

Automated external defibrillator accessibility and overcoverage across the urban-rural gradient: a national cross-sectional geospatial analysis

Sarah Maria Esther Jerjen^a, Armin Gemperli^a

^a University of Luzern, Faculty of Health Sciences and Medicine

Summary

STUDY AIMS: Timely defibrillation is a critical determinant of survival in out-of-hospital cardiac arrests, yet public access to automated external defibrillators (AEDs) remains spatially and temporally uneven, particularly in decentralised health systems. This study aimed to quantify AED accessibility and spatial overcoverage across the urban–rural gradient using high-resolution geospatial data from Switzerland as a model system.

METHODS: We conducted a national cross-sectional geospatial analysis using AED locations (n = 14,446) from Defikarte.ch (December 2024), hectare-level population grids from the Federal Statistical Office (2023) and the 9-category municipality typology. The primary outcome was AED accessibility, defined as the proportion of the population within a 300-metre retrieval buffer of a 24-hour-accessible AED. Secondary outcomes included population coverage gain, comparing current 24-hour AED access with a hypothetical scenario in which all AEDs are accessible 24-hours, and spatial overcoverage, defined as overlapping AED buffers, indicating redundancy. Population exposure quantified the share of residents within these zones. Differences across municipality types were tested using the chi-squared test, paired t-test and Kruskal–Wallis test with Dunn's post-hoc comparison.

RESULTS: Expanding all AEDs to 24-hour access significantly increased national coverage from 28.9% to 51.6% (t = 3.96, p < 0.005) but failed to resolve persistent deficits in agricultural and tourist communes. Statistical tests confirmed significant variation in accessibility (chi-squared test, p < 0.001) and overcoverage (Kruskal–Wallis test, p < 0.001) across municipality types. Overcoverage was concentrated in urban cores, while rural areas exhibited predominantly single-device coverage. Population exposure analysis indicated that overlap zones accounted for 28.6% of the covered population and 8.3% of the total population.

CONCLUSION: This national analysis identified major spatial and temporal inequities in AED accessibility across Switzerland. Expanding all AEDs to 24-hour availability improves coverage but does not resolve structural gaps, with persistent undercoverage in rural areas and clustering in urban cores. Equitable access will require coordinated planning, mandatory 24-hour availability, and spatial redistribution aligned with population needs.

Introduction

Defibrillation is a critical link in the Chain of Survival and one of the few proven interventions that improve outcomes in cardiac arrests with shockable rhythms [1, 2]. Without defibrillation, survival chances in witnessed shockable rhythms decrease by 3–4% per minute even if cardiopulmonary resuscitation (CPR) is provided; rapid intervention is therefore essential [3]. Recognising the time-critical nature of defibrillation, the Swiss Resuscitation Council (SWISSRECA) has set a national target: defibrillation within five minutes in at least 90% of out-of-hospital cardiac arrests (OHCA) [4].

Emergency medical services (EMS) in Switzerland are widely regarded for their reliability and speed, aiming to reach 90% of emergencies within 15 minutes [5]. Yet this benchmark still fails to meet the temporal demands of OHCA care. Even under optimal conditions, EMS response alone

Published

26 February 2026

doi

<https://doi.org/10.57187/4928>

Cite this as

Swiss Med Wkly. 2026;156:4928

Sarah Maria Esther Jerjen

University of Lucerne
Faculty of Health Sciences and
Medicine
Alpenquai 4
CH-6005 Luzern
sarah.jerjen[at]unilu.ch

is rarely fast enough to intervene within this narrow treatment window [3]. This misalignment demonstrates the need for public access interventions that can bridge the gap between collapse and professional care.

Automated external defibrillators (AED) are central to this early response strategy, enabling bystanders to deliver potentially life-saving shocks before EMS arrival. When combined with CPR, AED use by laypersons can double survival rates with good neurological outcomes if applied in a timely fashion [6]. However, the effectiveness of this approach depends not only on public training and awareness but, critically, on the spatial and temporal accessibility of devices [7–9].

In Switzerland, there is no centralised regulatory framework governing AED deployment. Devices are typically installed at the discretion of private entities or local actors, without national coordination or oversight [10]. Compounding this challenge, many AEDs remain inaccessible outside of business hours [11, 12]. This decentralised and unregulated model has produced a fragmented network, raising concerns about the equity, efficiency and strategic logic of AED accessibility across the country.

This study harnesses Switzerland's advanced EMS system as a reference model to examine how AEDs are distributed across space and time, and how decentralised deployment affects equity and efficiency. Specifically, it aims to:

- Assess coverage gaps by quantifying the population within 300 metres of a 24-hour-accessible AED, disaggregated by municipality type.
- Evaluate the effect of converting restricted-hour AEDs to 24-hour access on national and municipal coverage levels.
- Identify patterns of overcoverage under both current and expanded AED availability scenarios.

By quantifying these dimensions, the study provides evidence to inform more equitable and strategic AED deployment, not only in Switzerland, but in other health systems characterised by decentralised infrastructure and limited regulatory oversight.

Methodology

This study used a national cross-sectional observational design applying spatial analytical methods to assess AED accessibility and overcoverage across Switzerland.

Data sources and analytical tools

AED location data were sourced from Defikarte.ch, a public, continuously updated registry of AEDs. As of December 2024, the dataset comprised 14,446 AEDs, of which 5666 were accessible on a 24-hour basis and 8780 with restricted hours of availability [11]. Population data were obtained from the Federal Statistical Office's (FSO) 2023 hectare-level population grids [13]. Municipalities were classified according to the 2014 FSO typology, which delineates nine distinct categories in descending order of urbanisation: Big Centres, Secondary Centres, Crown Big Centres, Medium Centres, Crown Medium Centres, Small Centres, Peri-Urban Rural Communes, Agricultural Communes and Tourist Communes. This classification incorporates employment structure, commuting patterns, population density and accessibility, thereby providing a functional, rather than purely morphological, urban–rural distinction that accounts for daytime population flux and workplace clustering [14]. The study covered all Swiss municipalities and used a complete census of registered AEDs together with the national population grid. No sampling or sample size calculation was required.

All spatial analyses were performed using QGIS 3.32 and R 4.3.2 (EPSG:2056). Both software environments are distributed under GNU General Public License. Geospatial processing used the *sf*, *terra* and *exactextractr* packages. Statistical modelling and visualisation were performed using *tidyverse*, *car* and *ggspatial*. Statistical significance was set at $p < 0.05$.

Spatial accessibility analysis

The primary outcome was to quantify AED accessibility, defined as the proportion of the population within a 300-metre Euclidean retrieval buffer of a 24-hour available AED ("24-hour AEDs" scenario). This threshold represents a feasible retrieval distance for bystanders, corresponding to a round trip travel time of ~4 minutes at an average emergency walking speed, and thus falls well within the critical 10-minute defibrillation window [11, 15]. Buffers were intersected with population grids to calculate the number of individuals with access. Accessibility was first calculated for each municipality to enable detailed mapping and spatial visualisation and then aggregated by municipi-

pality type for comparative statistical analysis. Both covered and uncovered populations were quantified, and an absolute and relative difference metric, expressed as percentage deviation from the national mean, were calculated to standardise comparisons of accessibility disparities across municipality types. Statistical significance of differences in AED accessibility by municipality type was tested using a chi-squared test of independence. The chi-squared test used a 2×9 contingency table (covered/uncovered residents \times municipality types).

Population coverage gains under full AED accessibility assumption

To assess the potential impact of universal 24-hour AED accessibility, two scenarios were compared: (1) the status quo, considering only current 24-hour AEDs, and (2) a hypothetical scenario in which all AEDs, including those with restricted access hours, are assumed to be accessible 24-hours ("All AEDs" scenario). For each scenario, population coverage was recalculated, and absolute as well as percentage gains in accessibility were determined. The difference in coverage between the two scenarios, referred to as population coverage gain, served as a secondary outcome. The statistical significance of expanded coverage was tested via a paired t-test, comparing population coverage between the scenarios across the nine municipality types. Resultant percentage increases were mapped to visualise spatial variation in accessibility gains.

Quantification of spatial overcoverage

To assess for potential AED redundancy, a raster-based overlap analysis was conducted. AED buffers were rasterised at 10-metre resolution, with each cell recording the number of overlapping buffers. Cells with two or more overlaps were classified as overcovered, indicating possible spatial inefficiency, while single-buffer cells served as the baseline for comparison. These metrics formed the basis for additional analysis, included extreme overlap (cells with three or more AED buffers) and population exposure to overcoverage, expressed as both the proportion of the total population and the AED-covered population located within overlapping zones. Municipality types were assigned to each raster cell via spatial join, enabling stratified analysis by urbanisation level. National- and municipality-level summary statistics, including mean, maximum, standard deviation and coefficient of variation, were computed for both scenarios (24-hour AEDs and All AEDs). Single coverage cells were additionally reported as an indicator of unique AED reach to contextualise coverage efficiency.

Differences in raster-based overlap intensity across municipality types were tested using the Kruskal–Wallis test, followed by Dunn's pairwise comparisons with Bonferroni correction.

Results

AED coverage by municipality typology

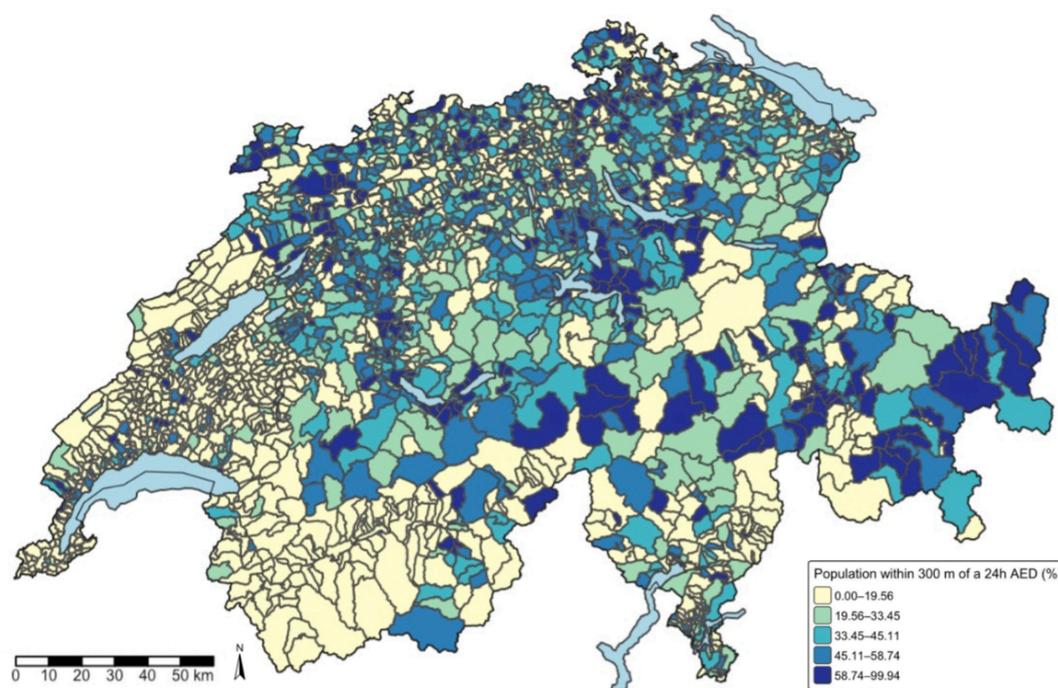
At the national level, 28.9% of the population resides within 300 metres of a 24h AED (table 1). A statistically significant association is observed between municipality type and AED accessibility ($\chi^2 = 18,034.35$, $p = 0.001$), indicating that coverage differences are unlikely to be attributable to random variation. Coverage is lower than the national average in Big Centres (25.5%) and Agricultural Communes (25.7%). Secondary Centres (28.4%) and Tourist Communes (28.8%) report values close to the national mean. Higher coverage is observed in Crown Big Centres (29.6%), Medium Centres (29.6%), Small Centres (30.0%), Crown Medium Centres (30.9%) and Peri-Urban Rural Communes (31.1%).

Table 1: Population distribution in relation to 24-hour AED accessibility, by municipality type. Values indicate the percentage of the population within and beyond a 300-metre buffer of a 24h AED. Absolute and relative differences were calculated with respect to the national mean, shown in percentage points (pp) and percent deviation. Each municipality type's share of the total population is also provided (Population share). Municipality categories follow the Federal Statistical Office functional urban-rural typology, which classifies municipalities into nine types in descending order of urbanisation based on employment structure, commuting intensity, population density and accessibility.

Municipality type	Population share (%)	Population not covered (%)	Population covered (%)	Absolute difference vs national value (pp)	Relative difference vs national value (%)
Aggregate national value	100.0%	71.07%	28.93%	0.00	0.00%
Big Centres	16.0%	74.54%	25.46%	-3.47	-11.99%
Secondary Centres	10.8%	71.64%	28.36%	-0.57	-1.97%
Crown Big Centres	17.9%	70.43%	29.57%	0.64	2.21%
Medium Centres	12.7%	70.41%	29.59%	0.66	2.28%
Crown Medium Centres	15.9%	69.05%	30.95%	2.02	6.99%
Small Centres	2.5%	69.98%	30.02%	1.09	3.77%
Peri-urban Rural Communes	14.6%	68.94%	31.06%	2.13	7.36%
Agricultural Communes	7.3%	74.32%	25.68%	-3.25	-11.23%
Tourist Communes	2.3%	71.19%	28.81%	-0.12	-0.42%

Figure 1 shows AED accessibility for each individual municipality across Switzerland, expressed as the percentage of residents within 300 metres of a 24-hour-accessible AED. Unlike table 1, which reports averages by municipality type, the map displays the distribution of accessibility at full municipal resolution.

Figure 1: Each polygon represents a single municipality, shaded by the percentage of residents located within 300 metres of a 24-hour-accessible AED. Values were derived by intersecting hectare-level population grids with 300-metre AED buffers. Classification intervals follow quantile breaks (EPSG:2056). Ranges are lower-bound inclusive and upper-bound exclusive; boundary values belong to the lower class.



Population coverage gains under universal 24h AED accessibility

Expanding all AEDs to 24-hour accessibility increases the national number of continuously available AEDs from 5666 to 14,446 and raises population coverage from 28.9% to 51.6%, corresponding to an absolute gain of 8780 devices and a 22.7 percentage point (pp) increase in coverage (table 2). Coverage gains vary across municipality types. The largest increases are observed in Big and Secondary Centres, with a 507.7% and 260.0% increase, respectively, in AED availability, and a 39.5 pp and 33.7 pp increase in population coverage. In contrast, Agricultural and Tourist Communes register smaller increases in AEDs, 54.1% and 100.2% respectively, and remain below the national post-expansion population coverage average (8.1 pp and 12.3 pp, respectively). A map visualising these coverage increases by municipality is shown in the appendix (figure S1).

A statistically significant increase in AED coverage is observed between the 24-hour AEDs and All AEDs scenarios ($t = 3.9594$, $df = 8$, $p < 0.005$). On average, 229,914 additional individuals gained coverage following the extension to 24-hour AED availability (95% confidence interval: [96,010– 363,818]).

Table 2: AED availability and population coverage under expanded 24-hour access, by municipality type. Counts reflect the number of AEDs in each scenario: currently 24-hour-accessible devices ("24-hour AEDs") and all registered devices ("All AEDs"). "Absolute increase" and "Percentage increase" measure the numerical and proportional growth in devices under universal 24-hour accessibility. "Population covered (%)" indicates the proportion of residents within a 300-metre retrieval buffer, and "Population coverage increase (pp)" indicates the absolute gain in coverage, expressed as the difference in percentage points between the current and expanded scenarios.

Municipality type	24-hour AEDs count	All AEDs count	Absolute increase	Percentage increase	Population not covered (%)	Population covered (%)	Population coverage increase (pp)
Aggregate national value	5666	14,446	8780	154.97%	48.36%	51.64%	22.71
Big Centres	337	2048	1711	507.71%	35.02%	64.98%	39.52
Secondary Centres	430	1548	1118	260.00%	37.93%	62.07%	33.71
Crown Big Centres	855	2005	1150	134.50%	51.54%	48.46%	18.93
Medium Centres	559	1898	1339	239.54%	41.14%	58.86%	29.27
Crown Medium Centres	909	2160	1251	137.65%	50.11%	49.89%	18.94
Small Centres	171	471	300	175.44%	49.21%	50.79%	20.78
Peri-urban Rural Communes	1214	2305	1091	89.84%	55.46%	44.54%	13.48
Agricultural Communes	811	1250	439	54.13%	66.24%	33.76%	8.08
Tourist Communes	380	761	381	100.26%	58.92%	41.08%	12.29

AED overcoverage by municipality type

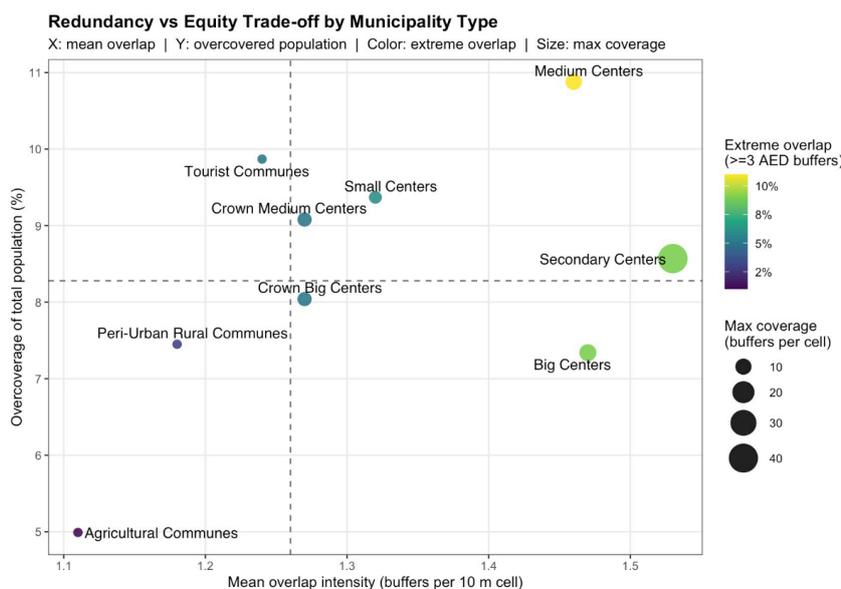
Under the current 24-hour AED availability scenario, the national mean buffer overlap is 1.3 with municipality-level means ranging from 1.1 (Agricultural Communes) to 1.5 (Secondary Centres). The median overlap across all types remains 1.0. The maximum observed overlap is 41, while standard deviations range from 0.4 to 2.1, and the coefficient of variation spans 0.3 to 1.3. In Big Centres, 70% of AEDs have single coverage; in Agricultural Communes it is 90%. The proportion of extreme overlap (three or more overlapping AEDs) relative to area with any overlapping coverage ranges from 1% (Agricultural Communes) to 11% (Medium Centres). In terms of population exposure, 28.6% of the AED-covered population resides in areas with overcoverage (≥ 2 AEDs), with values ranging from 19.4% (Agricultural Communes) to 36.8% (Medium Centres). As a share of the total population, overcoverage ranges from 5.0% to 10.9% with a national average of 8.3% (table 3).

Table 3: AED coverage density and population overcoverage under “24-hour AEDs” accessibility, by municipality type. Zone-based indicators quantify AED buffer overlap for the existing network of *currently 24-hour-accessible devices*. AED coverage was modelled using 300-metre buffers rasterised at 10-metre resolution. “Mean”, “Median”, “Max”, “Standard deviation (Std. Dev.)” and “Coefficient of variation (CV)” describe the distribution and variability of overlap intensity. “Single coverage” and “Extreme overlap” represent the proportion of raster cells with exactly one AED or with three or more overlapping AEDs, respectively, relative to all cells within AED-covered areas. Population-based indicators quantify residents located in overcovered zones (two or more overlapping buffers), expressed as a percentage of the AED-covered population (“Overcoverage within covered areas (%)”) and of the total national population (“Overcoverage of total population (%)”).

Municipality type	Zones							Population	
	Mean coverage	Median coverage	Max coverage	Std. dev. coverage	CV coverage	Single coverage	Extreme overlap	Overcoverage within covered areas (%)	Overcoverage of total population (%)
Aggregate national value	1.26	1	41	0.80	0.63	0.82	0.05	28.61%	8.28%
Big Centres	1.47	1	11	1.00	0.68	0.70	0.09	28.73%	7.34%
Secondary Centres	1.53	1	41	2.09	1.33	0.74	0.09	30.17%	8.57%
Crown Big Centres	1.27	1	8	0.62	0.49	0.80	0.05	27.24%	8.04%
Medium Centres	1.46	1	10	0.92	0.63	0.72	0.11	36.84%	10.88%
Crown Medium Centres	1.27	1	8	0.63	0.50	0.81	0.05	29.34%	9.08%
Small Centres	1.32	1	7	0.71	0.54	0.77	0.06	31.27%	9.37%
Peri-urban Rural Communes	1.18	1	6	0.50	0.43	0.86	0.03	24.00%	7.45%
Agricultural Communes	1.11	1	6	0.37	0.34	0.90	0.01	19.42%	4.99%
Tourist Communes	1.24	1	6	0.62	0.50	0.84	0.05	34.25%	9.87%

Figure 2 presents the same indicators, illustrating the relationship between mean overlap intensity, maximum overlap, extreme overlap proportion and population overcoverage.

Figure 2: Scatterplot showing the relationship between mean AED overlap intensity (x-axis) and the proportion of the total population living in overcovered zones (y-axis) across Swiss municipality types under the 24-hour AEDs scenario. Circle size indicates the maximum number of overlapping AED buffers per 10-metre raster cell, and colour represents the proportion of AED-covered area exhibiting extreme overlap (≥ 3 AED buffers). Dashed lines mark national mean values for both axes. The figure illustrates the spatial trade-off between redundancy (multiple overlapping AED zones) and equity (population share with access), showing that redundancy is concentrated in urban zones while rural and agricultural communes remain predominantly single-covered.



With expanded 24-hour accessibility for all AEDs, the national mean overlap increases to 1.8 with a range from 1.3 (Agricultural Communes) to 3.7 (Big Centres). The median remains 1.0, while the maximum overlap rises to 44. Standard deviations now range from 0.6 to 4.4, and coefficients of

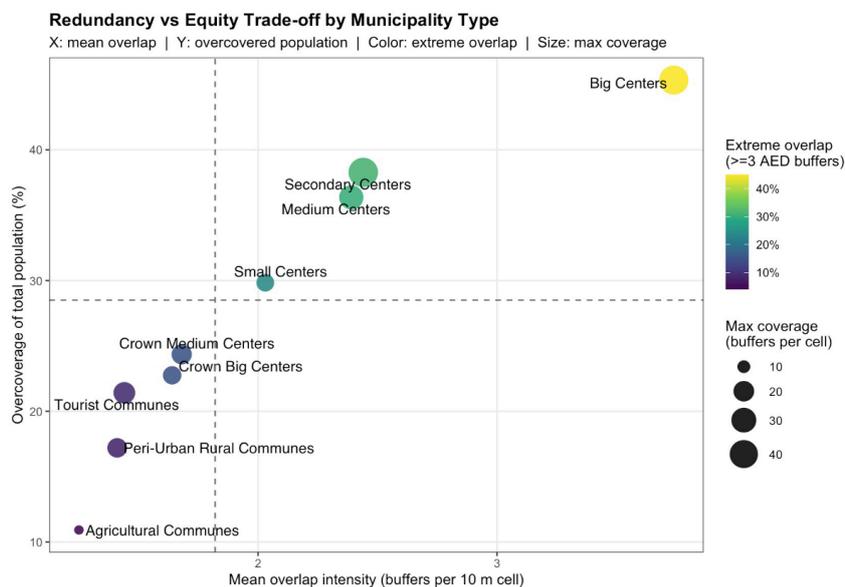
variation from 0.5 to 1.2. The share of single AED coverage declines, ranging from 34% (Big Centres) to 82% (Agricultural Communes). Extreme overlap becomes more pronounced, with values spanning 4% (Agricultural Communes) to 45% (Big Centres). Overcoverage within the covered population increases to a national average of 54.3%, with municipality values ranging from 32.2% (Agricultural Communes) to 69.7% (Big Centres). When considering the total population, overcoverage ranges from 10.9% (Agricultural Communes) to 45.3% (Big Centres) with a national mean of 28.5% (table 4).

Table 4: AED coverage density and population overcoverage under expanded “All AEDs” accessibility, by municipality type. Zone-based indicators quantify AED buffer overlap under a modelled scenario in which all registered AEDs are assumed to be accessible 24 hours. AED coverage was modelled using 300-metre buffers rasterised at 10-metre resolution. “Mean”, “Median”, “Max”, “Standard deviation (Std. Dev.)” and “Coefficient of variation (CV)” describe the distribution and variability of overlap intensity. “Single coverage” and “Extreme overlap” represent the proportion of raster cells with exactly one AED or with three or more overlapping AEDs, respectively, relative to all cells within AED-covered areas. Population-based indicators quantify residents located in overcovered zones (two or more overlapping buffers), expressed as a percentage of the AED-covered population (“Overcoverage within covered areas (%)”) and of the total national population (“Overcoverage of total population (%)”).

Municipality type	Zones							Population	
	Mean coverage	Median coverage	Max coverage	Std. Dev coverage	CV coverage	Single coverage	Extreme overlap	Overcoverage within covered areas (%)	Overcoverage of total population (%)
Aggregate national value	1.82	1	44	1.91	1.05	0.65	0.17	54.30%	28.50%
Big Centres	3.74	1	43	4.42	1.18	0.34	0.45	69.65%	45.33%
Secondary Centres	2.44	1	44	2.34	0.96	0.46	0.31	61.64%	38.27%
Crown Big Centres	1.64	1	16	1.21	0.74	0.66	0.15	46.86%	22.75%
Medium Centres	2.39	1	28	2.25	0.94	0.49	0.30	61.70%	36.36%
Crown Medium Centres	1.68	1	19	1.34	0.80	0.65	0.15	48.75%	24.35%
Small Centres	2.03	1	15	1.70	0.84	0.58	0.24	58.83%	29.83%
Peri-urban Rural Communes	1.41	1	18	1.00	0.70	0.76	0.08	38.46%	17.20%
Agricultural Communes	1.25	1	9	0.63	0.51	0.82	0.04	32.15%	10.92%
Tourist Communes	1.44	1	22	1.15	0.80	0.76	0.09	51.88%	21.41%

Figure 3 presents the corresponding distribution for the All AEDs scenario, illustrating the intensified overlap patterns and expansion of overcovered population areas.

Figure 3: Scatterplot showing the relationship between mean AED overlap intensity (x-axis) and the proportion of the total population living in overcovered zones (y-axis) across Swiss municipality types under the “All AEDs” scenario. Circle size indicates the maximum number of overlapping AED buffers per 10-metre raster cell, and colour represents the proportion of AED-covered area exhibiting extreme overlap (≥ 3 AED buffers). Dashed lines mark national mean values for both axes. The figure illustrates the spatial trade-off between redundancy (multiple overlapping AED zones) and equity (population share with access), showing that redundancy is concentrated in urban zones while rural and agricultural communes remain predominantly single-covered.



Non-parametric tests indicate statistically significant differences in AED buffer overlap across municipality types in both scenarios ($\chi^2 = 318,052$ and $\chi^2 = 2,320,102$; $p < 0.001$). All pairwise comparisons are statistically significant based on Bonferroni-adjusted Dunn's tests (adjusted $p < 0.001$). Figure S2 in the appendix illustrates this distribution of AED coverage density by municipality type.

Discussion

Key findings

This study identified spatial and temporal inequities in AED accessibility across Switzerland. Nationally, fewer than one-third of the population resides within 300 metres of a 24-hour AED. Accessibility varied by municipality type, with the lowest access observed in both highly urbanised centres and rural/agricultural communes. This dual underperformance challenges the assumption that population concentration ensures coverage and suggests structural deficiencies in current deployment practices. Peri-urban and mid-density municipalities performed best, combining moderate density with favourable spatial layouts that support broad coverage without excessive overlap. Their patterns offer a practical model for optimising AED deployment in underserved areas.

Scenario modelling showed that converting all AEDs to 24-hour availability would increase population coverage from 28.9% to 51.6%. However, gains were concentrated in Big and Secondary Centres, while Agricultural and Tourist Communes remained well below the national average. This indicates that expanding access hours improves coverage mostly where devices are already present. In areas lacking AEDs, temporal expansion alone offers limited benefit. Spatial redistribution remains essential to address persistent deficits.

Overcoverage analysis revealed extreme clustering in urban areas, with up to 44 AEDs overlapping, while rural zones exhibited almost exclusively single-device coverage. This imbalance reflects overcoverage where coverage is sufficient and exclusion where availability is most constrained. Extreme urban overlap appears driven by logistical convenience or institutional presence rather than strategy. In rural areas, the lack of overlap points to basic shortage of devices, not deliberate planning. Without oversight, both redundant deployment and systemic exclusion persist.

These findings expose a clear disconnect between AED deployment and population need. The network remains fragmented and inefficient, shaped by local discretion rather than coordinated public health strategy.

Implications

The spatial and temporal disparities identified in this study are not incidental. They are shaped by the absence of coordinated governance, binding regulation, and continued reliance on voluntary local initiative. Deployment is often left to firms, municipalities or civil societies based on the assumption that each actor will service its own population. This model of self-regulation has led to inconsistent coverage and uneven deployment. Switzerland's federalist structure enables regional flexibility, but in the absence of binding regulation, placement decisions remain uncoordinated and misaligned with population needs. This interpretation is directly grounded in the observed pattern of undercoverage in both highly urbanised and rural/agricultural municipalities, where current self-regulated deployment fails to align with exposure risk. Other countries have recognised this challenge: England introduced centralised AED placement strategies based on population need [16]; France identified major regional disparities and called for coordinated planning [17]; and Denmark established a national AED registry with real-time data integration and systematic oversight [18]. In line with these developments, Switzerland must prioritise a coordinated deployment strategy that aligns AED placement with population needs. A legal mandate for 24-hour accessibility could form part of this broader effort to guarantee accessibility regardless of ownership or location [9, 16, 18].

Expanding all AED availability to 24 hours improves temporal access; however, it does not fill spatial gaps where devices were never installed. Prior studies confirm the benefit of 24-hour availability, particularly in urban areas: Hansen et al. showed that over half of OHCA near AEDs occurred when the devices were inaccessible [7], and Sun et al. found that accounting for temporal availability improved modelled coverage by over 25% compared to spatial-only approaches [9]. Nevertheless, our findings show that this strategy has limited effect in structurally underserved areas. In rural and agricultural communes, where AEDs are largely absent, making all existing devices 24-hour-accessible does little to improve the population coverage. Redistribution of devices is therefore essential. AEDs bridge the critical time until EMS arrives, a function most vital in regions with prolonged response times. Swiss data confirm persistent EMS delays in rural areas despite system improvements [19], and English models link sparse coverage and delayed arrivals to higher mortality [20]. Our results, coupled with these findings, highlight a misalignment: the areas that benefit least from expanded availability are precisely those where rapid defibrillation is most urgently needed.

This disparity between exclusion in underserved areas and excessive overlap urban cores is compounded by inefficient device concentration in other areas. Our analysis showed excessive overlap in urban cores, with some locations covered by over 40 AEDs. While a certain level of redundancy may improve system reliability, overlaps beyond two AEDs offer diminishing returns and undermine overall efficiency. These patterns were clearly visible in the buffer overlap results, where extreme overcoverage in some areas contrasted with coverage gaps in others, confirming earlier national findings of clustered AED distribution [12]. Prior studies have raised similar concerns: Aeby et al. showed that retrospective analysis of OHCA locations in parts of Switzerland can identify inefficient AED clustering, and enable cost-neutral relocations to expand effective coverage [21]. Sun et al. similarly found that clustering in high-traffic areas generates spatial inefficiencies and proposed equity-based optimisation models [9]. Overcoverage persists due to the absence of regulatory mechanisms to limit oversupply or evaluate whether device concentration yields meaningful gains in coverage or survival. Without such evaluation, clustering can create the illusion of accessibility while leaving other areas underserved. The coexistence of extreme overlap and population segments entirely excluded from AED coverage stresses the need for redistribution, not just expansion.

Not all areas perform poorly. Peri-urban and mid-density municipalities consistently outperformed others in both accessibility and overlap metrics. Their moderate density and favourable spatial form supported broad coverage without excessive clustering. This suggests that spatial configuration and functional layout may matter more than population size or simple urban-rural distinction. In other words, geographic typology and not just density shapes coverage potential. This perspective is supported by prior research that has moved beyond binary urban-rural classifications: Brown et al. optimised AED placement in England using walking distance and land use-based points of interest [16], while others have integrated infrastructure-sensitive variables such as pedestrian networks, road connectivity and built environment intensity to better align deploy-

ment with actual access potential [22, 23]. Our typology-based findings align with these insights. Mid-density municipalities, with their favourable built form and functional layout, outperform both urban and rural areas without formal optimisation, offering a practical, transferable model for improving AED distribution through typology-informed planning. This highlights the strategic value of incorporating structural and functional context into deployment decisions.

Improving AED access requires integration between public and private stakeholders. Many devices are installed by private entities but are relied upon as part of the public response system. Defikarte.ch has advanced centralisation efforts and offers a functional model for registry-based coordination [11]. But for true system reliability, its continued support and expansion are essential. To be fully effective, participation must be mandatory. Formal coordination mechanisms, legal registration requirements and shared accountability frameworks are needed to ensure that all devices, regardless of ownership, contribute to a reliable and equitable emergency network [24].

The methods in this study provide a foundation for strategic planning. Typology-based disaggregation, buffer overlap and population-weighted accessibility offer actionable indicators of both inefficiency and exclusion. These tools should be embedded in regular spatial audits to guide deployment decisions. For example, identifying areas with extreme overlap or complete coverage gaps provides direct targets for intervention and risk mitigation. Unless guided by structured oversight and deliberate reallocation, future AED expansion will likely perpetuate existing geographic imbalances. The methodological approach used here integrates empirical statistical metrics, typology analysis and accessibility modelling and can be adapted for use in other decentralised systems facing similar coordination challenges.

Limitations and strengths

Several limitations should be considered when interpreting these findings. AED data were sourced from a community-driven, continuously updated registry based on OpenStreetMap infrastructure. Although it represents the most extensive dataset currently available, registration is voluntary and unvalidated so completeness cannot be verified. Regional participation may vary, and results should therefore be interpreted as conservative lower-bound estimates of AED accessibility. The analysis used hectare-level residential population grids, which do not capture daytime mobility or non-residential activity and may underestimate accessibility in workplace or transit areas. Nonetheless, this proxy remains epidemiologically justified, as approximately 67% of OHCA in Switzerland occur in private residences [25]. The municipality typology partly compensates for this limitation by integrating commuting and employment characteristics. Accessibility was modelled using uniform 300-metre Euclidean buffers, representing standardised potential retrieval ranges rather than confirmed real-world reach, which would need to account for barriers such as building configurations, terrain or vertical access. While this simplification may overestimate reach, it ensures reproducibility and comparability across municipalities and countries. The resulting bias is conservative, reinforcing confidence in the persistence of identified coverage gaps. Overcoverage likewise quantifies spatial redundancy, not functional inefficiency, considering that multiple AEDs within a high-traffic facility may be appropriate. These definitions are intentionally structural, providing transparent, reproducible measures of spatial equity rather than behavioural performance indicators of how devices are used. Accordingly, the results reflect infrastructure efficiency and do not directly measure clinical effectiveness or survival outcomes.

This study also brings several strengths. Unlike most AED research, which is often limited to individual cities or broad urban–rural comparisons, this analysis covers the entire country at high spatial resolution. It uses a functional municipality typology that reflects commuting patterns, density and access, allowing for more precise analysis of equity. The study also combines spatial and temporal availability, distinguishing between currently accessible AEDs and those that could be made available at all hours. While most studies treat expanded 24-hour availability as a sufficient solution, this analysis demonstrates that time-based access alone does not resolve underlying spatial gaps, particularly in rural and underserved areas. In addition, the analysis explicitly addresses AED overcoverage, a rarely examined aspect in the literature. By quantifying the extent and variation of spatial redundancy, the study sheds light on inefficiencies in heavily serviced urban zones and stresses the need for more coordinated deployment strategies. The focus on underserved areas, paired with policy-relevant scenario modelling, helps move beyond description and points to concrete options for improving emergency preparedness.

Conclusion

This national analysis revealed pronounced spatial and temporal disparities in public AED accessibility across Switzerland, shaped by the country's decentralised and voluntary deployment model. Expanding all AEDs to 24-hour availability improves overall coverage but leaves structural inequities largely unchanged, with persistent undercoverage in rural and tourist areas and inefficient clustering in urban cores. These findings point to systemic inefficiencies in both accessibility and coverage balance. To strengthen equity and reliability in defibrillation access, national efforts should prioritise spatial redistribution of devices, mandate 24-hour accessibility and establish co-ordinated planning frameworks that align AED deployment with population needs and emergency response capacity.

Data sharing statement

This study used publicly available, geospatial datasets. AED location data, as of 14 December 2024, were obtained from the Defikarte.ch repository maintained by Christian Nüssli and the OpenBrackets Association, accessible at https://github.com/OpenBracketsCH/defi_data. These data are licensed under the MIT License and updated daily via Overpass API automation. Population grids and municipality typologies were obtained from the Swiss Federal Statistical Office (FSO) and are available at <https://www.bfs.admin.ch> and <https://www.geo.admin.ch>.

All spatial and statistical analyses were performed under open-source environments and general public license (GPL). Geospatial processing was conducted in QGIS 3.32 (EPSG:2056) and R 4.3.2 using the following packages: *sf* (v1.0-20, GPL-2 | GPL-3), *terra* (v1.8-21, GPL-3), *exactextractr* (v0.10.0, GPL-3), *ggspatial* (v1.1-10, GPL-3), *car* (v3.1-3, GPL-2 | GPL-3) and the *tidyverse* collection (GPL-2 | GPL-3) for data management and visualisation.

All code was written in R using reproducible workflows and standardised syntax for spatial operations and statistical testing. The analysis pipeline relied exclusively on open-source tools and does not contain proprietary software or licensed algorithms. Analytical code can be made available upon reasonable request; no new or unpublished software libraries were developed for this study.

Acknowledgments

The authors thank Christian Nüssli for his work in developing and maintaining <https://defikarte.ch/>, the national AED registry that served as the primary data source for this study. His contributions to improving AED transparency and accessibility in Switzerland are gratefully acknowledged.

Financial disclosure

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Potential competing interests

Both authors have completed and submitted the International Committee of Medical Journal Editors form for disclosure of potential conflicts of interest. No potential conflict of interest related to the content of this manuscript was disclosed.

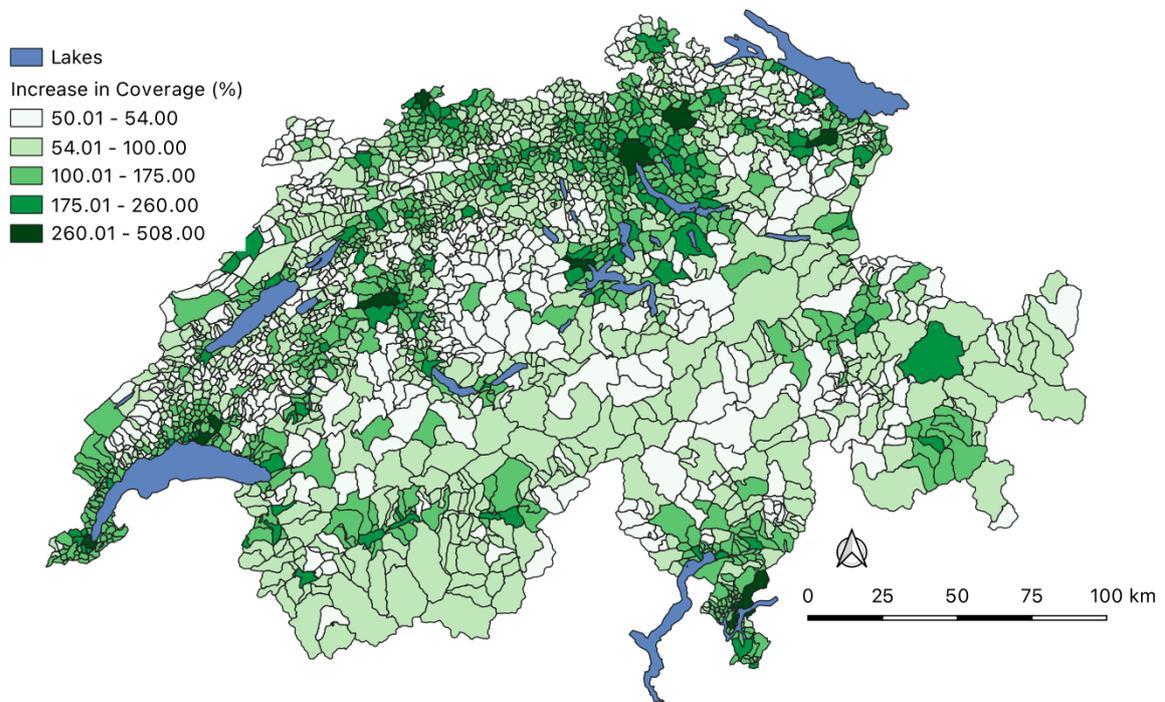
References

- Deakin CD, Nolan JP; European Resuscitation Council. European Resuscitation Council guidelines for resuscitation 2005. Section 3. Electrical therapies: automated external defibrillators, defibrillation, cardioversion and pacing. *Resuscitation*. 2005 Dec; Suppl 1:S25–37. <https://doi.org/10.1016/j.resuscitation.2005.10.008> 16321714 0300-9572
- Weisfeldt ML, Sittani CM, Ornato JP, Rea T, Aufderheide TP, Davis D, et al.; ROC Investigators. Survival after application of automatic external defibrillators before arrival of the emergency medical system: evaluation in the resuscitation outcomes consortium population of 21 million. *J Am Coll Cardiol*. 2010 Apr;(16):1713–20. <https://doi.org/10.1016/j.jacc.2009.11.077> 20394876 1558-3597
- Ibrahim WH. Recent advances and controversies in adult cardiopulmonary resuscitation. *Postgrad Med J*. 2007 Oct;(984):649–54. <https://doi.org/10.1136/pgmj.2007.057133> 17916874 1469-0756
- Swiss Resuscitation Council. Jahresbericht 2023. Annual Report, Bern: Swiss Resuscitation Council SRC.
- Strauss C, Bildstein G, Efe J, Flacher T, Hofmann K, Huggler M, et al. Optimizing Emergency Medical Service Structures Using a Rule-Based Discrete Event Simulation-A Practitioner's Point of View. *Int J Environ Res Public Health*. 2021 Mar;(5):2649. <https://doi.org/10.3390/ijerph18052649> 33808033 1660-4601
- Lee SG, Park JH, Ro YS, Hong KJ, Song KJ, Shin SD. Time to first defibrillation and survival outcomes of out-of-hospital cardiac arrest with refractory ventricular fibrillation. *Am J Emerg Med*. 2021 Feb;(96):96–102. <https://doi.org/10.1016/j.ajem.2020.12.019> 33360396 1532-8171
- Hansen CM, Wissenberg M, Weeke P, Ruwald MH, Lamberts M, Lippert FK, et al. Automated external defibrillators inaccessible to more than half of nearby cardiac arrests in public locations during evening, nighttime, and weekends. *Circulation*. 2013 Nov;(20):2224–31. <https://doi.org/10.1161/CIRCULATIONAHA.113.003066> 24036607 1524-4539
- Karlsson L, Malta Hansen C, Wissenberg M, Møller Hansen S, Lippert FK, Rajan S, et al. Automated external defibrillator accessibility is crucial for bystander defibrillation and survival: A registry-based study. *Resuscitation*. 2019 Mar;(30):7. <https://doi.org/10.1016/j.resuscitation.2019.01.014> 30682401 1873-1570

9. Sun CL, Demirtas D, Brooks SC, Morrison LJ, Chan TC. Overcoming Spatial and Temporal Barriers to Public Access Defibrillators Via Optimization. *J Am Coll Cardiol*. 2016 Aug; (8):836–45. <https://doi.org/10.1016/j.jacc.2016.03.609> 27539176 1558-3597
10. Moens E, Degraeuwe E, Caputo Maria L, Cresta R, Arys R, Van Moorter N, et al. A road-map to building first responder networks: lessons learned and best practices from Belgium and Switzerland. *Resusc Plus*. 2023 Sep;:100469. <https://doi.org/10.1016/j.resplu.2023.100469> 37779882 2666-5204
11. Nüssli C. <https://defikarte.ch/>.
12. Jerjen SM, Gemperli A. Spatiotemporal disparities in automated external defibrillator access: identifying national deficits. *Resusc Plus*. 2025 Oct;:101135. <https://doi.org/10.1016/j.resplu.2025.101135>; Epub ahead of print.41234716 2666-5204
13. Federal Statistical Office. Population and Households (STATPOP) 2023, <https://www.bfs.admin.ch/bfs/en/home/services/geostat/swiss-federal-statistics-geodata/population-buildings-dwellings-persons/population-housholds-from-2010.html>
14. Federal Office of Spatial Development. Typology of Municipality, <https://www.bfs.admin.ch/bfs/en/home/statistics/territory-environment/nomenclatures/gemtyp.html> (2014).
15. Basanta Camiño S, Navarro Patón R, Freire Tellado M, Barcala Furelos R, Pavón Prieto MP, Fernández López M, et al. Assessment of knowledge and skills in using an Automated External Defibrillator (AED) by university students. A quasi-experimental study. *Med Intensiva*. 2017;(5):270–6. <https://doi.org/10.1016/j.medine.2017.04.005> 27773493 1578-6749
16. Brown TP, Andronis L, El-Banna A, Leung BK, Arvanitis T, Deakin C, et al. Optimisation of the deployment of automated external defibrillators in public places in England. *Health Soc Care Deliv Res*. 2025 Feb;(5):1-179. <https://doi.org/10.3310/HTBT7685> 40022724 2755-0079
17. Karam N, Narayanan K, Bougouin W, Benameur N, Beganton F, Jost D, et al. Major regional differences in Automated External Defibrillator placement and Basic Life Support training in France: further needs for coordinated implementation. *Resuscitation*. 2017 Sep;:49–54. <https://doi.org/10.1016/j.resuscitation.2017.07.002> 28689047 1873-1570
18. Karlsson L, Hansen CM, Wissenberg M, Hansen SM, Lippert F, Rajan S, et al. Implementation, Temporal Changes, and Follow up of a Nationwide AED-Network. *Resuscitation*. 2016;:e10. <https://doi.org/10.1016/j.resuscitation.2016.07.024> 0300-9572
19. Strauss C, Schmid M, Kliem D, Müller M. Insights from a Decade of Optimizing Emergency Medical Services Across Three Major Regions in Switzerland. *Emerg Care Med*. 2024;(4):368–81. <https://doi.org/10.3390/ecm1040036> 2813-7914
20. Harries M, Ushakova A. Modelling emergency response times for Out-of-Hospital Cardiac Arrest (OHCA) patients in rural areas of the North of England using routinely collected data. *BMC Emerg Med*. 2025 Jan;(1):8. <https://doi.org/10.1186/s12873-025-01170-7> 39794728 1471-227X
21. Aeby D, Staeger P, Dami F. How to improve automated external defibrillator placement for out-of-hospital cardiac arrests: A case study. *PLoS One*. 2021 May;(5):e0250591. <https://doi.org/10.1371/journal.pone.0250591> 34014960 1932-6203
22. Despoina K, Evangelos K, Yiannis B; Science IJ of SR in C. Ijrcseit E and IT. Strategic Mapping and Optimised Allocation of Automated External Defibrillators in Urban Areas. *Int J Sci Res Comput Sci Eng Inf Technol*. 2020 Jan;:138–45. <https://doi.org/10.32628/CSEIT206617>; Epub ahead of print.2456-3307
23. Wu C, Wu Y, Qiao L. Revealing the decision-making practices in automated external defibrillator deployment: insights from Shanghai, China. *BMC Public Health*. 2025 Jan;(1):152. <https://doi.org/10.1186/s12889-025-21341-2> 39810171 1471-2458
24. Centers for Disease Control and Prevention. Public Access Defibrillation (PAD) State Law Fact Sheet. Cardiovascular Disease Data, Tools, and Evaluation Resources, <https://www.cdc.gov/cardiovascular-resources/php/pad-sifs/index.html> (2024, accessed 3 July 2025).
25. Schweizerische Register Ausserklinischer Kreislaufstillstände. Kurzbericht 2023. Kurzbericht 2023, Schweizerische Register Ausserklinischer Kreislaufstillstände.

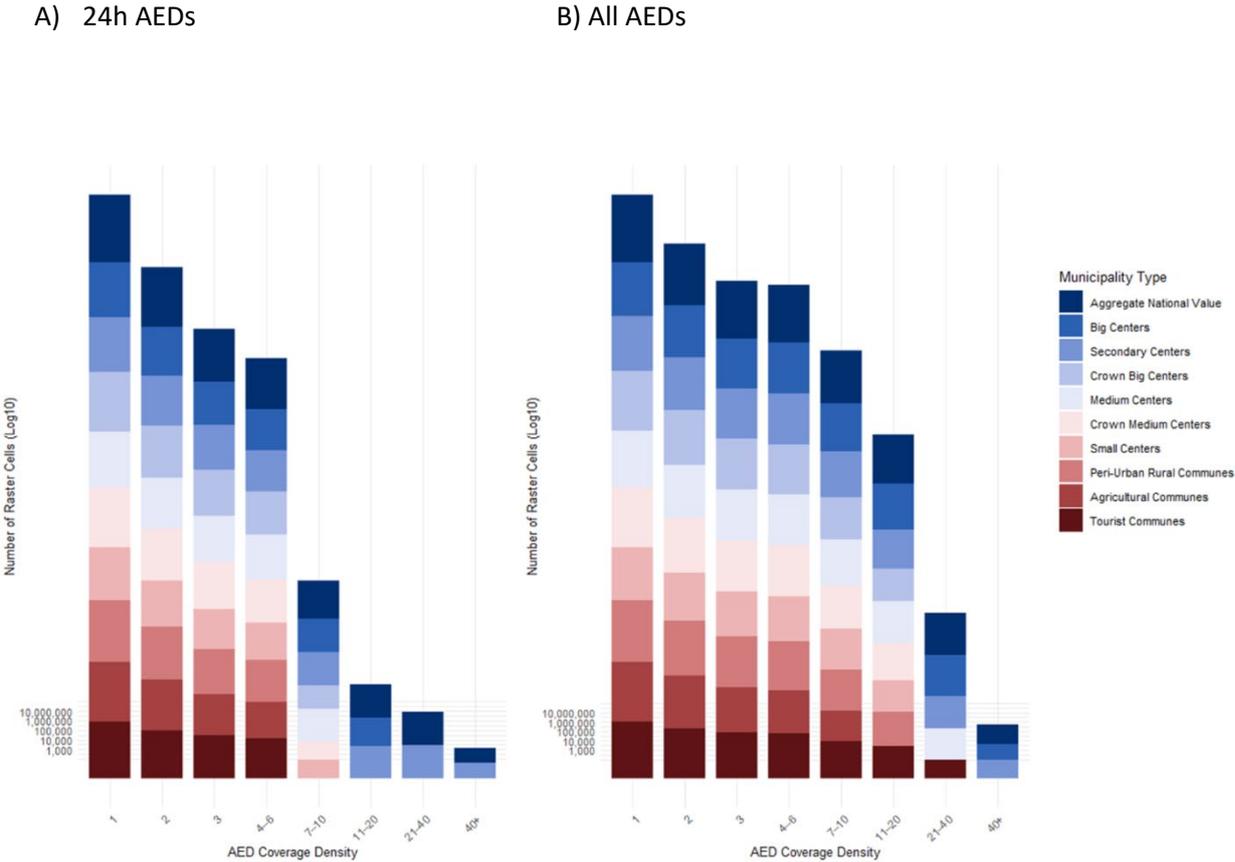
Appendix

Figure S1: Geographic Distribution of Population Coverage Gains Following Expansion of 24h Accessibility to All AEDs



A spatial analysis using Jenks natural breaks categorized percentage increases in population coverage by an AED across municipality types. The resulting maps illustrate the geographic distribution of accessibility gains following the conversion of non-24h AEDs to 24h availability.

Figure S2: Variation in AED Coverage Density Distribution, by Municipality Type



Each bar shows the number of 10-meter raster cells in Switzerland that fall into a specific AED coverage density category, based on how many 300-meter buffers overlap. The y-axis uses a base-10 logarithmic scale.