INDICATOR-BASED METHOD FOR EVALUATING RURAL TRANSPORT ACCESSIBILITY

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Abstract. Rural areas frequently experience limited transport accessibility due to insufficient public transport provision and underdeveloped active mobility infrastructure. This study proposes an indicator-based method for evaluating rural transport accessibility at the municipal level, with the aim of identifying structural transport vulnerability. The method integrates three per-capita indicators representing key dimensions of mobility provision: private car ownership, public bus service availability, and pedestrian–cycling infrastructure. The indicators are derived from administrative data and combined into a composite measure, the Triple Vulnerability Index (TVI), to enable comparative assessment across municipalities. The method is applied to municipalities outside the seven state cities (hereafter referred to as regional municipalities) in Latvia. The results reveal substantial spatial disparities in accessibility, with a significant share of municipalities characterised by high car dependence alongside limited public and active transport options. In these cases, restricted mobility emerges as a structural condition associated with infrastructure and service provision rather than individual characteristics. The proposed approach provides a transparent diagnostic tool for identifying priority areas for intervention and supports evidence-based planning of integrated, multimodal measures aimed at improving rural accessibility and transport equity.

Keywords: rural accessibility, transport vulnerability, forced car dependence, sustainable mobility.

Introduction

Rural and peripheral communities frequently exhibit limited transport accessibility, which contributes to structurally embedded mobility disadvantages. Unlike urban residents, rural populations often have few alternatives to private car use due to sparse public transport services and inadequate pedestrian and cycling infrastructure. This situation leads to *forced car dependence*, where households must either bear the financial burden of vehicle ownership or face severe restrictions in access to employment, education, healthcare, and social activities [1]. Such transport disadvantage has clear equity implications, particularly for population groups unable to drive, including older adults, young people, and low-income households [2]. Accessibility is widely recognised as a core objective of transport planning and a key determinant of social inclusion and regional development [3]. Poor accessibility in rural areas has been linked to economic stagnation, population decline, and social exclusion, reinforcing a self-perpetuating cycle of underinvestment and declining service viability. While numerous methods exist to measure accessibility, many rely on detailed spatial data, complex modelling techniques, or travel-time calculations that are difficult to implement in routine planning practice, particularly at the local or municipal level [4].

Traditional rural accessibility indicators have often focused on road infrastructure provision or proximity to all-season roads, such as the Rural Access Index (RAI) [5]. While these measures capture basic connectivity, they do not adequately reflect the availability of alternative transport modes or the everyday mobility options available to residents. More advanced accessibility approaches, including cumulative-opportunity and network-based models, provide richer insights but require specialised data and analytical capacity that may be unavailable to local authorities [6]. There is therefore a need for a transparent and data-efficient assessment framework that can be applied using routinely available information and support decision-making at the municipal level. In particular, accessibility assessment should distinguish between situations where car use reflects genuine choice and those where it is a necessity imposed by the absence of viable alternatives [7]. This paper proposes an indicator-based method for evaluating rural transport accessibility at the municipal level using readily available administrative data. The approach integrates three per-capita indicators representing key dimensions of mobility provision: private car ownership, public bus service availability, and pedestrian–cycling infrastructure. Together, these indicators provide a holistic yet intuitive picture of local mobility conditions. By combining them into a composite measure – the Triple Vulnerability Index (TVI) – the method identifies regional municipalities where high car dependence coincides with weak public and active transport provision, signalling structural transport vulnerability [4]. The method is applied to regional municipalities in Latvia to demonstrate its diagnostic value. The results reveal substantial spatial disparities in accessibility and highlight areas where transport disadvantage arises from systemic under-provision rather than individual circumstances. By reframing rural transport poverty as a structural issue, the proposed approach offers policymakers a practical tool for prioritising targeted, multimodal interventions aimed at improving equity and resilience in rural transport systems[8]. Similarly, other works have employed network-based algorithms to pinpoint underserved rural areas or to plan improvements in rural transport networks [10]. Poor accessibility and socioeconomic marginalization in these areas become mutually reinforcing limited transport undermines local liveability and services, leading to depopulation, which in turn makes providing transport less viable. Alarmingly, recent public transport cuts and cost-saving measures (as seen in the post-pandemic period) risk accelerating this spiral [11]. The structural nature of this challenge is further illustrated by global indicators – for instance, the SDG 9.1.1-based RAI (proportion of population within 2 km of an all-season road) is used as a development metric because lack of basic road access correlates strongly with poverty and social exclusion [12]. Zhang et al. (2024) examined transport infrastructure and a multi-dimensional "rurality index" in China's Guangdong province. They found that areas with rising transport accessibility tended to exhibit declining rurality scores, and that transport access and rurality were strongly spatially correlated, higher access, lower rurality [13].

Materials and methods

This study applies an indicator-based evaluation framework to regional municipalities in Latvia. The analysis includes all counties excluding major cities. Data were obtained from administrative sources and include population size, registered private vehicles, scheduled daily public bus trips, and the length of pedestrian and cycling infrastructure. Three per-capita indicators were calculated to represent key dimensions of transport accessibility: private car ownership (vehicles per 1000 residents), public bus service availability (daily bus trips per 1000 residents), and pedestrian-cycling infrastructure provision (kilometres per 1000 residents). Median values across regional municipalities were used as reference thresholds to enable relative comparison and classification.

1. **Private car ownership across regional municipalities.** To understand the level of car dependence in rural Latvia, we measured registered private vehicles per 1000 residents for each regional municipality. Car ownership varies substantially across municipalities, ranging from approximately 250 to over 450 vehicles per 1000 residents. The rural median value is around 361 vehicles per 1000 residents, indicating generally high levels of motorisation. Municipalities with the highest car ownership are predominantly located in peripheral regions and often coincide with weak public transport and limited active mobility infrastructure, indicating structurally constrained mobility options.
2. **Public bus service availability.** To understand the availability of public transport alternatives, we measured the number of scheduled daily bus trips per 1000 residents in each regional municipality. Public transport provision is low across rural Latvia, with a median of 3.5 daily bus trips per 1000 residents. Many municipalities fall well below this value, with some averaging fewer than 2 trips per 1000 residents per day. In practical terms, this corresponds to only a few dozen bus departures per day even in moderately populated counties, limiting the feasibility of non-car travel for work, education, or services. In contrast, a small number of municipalities reach values above 5-6 trips per 1000 residents, reflecting relatively stronger transit provision.
3. **Pedestrian and cycling infrastructure provision.** To understand the availability of active mobility options, we measured kilometres of pedestrian and cycling infrastructure per 1000 residents. Pedestrian and cycling infrastructure include dedicated bicycle paths, shared pedestrian-cycling paths, and sidewalks where these are recorded in the state limited liability company "Latvian State Roads" infrastructure datasets. The provision of active mobility infrastructure is minimal in most regional municipalities. The median value is approximately 0.423 km per 1000 residents, and many municipalities report values below 0.1 km per 1000 residents, indicating an almost complete absence of dedicated walking or cycling facilities. Only a small number of municipalities exceed 1 km per 1000 residents, with the highest observed value slightly above 2 km per 1000 residents.
4. **Combined structural vulnerability – the Triple Vulnerability Index.** To understand how car dependence, public transport supply, and active mobility infrastructure interact, we computed the

Triple Vulnerability Index (TVI) by combining the three indicators normalised by their rural medians. The index is expressed as:

$$TVI = (CC + IC + BC)$$

$$C_a = C_m^{-1}$$

$$CC = \widetilde{C}_a / C_a$$

$$IC = I_m / \widetilde{I}_m$$

$$BC = B_m / \widetilde{B}_m$$

where CC – car ownership component;
IC – pedestrian and cycling infrastructure component;
BC – public bus service component;
C_a – adjust value for cars;
m – denotes municipality;
$\widetilde{C}_m$ $\widetilde{I}_m$ $\widetilde{B}_m$ – median values.

TVI values show strong spatial differentiation across rural Latvia. Municipalities with low TVI scores are characterised by high car ownership combined with weak public and active transport provision, indicating forced car dependence. Conversely, higher TVI values reflect municipalities with at least one compensating strength, such as better transit frequency or more extensive pedestrian and cycling infrastructure. The lowest-ranked municipalities cluster among peripheral counties, while higher TVI values are more common in suburban or better-connected areas. This pattern confirms that rural transport disadvantage is largely structural and place-based rather than individual, as we see in Table 1.

Table 1

Key statistics of TVI across 35 Latvian regional municipalities

Regional municipality	C_m	C_a	CC	I_m	IC	B_m	BC	TVI
Kuldīgas	407.4	0.00245	0.896	0.182	0.431	1.46	0.420	**1.744**
Ventspils	443.3	0.00226	0.823	0.190	0.450	2.66	0.760	**2.033**
Talsu	395.9	0.00253	0.922	0.309	0.730	1.54	0.440	**2.091**
Balvu	391.9	0.00255	0.931	0.167	0.394	3.16	0.900	**2.229**
Jelgavas	397.3	0.00252	0.919	0.312	0.738	2.10	0.600	**2.257**
Rēzeknes	392.6	0.00255	0.930	0.228	0.539	3.26	0.930	**2.398**
Smiltenes	399.7	0.00250	0.913	0.445	1.052	1.67	0.480	**2.442**
Gulbenes	442.9	0.00226	0.824	0.418	0.988	2.36	0.680	**2.487**
Alūksnes	452.3	0.00221	0.807	0.401	0.947	2.62	0.750	**2.503**
Bauskas	364.6	0.00274	1.001	0.394	0.933	2.33	0.670	**2.601**
Ludzas	346.2	0.00289	1.054	0.240	0.567	3.65	1.040	**2.663**
Tukuma	368.8	0.00271	0.990	0.428	1.011	2.57	0.740	**2.736**
Jēkabpils	291.3	0.00343	1.253	0.396	0.937	1.99	0.570	**2.759**
Cēsu	344.5	0.00290	1.059	0.466	1.102	2.16	0.620	**2.778**
Dienvidkurzemes	281.2	0.00356	1.298	0.320	0.756	2.74	0.780	**2.835**
Krāslavas	334.6	0.00299	1.091	0.332	0.786	3.70	1.060	**2.933**
Limbažu	358.7	0.00279	1.017	0.593	1.402	2.24	0.640	**3.058**
Ogres	334.3	0.00299	1.092	0.492	1.162	2.97	0.850	**3.103**
Dobeles	375.3	0.00266	0.972	0.604	1.427	2.55	0.730	**3.129**
Madonas and Varakļānu	386.1	0.00259	0.945	0.358	0.845	5.01	1.430	**3.221**
Augšdaugavas	250.1	0.00400	1.459	0.220	0.520	4.41	1.260	**3.238**
Mārupes	301.6	0.00332	1.210	0.423	1.000	3.79	1.080	**3.293**
Ropažu	293.5	0.00341	1.244	0.501	1.184	3.07	0.880	**3.304**
Saldus	394.4	0.00254	0.925	0.547	1.293	3.94	1.130	**3.344**
Preiļu	358.8	0.00279	1.017	0.404	0.956	4.94	1.410	**3.383**
Aizkraukles	317.9	0.00315	1.148	0.394	0.931	4.62	1.320	**3.400**
Siguldas	352.4	0.00284	1.036	0.753	1.780	2.59	0.740	**3.556**

Table 1 (continued)

Regional municipality	C_m	C_a	*CC*	I_m	*IC*	B_m	*BC*	*TVI*
Valmieras	323.7	0.00309	1.128	0.784	1.854	2.34	0.670	**3.650**
Ķekavas	378.7	0.00264	0.964	0.715	1.691	4.36	1.240	**3.900**
Salaspils	363.4	0.00275	1.004	1.143	2.702	2.12	0.610	**4.313**
Saulkrastu	377.2	0.00265	0.968	0.775	1.831	6.27	1.790	**4.591**
Valkas	386.1	0.00259	0.945	0.861	2.036	5.87	1.680	**4.657**
Ādažu	315.3	0.00317	1.157	0.973	2.301	4.81	1.370	**4.832**
Olaines	349.2	0.00286	1.045	1.484	3.507	5.67	1.620	**6.172**
Līvānu	381.0	0.00262	0.958	2.086	4.932	4.88	1.390	**7.285**

Results and Discussion

To assess the level of car dependence in regional municipalities, we measured private car ownership per 1000 residents. Private car ownership ranges from approximately 250 to over 450 vehicles per 1000 residents, indicating substantial variation in motorisation levels. Municipalities with the highest car ownership are predominantly located in peripheral regions and are characterised by limited public transport and active mobility provision.

To understand public transport availability in rural Latvia, we measured the number of scheduled daily bus trips per 1000 residents. This level corresponds to roughly 35 daily departures in a municipality of 10000 residents, indicating sparse public transport supply. Yet, half of the rural communities have even fewer buses. In the most underserved cases, such as Kuldīga and Talsi counties, there are only about 1.5 bus trips per 1000 residents per day. For a population of ~27000 (Kuldīga), 1.5/1000 equates to roughly 40 daily bus trips total, which is insufficient to offer meaningful mobility (perhaps just a couple of routes with a few departures each). On the other end, a handful of municipalities approach 5-6 bus trips per 1000 people daily. Saulkrasti, a smaller municipality with rail connections and summer tourism, tops the list at about 6.3 bus trips/1000. Others like Valka (5.9) and Olaine (5.7) also have relatively robust transit service for a rural area. This wide variation highlights substantial inequalities in public transport access between regional municipalities, with direct consequences for everyday mobility opportunities.

To evaluate opportunities for non-motorised travel, we measured the length of pedestrian and cycling infrastructure per 1000 residents. Rural Latvia's pedestrian and cycling networks are minimal in most places. The median supply of ~0.423 km per 1000 residents is low, and numerous municipalities fall far below that. For instance, Ventspils municipality (surrounding Ventspils city) has practically no dedicated active travel paths – only about 0.036 km per 1000 residents, essentially zero in per capita terms. Several other counties likewise report less than 0.1 km per 1000 residents, meaning just a few tens of meters of sidewalk or bike lane per thousand inhabitants. Such places likely lack safe walking routes even in village centres or to reach bus stops. In contrast, a few better-equipped municipalities provide over 0.5 km per 1000 residents, and the standout Līvāni has about 2.1 km per 1000 residents. Līvāni active transport provision – albeit the highest – still amounts to only ~22 km for its ~10000 people, concentrated in town. Another example is Olaines municipality with ~1.484 km per 1000 residents, reflecting investments in pedestrian sidewalks and cycling trails in a suburban context. The scarcity of such infrastructure constrains both local travel and access to public transport, reinforcing car dependence even for short trips.

Taken together, these patterns indicate that high motorisation in rural Latvia is largely a structural response to limited transport alternatives, as we see in Fig. 1.

TVI combines three per-capita indicators – private car ownership (inverse), public bus service availability, and pedestrian-cycling infrastructure provision – to assess structural transport vulnerability. Lower TVI values (darker shading) indicate higher vulnerability, characterised by strong car dependence alongside limited public and active transport options. Higher TVI values (lighter shading) represent more balanced accessibility conditions. Municipal boundaries correspond to Latvia's rural counties; major cities are excluded from the analysis.

In conclusion, our results highlight that equity in accessibility outcomes depends on addressing structural transport deficits rather than average accessibility levels. It is not enough to raise average accessibility; policy must ensure that improvements benefit the currently underserved groups and regions. Researchers have proposed measures like the Socially Required Accessibility Index (SRAI) to evaluate whether transport networks meet a socially acceptable minimum for all citizens [14]. Overall, the Latvian results reinforce Siddiq and Taylor's conclusions. Both studies show that combining multiple accessibility indicators yields a richer picture of transport inequity than single-mode metrics [15]. This reframing provides a stronger foundation for equitable transport policy that addresses infrastructure and service provision rather than individual behaviour.

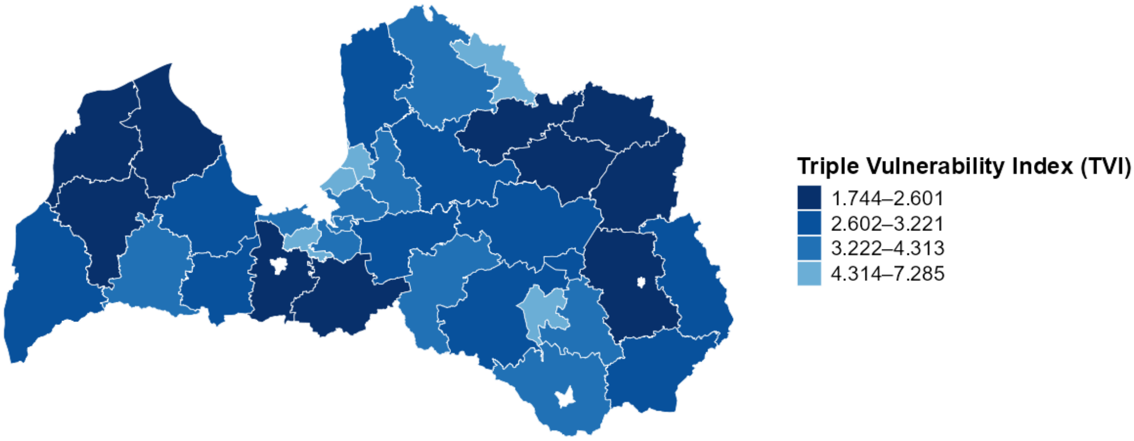

Fig. 1. **Spatial distribution of the Triple Vulnerability Index (TVI) across regional municipalities in Latvia (study period: November 2025)**

Nevertheless, direct numerical comparison with other countries is challenging because accessibility indicators are often calculated using different methodologies, spatial units, and transport datasets. Many international studies rely on travel-time accessibility measures or network-based indicators rather than simple service-frequency metrics. Therefore, while international research consistently highlights transport accessibility challenges in rural regions, further research would be required to establish directly comparable indicator values for different countries.

Conclusions

We have shown that rural transport accessibility in Latvia can be systematically assessed using a small set of per-capita indicators that capture not only connectivity, but also the availability of genuine mobility alternatives. By combining private car ownership, public bus service provision, and pedestrian–cycling infrastructure into the Triple Vulnerability Index, the analysis demonstrates that a large share of regional municipalities experiences forced car dependence as a structural condition rather than a result of individual choice.

The analysis shows that car ownership ranges from approximately 250 to more than 450 vehicles per 1000 residents, while the median public transport supply is 3.5 daily bus trips per 1000 residents. Pedestrian and cycling infrastructure remain very limited, with a median of 0.423 km per 1000 residents. These values highlight the structural imbalance between private vehicle dependence and the availability of alternative mobility options across municipalities. Moreover, high car ownership frequently coexists with weak public transport and minimal active mobility infrastructure, while in some municipalities low car ownership coincides with similarly poor alternatives, indicating suppressed mobility and heightened exclusion risks. This distinction is important because it reveals different forms of transport disadvantage that are obscured when accessibility is assessed through single-mode or infrastructure-only metrics. Our results therefore reinforce recent calls in the literature to move beyond road-based or travel-time indicators and to adopt multi-dimensional accessibility assessments that better reflect everyday mobility realities in rural contexts.

The broader implication of this work is that rural transport poverty should be understood as a place-based and systemic challenge, shaped by long-term patterns of infrastructure investment and service provision. By relying on routinely available administrative data, the proposed approach lowers the analytical barrier for local and regional authorities and enables regular monitoring of accessibility outcomes without the need for complex modelling. In this sense, the Triple Vulnerability Index complements more data-intensive accessibility methods by offering a transparent diagnostic tool suitable for early-stage planning and policy prioritisation.

Based on the results of this paper, we can now identify and compare structurally vulnerable regional municipalities using a simple, replicable method, allowing policymakers to target integrated, multimodal interventions more effectively. This brings transport planning closer to the goal of equitable, resilient, and sustainable mobility systems in rural areas, where access to essential services does not depend on mandatory car ownership.

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