Very High accessibility class, reachable within half an hour, and a further 18.57% (39 districts) within half to one hour. At the other end of the scale, 42.86% of districts, 90 in total, required more than two hours of travel, the largest single class. Figure 3 maps this travel-time surface nationally, showing accessibility concentrated in the central, northern and north-western corridors around Yaoundé, Douala and the main road axes, and lowest in the North-West, South-West, and the eastern and north-eastern border areas.

Table 2. Classification of health districts by travel time to the nearest incubator-equipped facility, 2024 baseline.

Accessibility Class	Travel Time Range	No. of Districts	% of Districts
Very High	0 – ½ hour	33	15.71%
High	½ – 1 hour	39	18.57%
Moderate	1 – 1½ hours	24	11.43%
Low	1½ – 2 hours	24	11.43%
Very Low	> 2 hours	90	42.86%
Total	—	210	100%

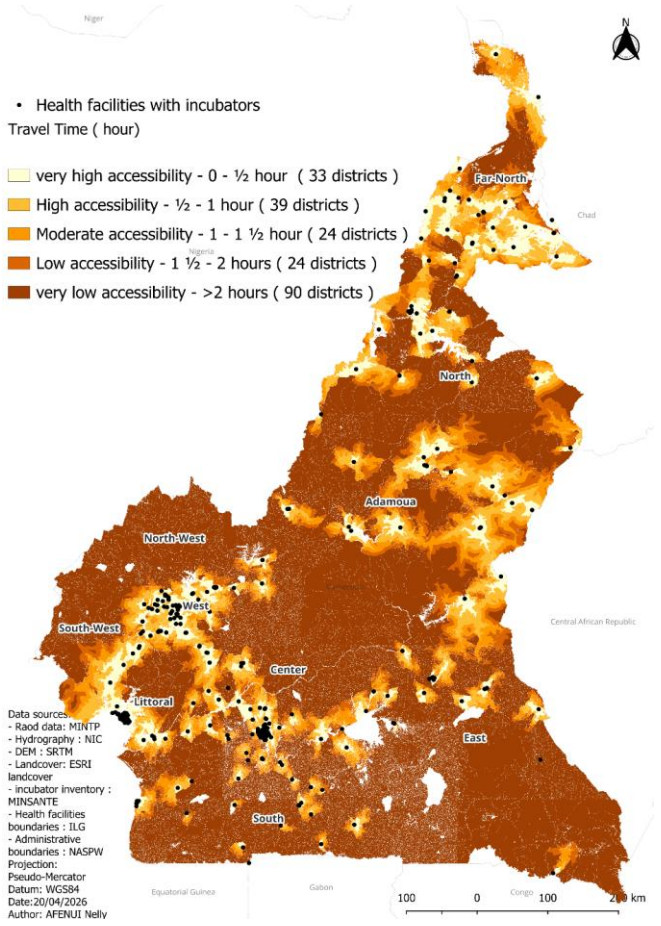

Figure 3. Travel time to the nearest incubator-equipped facility, 2024 baseline (AccessMod cost-distance surface).

3.2. National Population Coverage and Underserved Districts

National population coverage rose progressively with the travel-time threshold: 53.60% of the population (13.11 million people) was covered within half an hour, 65.54% (16.03 million) within 1 hour, 72.56% (17.75 million) within 1½ hours, and 77.15% (18.87 million) within 2 hours. Even at the 2-hour threshold, national coverage remained 2.85 percentage points short of the WHO/Lancet Commission's 80% benchmark, leaving 5.59 million people beyond reasonable reach of an incubator-equipped facility as seen in Table 3.

Table 3. National population coverage at four travel-time thresholds, 2024 baseline.

Threshold	National Coverage	Population Covered	Population Uncovered	Gap to WHO 80% (pp)
½ hour	53.60%	13.11 million	11.35 million	−26.40
1 hour	65.54%	16.03 million	8.43 million	−14.46
1½ hours	72.56%	17.75 million	6.71 million	−7.44
2 hours	77.15%	18.87 million	5.59 million	−2.85

Applying the WHO/Lancet 80%-at-2-hours benchmark at district level identified 95 underserved districts nationally (45.2% of all districts), against 115 served districts (54.8%). These 95 districts were further classified into four priority tiers (Table 4). Sixty-five districts, two-thirds of all underserved districts, fell into Tier 1 (Critical), recording less than 40% coverage even at 90 minutes; of these, 25 districts recorded literally 0% coverage at every threshold up to 2 hours. Most Tier 1 districts were concentrated in the North-West and South-West regions, with Bamenda (230,369 people, 0% coverage at 2 hours) the single largest critical district nationally (Table 4).

Table 4. Four-tier priority classification of underserved districts.

Tier	Districts	Population	Share of National Population
Tier 1 – Critical	65	4,860,693	19.9%
Tier 2 – High	23	2,333,529	9.5%
Tier 3 – Moderate	5	506,810	2.1%
Tier 4 – Watch	2	296,187	1.2%
Served	115	16,462,315	67.3%

3.3. Prospective Coverage to the Agenda 2063 Horizon

Table 5 and Figure 4 compare national population-weighted coverage at all four thresholds across the three scenarios. At the 2-hour reference threshold, the Catastrophic scenario (S1) projected coverage collapsing to 67.14%, a loss of 10.01 percentage points relative to baseline, driven jointly by road degradation and the high-growth SSP3 population trajectory; 16.99 million people would remain uncovered. The Desirable scenario (S2) projected coverage rising to 89.40%, a gain of 12.25 percentage points above baseline and 9.40 percentage points above the WHO 80% standard, leaving only 4.50 million people uncovered. The gap between the two scenarios, 22.26 percentage points at the 2-hour threshold, quantifies the cost of policy inaction over the 2024–2063 period.

Table 5. National population-weighted coverage comparison across scenarios (S0 vs S1 vs S2).

Threshold	S0 Status Quo	S1 Catastrophic	S2 Desirable	S2 − S0 (pp)	S1 − S0 (pp)
½ hour	53.60%	36.86%	59.44%	+5.84	−16.74
1 hour	65.54%	50.37%	75.84%	+10.30	−15.17
1½ hours	72.56%	59.84%	84.27%	+11.71	−12.72
2 hours	77.15%	67.14%	89.40%	+12.25	−10.01

3.4. Districts Brought into WHO Compliance Across Scenarios

Table 6 tracks the number of districts meeting the WHO 80% coverage standard at 2 hours across the three scenarios. Under the Catastrophic scenario, WHO-compliant districts fell from 115 to 95 (a loss of 20 districts), and the number of districts with literally zero coverage rose from 25 to 33. Under the Desirable scenario, compliant districts rose to 152 (72.4% of all districts), a gain of 37 districts relative to baseline, and all but a single district recorded non-zero coverage at 2 hours, representing a near-complete elimination of absolute accessibility exclusion nationally and shown in Figure 4.

Table 6. Districts meeting the WHO 80% coverage standard at 2 hours, by scenario.

Scenario	Districts ≥ 80% Coverage	Share of 210 Districts	Districts at 0% Coverage
S0 – Status Quo	115	54.8%	25
S1 – Catastrophic	95	45.2%	33
S2 – Desirable	152	72.4%	1

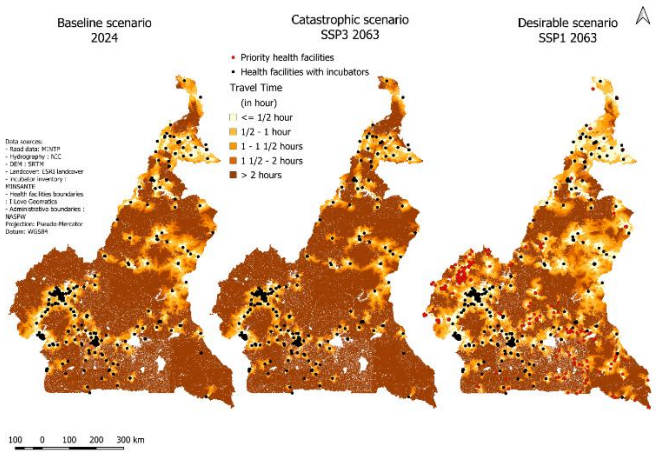

Figure 4: Travel times across the 3 scenarios

4. Discussion

At 77.15% national coverage within two hours, Cameroon's current geographic accessibility to neonatal incubators falls just short, by 2.85 percentage points, of the WHO/Lancet Commission's 80% benchmark, but well behind comparable cost-distance assessments of emergency newborn care elsewhere: Bangladesh reported 72.0% coverage within two hours for basic emergency obstetric and newborn care in 2012, and Malawi 88.1% for emergency obstetric and newborn care in 2015, while Ethiopia's 2016 assessment found only 46.4% coverage for fully functioning emergency neonatal care, with coverage ranging from 15.3% to 100% across its regions [8]. Cameroon's overall figure therefore sits between the Ethiopian and Malawian benchmarks, but these national average masks the same kind of stark sub-national inequality documented in Ethiopia: the North-West and South-West regions recorded zero incubator-equipped facilities in the 2024 inventory, a gap compounded by disrupted health-facility surveying during the ongoing socio-political crisis in those regions.

The prospective analysis shows that this gap is not fixed. Left on its current trajectory and combined with continued road-network neglect and high population growth, national coverage would fall to 67.14% by the Agenda 2063 horizon, a further 10.01 percentage points below today's already-insufficient baseline, and the number of districts recording zero coverage would rise from 25 to 33. Conversely, a Desirable trajectory built on three concrete, costable interventions, road-speed improvement, capacity-strengthening of roughly 2,000 additional priority facilities identified through population-weighted prioritisation, together with a lower-fertility demographic path, would raise national coverage to 89.40%, 9.40 percentage points above the WHO standard, and would bring 152 of 210 districts into compliance. The 22.26 percentage-point spread between the

Catastrophic and Desirable trajectories at the 2-hour threshold is, in effect, a quantified measure of the cost of policy inaction between now and 2063.

These results directly reinforce the equity objectives of Cameroon's PNDS 2021–2025 and give Aspiration 1 of the African Union's Agenda 2063, good health and well-being for all regardless of location, a concrete, spatially explicit target: the difference between Cameroon's best and worst 2063 futures for neonatal incubator accessibility rests on identifiable, costable decisions rather than on chance.

5. Strengths and limitations of this study

- This is, to our knowledge, the first study to model the geographic accessibility of neonatal incubators specifically, rather than obstetric or newborn care services more broadly, across the whole of Cameroon's health-district network.
- The cost-distance surface accounts jointly for road network, land cover, terrain slope, and hydrographic barriers, and the prospective scenarios link travel time directly to costable policy levers, road speed and facility capacity, rather than to abstract projections.
- The analysis measures geographic accessibility exclusively; it does not capture financial, acceptability, or awareness barriers to care, which may further reduce effective access beyond what travel time alone predicts.
- The facility inventory is anchored to 2024 and, in the North-West and South-West regions, may understate true incubator availability owing to disrupted surveying during the ongoing socio-political crisis.
- Prospective scenarios rely on assumed, rather than observed, 2063 road speeds and facility networks; they should be read as bounding trajectories rather than forecasts.

6. Conclusion and Recommendations

Geographic accessibility to neonatal incubators in Cameroon is currently below the WHO/Lancet Commission benchmark and highly unequal across regions, with the North-West and South-West carrying the heaviest and least visible burden. The prospective analysis shows, however, that near-universal accessibility within the Agenda 2063 horizon is achievable, not through an idealised set of conditions, but through concrete and costable interventions: sustained road investment and the targeted strengthening of incubator capacity at the roughly 2,000 facilities identified as priorities in this analysis.

The study recommends that Cameroon's Ministry of Public Health prioritise the Tier 1 Critical districts identified here, most urgently Bamenda, Ndop, Kumbo East, Wum, Kumbo West, Fundong, Ndu and Nkambe, for incubator capacity-strengthening, and that geospatial cost-distance modelling of this kind be integrated as a standing tool in national neonatal health infrastructure planning.

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